Environmental Requirements for Electromechanical and Electronic Equipment

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Newnes

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About the authors

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Currently he is the Co-ordinator for a Commission-sponsored project aimed at harmonising the Rules and Regulations for the future high speed European Railway networks.

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Preface

With the recent introduction of mandatory European ElectroMagnetic Compatibility (EMC) regulations has come the acknowledged requirement for manufacturers, suppliers and end users of all electrical, mechanical, electromechanical and electronic equipment and components to have a broad knowledge of the requirements of the application environment.

Although there is an international standard (i.e. BS EN ISO 14001 which replaced ISO 7750) that is aimed at environmental management, this specification mainly concerns waste products and the home environment. There are also numerous national, European and international standards and specifications (e.g. BS, EN, CEN, CENELEC, IEC and ISO) that touch on the topic of environmental requirements. There is, however, no single, standalone specification, standard or book that adequately covers the whole topic of the application environment for electromechanical and electronic equipment.

This book, written in the form of a reference book, contains background guidance concerning the environment and environmental requirements. It also provides a case study of typical requirements, together with values and ranges currently being requested from industry in today's contracts. Test specifications aimed at proving conformance to these requirements are also listed and the most used international and European standards are described in relative detail.

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Acknowledgements

Writing a book on environmental specifications was never going to be an easy task. There are literally hundreds of books written on this topic but none of these tell the whole story.

The research, therefore, was enormous and we, as authors, relied heavily on the contributions, support and assistance so freely given by our friends, professional associates and business acquaintances.

Unfortunately space does not permit us to name all of these people who have helped us over the years, but we cannot permit publication without particularly mentioning the assistance provided by Pamela Danvers and the library staff of BSI Chiswick, Infonorme London Information (ILI) (for their invaluable help with standards and their implementations), Bruce Sherring-Lucas (for copy editing and indexing the final draft) but most of all, Peta Miers for keeping us in order and ensuring that the manuscript was completed on time.

Thank you everybody!

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Chapter 1

Introduction

Implementation of any system on a world market cannot be achieved without allowing for local peculiarities and variations, particularly those concerning the application environment.

Although the International Standards Organisation (ISO), the International Electrotechnical Commission (IEC), the Comité Européen de Normalisation (CEN), the Comité Européen de Normalisation Electrotechnique (CENELEC) and the national bodies (e.g. British Standards Institution (BSI)) produce standards and specifications that:

- establish classes of environmental parameters and list their severity;
- list the limitations and restrictions that will be imposed on equipment by the intrinsic environmental conditions that occur at locations where equipment is likely to be installed or stored;

there is no single standalone specification, standard or book that completely covers the application environment. The availability of system specific environmental specifications are also few and far between.

Several CENELEC Working Groups are in the process of producing generic standards (e.g. ENV 50121, prEN 50198 and EN 50125, etc.), which are mainly aimed at the railways application environment. But no complete 'set' of ISO, IEC or CEN/CENELEC agreed standards currently exists that adequately covers the environment in which electrical, mechanical, electromechanical and/or electronic equipment (hereafter referred to in this book simply as 'electronic equipment' or 'equipment') are intended to operate.

CENELEC recognised that there was a need to establish a Working Group specifically tasked with the drafting of a set of harmonised environmental conditions but admit that they will probably *not* be able to produce such a standard much before the end of the century. It has been confirmed, however, that any future CENELEC standard will always state the *minimum*, general, values and ranges which will apply to 95% of all equipment. This standard will thus only serve as a basic *generic* document thereby allowing specifiers to increase severities but *not* decrease them. Most Calls for Tender, contracts and purchases of equipment on the other hand require individual system specific specifications to define the actual product or product requirement. In all instances, these system specific specifications must *never* be less than the CENELEC figure but, in some cases, they may be more stringent.

This book has, therefore, been written in order to provide industry and their customers with an indication of the existing environmental specifications and requirements that they are likely to come across and which are frequently quoted in Calls for Tender. Case studies of typical requirements, values and ranges are also supplied and test specifications aimed at proving conformance are listed and described.

In writing these specifications, care has always been taken to incorporate the current requirements that are common to ISO, IEC, CEN/CENELEC, EN and national existing standards together with all available standards and specifications obtained from industry and the military services. Where no existing standard, specification or guidance is available, a considered recommendation has been made. Throughout this book, optimum use has always been made of the IEC 721 series of standards, 'Classification of environmental conditions'.

1.1 Purpose and layout of this book

The purpose of this book is to provide guidance on the operation, storage and use of electronic equipment within an application environment. Also included are details of typical environmental requirements found in modern contracts and the test standards that are normally used to ensure compliance with these requirements.

This book:

- defines performance and interface specifications for equipment;
- establishes classes of environmental parameters and lists their severity;
- covers long- and short-term environmental conditions which may be met by equipment when being transported, operated or stored;
- lists the limitations and restrictions that will be imposed on equipment when installed or stored;
- provides details of the environmental conditions (natural as well as man-made) that equipment must be proof against;
- records the degree that equipment may be allowed to exert influence on the environment.

1.2 Structure of the document

For convenience, this book is divided into 11 sections which relate to the following environmental conditions:

- Ambient temperature

- Solar radiation
- Humidity
- Air pressure and altitude
- Weather and precipitation
- Pollutants and contaminants
- Mechanical
- Electrical
- Electromagnetic compatibility
- Ergonomics
- General

For ease of reference, each environmental condition described in this book has four subsections:

- Guidance
- Typical contract requirements
- Values and ranges
- Tests

These are as follows.

1.2.1 Guidance

This is a user friendly general description of the environmental condition giving:

- an introduction to the condition, detailing what it is and the effects it can have on equipment;
- details of the considerations to be made when producing a system specific or generic environmental specification, contract, etc.;
- recommended test procedures used by manufacturers and suppliers to demonstrate that their equipment is capable of meeting the environmental requirements.

1.2.2 Typical contract requirements

This subsection provides (in the form of a case study) typical environmental requirements normally found in contracts for the production and supply of electronic equipment and which are frequently stipulated in Calls for Tender.

1.2.3 Values and ranges

Within this subsection can be found typical values and ranges of environmental requirements.

Other than the few mandatory requirements imposed by CENELEC and CEN, etc., each requirement typifies recommended maximum and minimum environmental values.

The following statements are frequently found in contracts:

- all equipment, components or other articles shall be tested in their production configuration without the use of any additional external devices, especially those that have been added expressly for the purpose of passing these tests;
- when tested, the sample (component, subassembly or equipment) shall perform as stipulated in the procuring specification and over the designated temperature range;
- when equipment is turned on, it shall be expected to operate within the temperature ranges stipulated and be fully operational within a specified period of time after initial turn on.

1.2.4 Tests

This subsection details some of the test standards which may be applied to equipment and contains:

- details of the most used environmental tests that a purchaser will normally require a manufacturer to adhere to;
- a list of other related standards and specifications;
- a brief description of the most common tests.

Note: Full details of each of these recommended tests are contained in the relevant ISO, IEC or other standard. A complete list of these standards is supplied in the reference section of this book. Copies of all these standards may be obtained from any National Standards Organisation.

1.2.4.1 Severity

Normally the severity of the Test Specifications is restricted to the severity of the environmental conditions to which equipment is likely to be exposed. They are *not* intended to cover the severity of the resulting stresses on equipment. For example, the severity is intended to cover the temperatures of the surrounding media (e.g. air) and the temperatures of the structure to which the equipment is connected. They are not intended to cover the temperatures of hot points within the equipment itself or the severity of resulting stresses on equipment.

1.3 Environmental factors and influences

The actual environment to which equipment is likely to be exposed is normally complex and comprises a number of environmental conditions. When defining these conditions for a certain application it is, therefore, necessary to consider all environmental influences.

The environmental influences on equipment in a certain application may thus be considered as a result of:

- conditions from the surrounding medium;

- conditions caused by the structure in which the equipment is situated or attached;
- influences from external sources or activities.

1.3.1 Combined environmental factors

Equipment may, of course, be simultaneously exposed to a large number of environmental factors and corresponding parameters. Some of the parameters are statistically interdependent (e.g. low air velocity and low temperature; sun radiation and high temperature). Other parameters are statistically independent (e.g. vibration and temperature). The effect of a combination of environmental factors is, therefore, extremely important and has to be considered during manufacture and operation.

1.3.2 Sequences of environmental factors

Certain effects of exposing equipment to environmental conditions are a direct result of two or more factors or parameters happening either simultaneously or after each other (e.g. thermal shock caused when exposing equipment to a high temperature immediately after exposing it to a low temperature). These possibilities must always be taken into account when designing and evaluating equipment.

1.4 Environmental classes

In accordance with the recommendations of IEC 721, environmental classes are identified by:

First digit

1 Storage
2 Transport
3 Operational – Stationary use at weather protected locations
4 Operational – Stationary use at non-weather protected locations
5 Ground vehicle installations (lorries, trains, etc.)
6 Ship environment
7 Portable equipment

Second digit

K Climatic conditions
Z Special values which can be applied to climatic conditions
B Biological conditions
C Chemically active substances
S Mechanically active substances
M Mechanical conditions
E Predetermined combination of environmental conditions
F Contaminating fluids

Third digit A minimum value taken from the appropriate tables within IEC 721 which indicates the severity of the environmental condition.

A class may be further divided as H (high) or L (low) to allow for conditions where, for example, the temperature may be extremely low but never high.

For example, 2M4 denotes the fourth severity of mechanical conditions during transportation.

A summary of the IEC 721 classifications follows. Note, however, that variations and combinations of these classifications can be found within the standard. Consequently, these tables should be considered as a guide and not as a substitute for the complete standard.

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1.4.1 Storage

Table 1.1 Storage – climatic conditions

Environmental parameter	Unit	Classification										
		1K1	1K2	1K3	1K4	1K5	1K6	1K7	1K8	1K9	1K10	1K11
Low temp. air	°C	+20	+5	−5	−25	−40	−55	−20	−33	−65	+5	−20
High temp. air	°C	+25	+40	+45	+55	+70	+70	+35	+40	+55	+40	+55
Low relative humidity	%	20	5	5	10	10	10	20	15	4	30	4
High relative humidity	%	75	85	95	100	100	100	100	100	100	100	100
Low absolute humidity	g/m^3	4	1	1	0.5	0.1	0.02	0.9	0.26	0.003	6	0.9
High absolute humidity	g/m^3	15	25	29	29	35	35	22	25	36	36	27
Rate of change of temperature	°C/min	0.1	0.5	0.5	0.5	1.0	1.0	0.5	0.5	0.5	0.5	0.5
Low air pressure	kPa	70	70	70	70	70	70	70	70	70	70	70
High air pressure	kPa	106	106	106	106	106	106	106	106	106	106	106
Solar radiation	W/m^2	500	700	700	1120	1120	1120	1120	1120	1120	1120	1120
Heat radiation	None	No	A suitable severity should be chosen from the Special Climatic Conditions shown on the following table									
Movement of surrounding air	m/s	0.5	1.0	1.0	1.0	5.0	5.0	A suitable severity should be chosen from the Special Climatic Conditions shown on the following table			50	50
Condensation	None	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation	None	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rain intensity	mm/min	None	None	None	None	None	None	6	6	15	15	15
Low rain temperature	°C	None	None	None	None	None	None	+5	+5	+5	+5	+5
Water from sources other than rain	None	No	No	A suitable severity should be chosen from the Special Climatic Conditions shown on the following table								
Ice and frost formation	None	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes

Table 1.2 Storage – special climatic conditions

Environmental parameter	Class	Unit	Special condition Z
Heat radiation	1Z1	None	Negligible
	1Z2	None	Conditions of heat radiation, e.g. near room heating systems
Movement of surrounding air	1Z3	m/s	30
	1Z4	m/s	50
Water from sources other than rain	1Z5	None	Dripping water
	1Z6	None	Water jets
	1Z7	None	Water waves

Table 1.3 Storage – biological conditions

Environmental parameter		Classification		
	Unit	1B1	1B2	1B3
Flora	None	Negligible	Presence of mould, fungus, etc.	Presence of mould, fungus, etc.
Fauna	None	Negligible	Presence of rodents or other animals harmful to products Excludes termites	Presence of rodents or other animals harmful to products Including termites

Table 1.4 Storage – chemically active substances

Environmental parameter	Unit	Classification					
		1C1L	1C1	1C2		1C3	
		Max.	Max.	Mean	Max.	Mean	Max.
Sea and road salt	None	No	No	Salt mist			
Sulphur dioxide	mg/m^3	0.1	0.1	0.3	1.0	5.0	10
	cm^3/m^3	0.037	0.037	0.11	0.37	1.85	3.7
Hydrogen sulphide	mg/m^3	0.01	0.01	0.1	0.5	3.0	10
	cm^3/m^3	0.0071	0.0071	0.071	0.36	2.1	7.1
Chlorine	mg/m^3	0.01	0.1	0.1	0.3	0.3	1
	cm^3/m^3	0.0034	0.034	0.034	0.1	0.1	0.34
Hydrogen chloride	mg/m^3	0.01	0.1	0.1	0.5	1.0	5.0
	cm^3/m^3	0.0066	0.066	0.066	0.33	0.66	3.3
Hydrogen fluoride	mg/m^3	0.003	0.003	0.1	0.03	0.1	2.0
	cm^3/m^3	0.0036	0.0036	0.012	0.036	0.12	2.4
Ammonia	mg/m^3	0.3	0.3	1.0	3.0	10	35
	cm^3/m^3	0.42	0.42	1.4	4.2	14	49
Ozone	mg/m^3	0.01	0.01	0.05	0.1	0.1	0.3
	cm^3/m^3	0.005	0.005	0.025	0.05	0.05	0.15
Nitrogen oxides (expressed in equivalent	mg/m^3	0.1	0.1	0.5	1.0	3.0	9.0
values of nitrogen dioxides)	cm^3/m^3	0.052	0.052	0.26	0.52	1.56	4.68

Table 1.5 Storage – mechanically active substances

Environmental parameter	Unit	Classification			
		1S1	1S2	1S3	1S4
Sand	g/m^3 of air	None	30	300	1000
Dust suspension	mg/m^3	0.01	0.2	5.0	15
Dust sedimentation	$mg/(m^2 \cdot h)$	0.4	1.5	20	40

Table 1.6 Storage – mechanical conditions

Environmental parameter	Unit	Classification							
		1M1		1M2		1M3		1M4	
Stationary sinusoidal vibration									
Displacement amplitude	mm	0.3		1.5		3.0		7.0	
Acceleration amplitude	m/s^2		1		5		1.0		20
Frequency range	Hz	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200
Non-stationary vibration including shock									
Shock response spectrum type L peak acceleration $\hat{a}$	m/s^2	40		40		No		No	
Shock response spectrum type I peak acceleration $\hat{a}$	m/s^2	No		No		100		No	
Shock response spectrum type II peak acceleration $\hat{a}$	m/s^2	No		No		No		250	
Static load	kPa	5		5		5		5	

1.4.2 Transportation

Table 1.7 Transportation – climatic conditions

Environmental parameter	Unit	Classification								
		2K1	2K2	2K3	2K4	2K5	2K5H	2K5L	2K6	2K7
Low temp. air	°C	+5	−25	−25	−40	−65	−25	−65	+5	−20
High temp. air in unventilated enclosures	°C	No	+60	+70	+70	+85	+85	+70	+70	+85
High temp. air in ventilated enclosures or outdoor air	°C	+40	+40	+40	+40	+55	+55	+40	+40	+55
Change of temp. Air to air	°C	No	−25/+25	−25/+30	−40/+30	−65/+30	−25/+30	−65/+30	+5/+30	−20/+30
Change of temp. Air to water	°C	No	No	+40/+5	+40/+5	+55/+5	+55/+5	+40/+5	+40/+5	+55/+5
Relative humidity, not combined with rapid temp. changes	% °C	75 +30	75 +30	95 +40	95 +40	95 +50	95 +50	95 +45	95 +45	95 +50
Relative humidity, combined with rapid temp. changes: air/air at high relative humidity	% °C	No	No	95 −25/+30	95 −40/+30	95 −65/+0	95 −25/+30	95 −65/+30	95 +5/+30	95 −20/+30
Absolute humidity, combined with rapid temp. changes: air/air at high water content	g/m^3 °C	No	No	60 +70/+15	60 +70/+15	80 +85/+15	80 +85/+15	60 +70/+15	60 +70/+15	80 +85/+15
Low air pressure	kPa	70	70	70	70	30	30	30	30	30
Change of air pressure	kPa/min	No	No	No	No	6	6	6	6	6
Movement of surrounding air	m/s	No	No	20	20	30	30	30	30	30
Precipitation	mm/min	No	No	6	6	15	15	6	15	15
Radiation, solar	W/m^2	700	700	1120	1120	1120	1120	1120	1120	1120
Radiation, heat	W/m^2	No	No	600	600	600	600	600	600	600
Water from sources other than rain	m/s	No	No	1	1	3	3	3	3	3
Wetness	None	No	No	Conditions of wet surfaces						

Table 1.8 Transportation: biological conditions

Environmental parameter	Unit	Classification		
		2B1	2B2	2B3
Flora	None	No	Presence of mould, fungus, etc.	Presence of mould, fungus, etc.
Fauna	None	No	Presence of rodents or other animals harmful to products. Excludes termites	Presence of rodents or other animals harmful to products. Includes termites

Table 1.9 Transportation – chemically active substances

Environmental parameter	Unit	Classification		
		2C1	2C2	2C3
Sea salt/road salts	None	No	Conditions of salt mist	Conditions of salt mist
Sulphur dioxide	mg/m^3	0.1	1.0 (0.3)	10.0 (0.5)
Hydrogen sulphide	mg/m^3	0.01	0.5 (0.1)	10.0 (3.0)
Nitrogen oxides (expressed in equivalent values of nitrogen dioxides)	mg/m^3	0.1	1.0 (0.5)	10.0 (3.0)
Ozone	mg/m^3	0.01	0.1 (0.05)	0.3 (0.1)
Hydrogen chloride	mg/m^3	0.1	0.5 (0.1)	5.0 (1.0)
Hydrogen fluoride	mg/m^3	0.003	0.03 (0.01)	2.0 (0.1)
Ammonia	mg/m^3	0.3	3.0 (1.0)	35.0 (10)

Notes
Figures in brackets are expected long-term mean values.
Figures are maximum values occurring over a 30 minute period per day.

Table 1.10 Transportation – mechanically active substances

Environmental parameter	Unit	Classification		
		2S1	2S2	2S3
Sand	g/m^3 of air	No	0.1	10
Dust sedimentation	mg/(m$^2\cdot$h)	No	3.0	3.0

Table 1.11 Transportation – mechanical conditions

Environmental parameter	Unit	Classification								
		2M1			2M2			3M3		
Stationary sinusoidal vibration										
Displacement amplitude	mm	3.5			3.5			7.5		
Acceleration amplitude	m/s^2		10	15		10	15		20	40
Frequency range	Hz	2–9	9–200	200–500	2–9	9–200	200–500	2–8	8–200	200–500
Stationary vibration, random										
Acceleration spectral density	m^2/s^3	1	0.3		1	0.3		3	1	
Frequency range	Hz	10–200	200–2000		10–200	200–2000		10–2001	200–2000	
Non-stationary vibration including shock										
Shock response spectrum type I peak acceleration $\hat{a}$	m/s^2	100			100				300	
Shock response spectrum type II peak acceleration $\hat{a}$	m/s^2	No			300				1000	
Free fall										
Mass less than 20 kg	m		0.25			1.2			1.5	
Mass 20 kg to 100 kg	m		0.25			1.0			1.2	
Mass more than 100 kg	m		0.1			0.25			0.5	
Toppling	None									
Mass less than 20 kg					Toppling around any of the edges					
Mass 20 kg to 100 kg			No				Toppling around any of the edges			
Mass more than 100 kg			No			No				
Rolling, pitching										
Angle	degree		No			±35			±35	
Period	s		No			8			8	
Steady state acceleration	m/s^2		20			20			20	
Static load	kPa		5			10			10	

1.4.3 Operational

1.4.3.1 Weather protected stationary equipment

Table 1.12 Operational – weather protected stationary equipment – climatic conditions

Environmental parameter	Unit	Classification												
		3K1	3K2	3K3	3K4	3K5	3K6	3K7	3K7L	3K8	3K8H	3K8L	3K9	3K10
Low temp. air	°C	+20	+15	+5	+5	−5	−25	−40	−40	−55	−25	−55	+5	−20
High temp. air	°C	+25	+30	+40	+40	+45	+55	+70	+40	+70	+70	+55	+40	+55
Low relative humidity	%	20	10	5	5	5	10	10	10	10	10	10	30	4
High relative humidity	%	75	75	85	95	95	100	100	100	100	100	100	100	100
Low absolute humidity	g/m³	4	2	1	1	1	0.5	0.1	0.1	0.02	0.5	0.02	6	0.9
High absolute humidity	g/m³	15	22	25	29	29	29	35	35	35	35	29	36	27
Rate of change of temp.	°C/min	0.1	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low air pressure	kPa	70	70	70	70	70	70	70	70	70	70	70	70	70
High air pressure	kPa	106	106	106	106	106	106	106	106	106	106	106	106	106
Solar radiation	W/m²	500	700	700	700	700	1120	1120	None	1120	1120	1120	1120	1120
Heat radiation	None	No			Select from the following Special Climatic Conditions table									
Movement of surrounding air[1]	m/s	0.5	1.0	1.0	1.0	1.0	1.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Condensation	None	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation	None	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Water from sources other than rain	None	No	No	No				See note[1]						
Ice and frost formation	None	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes

Notes
1 If necessary, a special value can be selected from the Special Climatic Conditions table.

Table 1.13 Operational – weather protected stationary equipment – special climatic conditions

Environmental parameter	Class	Unit	Special condition Z
High air temp.	3Z11	°C	+55
Low air pressure	3Z12	kPa	84
Heat radiation	3Z1	None	Negligible
	3Z2	None	Heat radiation, e.g. near room heating systems
	3Z3	None	Heat radiation, e.g. near room heating systems or commercial ovens/furnaces
Movement of surrounding air	3Z4	m/s	5
	3Z5	m/s	10
	3Z6	m/s	30
Water from sources other than rain	3Z7	None	Dripping water
	3Z8	None	Spraying water
	3Z9	None	Splashing water
	3Z10	None	Water jets

Table 1.14 Operational – weather protected stationary equipment – biological conditions

Environmental parameter	Unit	Classification		
		3B1	3B2	3B3
Flora	None	No	Presence of mould, fungus, etc.	Presence of mould, fungus, etc.
Fauna	None	No	Presence of rodents or other animals harmful to products. Excludes termites	Presence of rodents or other animals harmful to products. Including termites

Table 1.15 Operational – weather protected stationary equipment – chemically active substances

Environmental parameter	Unit	Classification			
		3C1	3C2	3C3	3C4
Sea salt	None	No	Salt mist		
Sulphur dioxide	mg/m^3	0.1	1.0 (0.3)	10 (5.0)	40 (13)
Hydrogen sulphide	mg/m^3	0.01	0.5 (0.1)	10 (3.0)	70 (14)
Chlorine	mg/m^3	0.1	0.3 (0.1)	1.0 (0.3)	3.0 (0.6)
Hydrogen chloride	mg/m^3	0.1	0.5 (0.1)	5.0 (1.0)	5.0 (1.0)
Hydrogen fluoride	mg/m^3	0.003	0.03 (0.01)	2.0 (0.1)	2.0 (0.1)
Ammonia	mg/m^3	0.3	3.0 (1.0)	35 (10)	175 (35)
Ozone	mg/m^3	0.01	0.1 (0.05)	0.3 (0.1)	2.0 (0.2)
Nitrogen oxides (expressed in equivalent values of nitrogen dioxides)	mg/m^3	0.1	1.0 (0.5)	9.0 (3.0)	20 (10)

Notes
Figures in brackets are mean values.
Figures are maximum values occurring over a 30 minute period per day.

Table 1.16 Operational – weather protected stationary equipment – mechanically active substances

Environmental parameter	Unit	Classification			
		3S1	3S2	3S3	3S4
Sand	g/m^3 of air	None	30	300	3000
Dust suspension	mg/m^3	0.01	0.2	0.4	4.0
Dust sedimentation	$mg/(m^2 \cdot h)$	0.4	1.5	15	40

Table 1.17 Operational – weather protected stationary equipment – mechanical conditions

Environmental parameter	Unit	Classification															
		3M1		3M2		3M3		3M4		3M5		3M6		3M7		3M8	
Stationary sinusoidal vibration																	
Displacement amplitude	mm	0.3		1.5		1.5		3.0		3.0		7.0		10		15	
Acceleration amplitude	m/s^2		1		5		5		10		10		20		30		50
Frequency range	Hz	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200
Non-stationary vibration including shock																	
Shock response spectrum type L peak acceleration $\hat{a}$	m/s^2	40		40		70		No		No		No		No		No	
Shock response spectrum type I peak acceleration $\hat{a}$	m/s^2	No		No		No		100		No		No		No		No	
Shock response spectrum type II peak acceleration $\hat{a}$	m/s^2	No		No		No		No		250		250		250		250	

1.4.3.2 Non-weather protected stationary equipment

Table 1.18 Operational – non-weather protected stationary equipment – climatic conditions

Environmental parameter	Unit	Classification							
		4K1	4K2	4K3	4K4	4K4H	4K4L	4K5	4K6
Low temp. air	°C	−20	−33	−50	−65	−20	−65	+5	−20
High temp. air	°C	+35	+40	+40	+55	+55	+35	+40	+55
Low relative humidity	%	20	15	15	4	4	20	30	4
High relative humidity	%	100	100	100	100	100	100	100	100
Low absolute humidity	g/m^3	0.9	0.26	0.03	0.003	0.9	0.003	6	0.9
High absolute humidity	g/m^3	22	25	36	36	36	22	36	27
Rain intensity	mm/min	6	6	15	15	15	15	15	15
Rate of change of temperature	°C/min	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Low air pressure	kPa	70	70	70	70	70	70	70	70
High air pressure	kPa	106	106	106	106	106	106	106	106
Solar radiation	W/m^2	No	1120	1120	1120	1120	1120	1120	1120
Heat radiation	None	A suitable severity should be chosen from the Special Climatic Conditions shown on the following table							
Movement of surrounding air	m/s	A suitable severity should be chosen from the Special Climatic Conditions shown on the following table						50	50
Condensation	None	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation	None	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Low rain temperature	°C	+5	+5	+5	+5	+5	+5	+5	+5
Water from sources other than rain	None	A suitable severity should be chosen from the Special Climatic Conditions shown on the following table							
Ice and frost formation	None	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 1.19 Operational – non-weather protected stationary equipment – climatic conditions

Environmental parameter	Class	Unit	Special condition Z
Low air pressure	4Z10	kPa	84
Heat radiation	4Z1	None	Negligible
	4Z2	None	Heat radiation due for instance to process conditions
Movement of surrounding air	4Z3	m/s	20
	4Z4	m/s	30
	4Z5	m/s	50
Water from sources other than rain	4Z6	None	Negligible
	4Z7	None	Splashing water
	4Z8	None	Water jets
	4Z9	None	Water waves

Table 1.20 Operational – non-weather protected stationary equipment – biological conditions

Environmental parameter	Unit	Classification	
		4B1	4B2
Flora	None	Presence of mould, fungus, etc.	Presence of mould, fungus, etc.
Fauna	None	Presence of rodents or other animals harmful to products. Excludes termites	Presence of rodents or other animals harmful to products. Including termites

Table 1.21 Operational – non-weather protected stationary equipment – chemically active substances

Environmental parameter	Unit	Classification			
		4C1	4C2	4C3	4C4
Sea salt/road salts	None	No	Conditions of salt mist		
Sulphur dioxide	mg/m^3	0.1	1.0 (0.3)	10 (5.0)	40 (13)
Hydrogen sulphide	mg/m^3	0.01	0.5 (0.1)	10 (3.0)	70 (14)
Chlorine	mg/m^3	0.1	0.3 (0.1)	1.0 (0.3)	3.0 (0.6)
Hydrogen chloride	mg/m^3	0.1	0.5 (0.1)	5.0 (1.0)	5.0 (1.0)
Hydrogen fluoride	mg/m^3	0.003	0.03 (0.01)	2.0 (0.1)	2.0 (0.1)
Ammonia	mg/m^3	0.3	3.0 (1.0)	35 (10)	175 (35)
Ozone	mg/m^3	0.01	0.1 (0.05)	0.3 (0.1)	2.0 (0.2)
Nitrogen oxides (expressed in equivalent values of nitrogen dioxides)	mg/m^3	0.1	1.0 (0.5)	9.0 (3.0)	20 (10)

Notes
Figures in brackets are mean values.
Figures are maximum values occurring over a 30 minute period per day.

Table 1.22 Operational – non-weather protected stationary equipment – mechanically active substances

Environmental parameter	Unit	Classification			
		4S1	4S2	4S3	4S4
Sand	g/m^3 of air	30	300	1000	4000
Dust sedimentation	$mg/(m^2 \cdot h)$	15	20	40	80
Dust suspension	mg/m^3	0.5	5.0	15	20

Table 1.23 Operational – non-weather protected stationary equipment – mechanical conditions

Environmental parameter	Unit	Classification															
		4M1		4M2		4M3		4M4		4M5		4M6		4M7		4M8	
Stationary sinusoidal vibration																	
Displacement amplitude	mm	0.3		1.5		1.5		3.0		3.0		7.0		10		15	
Acceleration amplitude	m/s^2		1		5		5		10		10		20		30		50
Frequency range	Hz	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200	2–9	9–200
Non-stationary vibration including shock																	
Shock response spectrum type L peak acceleration $\hat{a}$	m/s^2	40		40		70		No		No		No		No		No	
Shock response spectrum type I peak acceleration $\hat{a}$	m/s^2	No		No		No		100		No		No		No		No	
Shock response spectrum type II peak acceleration $\hat{a}$	m/s^2	No		No		No		No		250		250		250		250	

1.4.3.3 Ground vehicle equipment

Table 1.24 Operational – ground vehicle equipment – climatic conditions

Environmental parameter	Unit	Classification							
		5K1	5K2	5K3	5K4	5K4H	5K4L	5K5	5K6
Low temp. air	°C	+5	−25	−40	−65	−25	−65	+5	−20
High temp. air – ventilated compartment (except engine compartments) or outdoor air	°C	+40	+40	+40	+55	+55	+40	+40	+55
High temp. air – unventilated compartment (except engine compartments)	°C	No	+70	+70	+85	+85	+70	+70	+85
High temp. engine compartments	°C	+60	+70	+70	+85	+85	+70	+70	+85
Change of temp. air to air	°C	No	−25/+30	−40/+30	−65/+30	−25/+30	−65/+30	+5/+30	−20/+30
Gradual change of temp. air to air,	°C	No	−25/+30	−40/+30	−65/+30	−25/+30	−65/+30	+5/+30	−20/+30
except engine compartments	°C/min	No	5	5	5	5	5	5	5
Gradual change of temp. air to air,	°C	No	−25/+60	−40/+70	−65/+70	−25/+70	−65/+70	+5/+70	−20/+70
engine compartments	°C/min	No	10	10	10	10	10	10	10
Change of temp. air to water, except engine compartments	°C	No	No	+40/+5	+55/+5	+55/+5	+40/+5	+40/+5	+55/+5
Change of temp. air to water, engine compartments	°C	No	+60/+5	+70/+5	+85/+5	+85/+5	+70/+5	+70/+5	+85/−5
Change of temp. air to snow in engine compartments only	°C	No	+60/−5	+70/−5	+70/−5	+70/−5	+70/−5	+70/−5	+70/−5
Relative humidity not combined with	%	75	95	95	95	95	95	95	95
rapid temp. changes (except in engine compartments of vehicles powered by internal combustion engines)	°C	+30	+40	+45	+50	+50	+45	+45	+50

continued

Table 1.24 (*cont.*)

Environmental parameter	Unit	Classification							
		5K1	5K2	5K3	5K4	5K4H	5K4L	5K5	5K6
Relative humidity not combined with rapid temp. changes in engine compartments of vehicles powered by internal combustion engines	%	No	No	95	95	95	95	95	95
	°C	No	No	+70	+85	+85	+70	+85	+85
Relative humidity combined with rapid temp. changes, air/air at high relative humidities. Not in close proximity to refrigerated air conditioning units	%	No	95	95	95	95	95	95	95
	°C	No	−25/+30	−40/+30	−65/+30	−25/+30	−65/+30	+5/+30	−20/+30
Relative humidity combined with rapid temp. changes, air/air at high relative humidities. In close proximity to refrigerated air conditioning units	%	No	95	95	95	95	95	95	95
	°C	No	+10/+70	+10/+70	+10/+85	+10/+85	+10/+70	+10/+85	+10/+85
Absolute humidity combined with rapid temp. changes, air/air at high water content	g/m^3 of air	No	60	60	80	80	60	60	60
	°C	No	+70/+15	+70/+15	+85/+15	+85/+15	+70/+15	+70/+15	+85/+15
Low relative humidity	%	10	10	10	10	10	10	10	10
	°C	+30	+30	+30	+30	+30	+30	+30	+30
Low air pressure	kPa	70	70	70	70	70	70	70	70
Movement of surrounding air	m/s	No	20	20	30	30	30	30	30
Precipitation, rain	mm/min	No	No	6	15	15	6	15	15
Solar radiation	W/m^2	No	700	1120	1120	1120	1120	1120	1120
Radiation, heat, not in engine compartment	W/m^2	No	600	600	600	600	600	600	600
Radiation, heat, in engine compartment	W/m^2	600	600	1200	1200	1200	1200	1200	1200
Water from other sources (not rain)	m/s	No	0.3	1	3	3	3	3	3
Wetness	None	No	Conditions of wet surfaces						

Table 1.25 Operational – ground vehicle equipment – biological conditions

Environmental parameter	Unit	Classification		
		5B1	5B2	5B3
Flora	None	No	Presence of mould, fungus, etc.	Presence of mould, fungus, etc.
Fauna	None	No	Presence of rodents or other animals harmful to products. Excludes termites	Presence of rodents or other animals harmful to products. Including termites

Table 1.26 Operational – ground vehicle equipment – chemically active substances

Environmental parameter	Unit	Classification		
		5C1	5C2	5C3
Sea salt	None	No	Conditions of salt mist	
Road salts	None	No	Conditions of solid salt and salt water	
Sulphur dioxide	mg/m^3	0.1	1.0 (0.3)	10 (5.0)
Hydrogen sulphide	mg/m^3	0.01	0.5 (0.1)	10 (3.0)
Nitrogen oxides (expressed in equivalent values of nitrogen dioxides)	mg/m^3	0.1	1.0 (0.5)	10 (3.0)
Ozone	mg/m^3	0.01	0.1 (0.05)	0.3 (0.1)
Hydrogen chloride	mg/m^3	0.1	0.5 (0.1)	5.0 (1.0)
Hydrogen fluoride	mg/m^3	0.003	0.03 (0.01)	2.0 (0.1)
Ammonia	mg/m^3	0.3	3.0 (1.0)	35 (10)

Notes
Figures in brackets are mean values.
Figures are maximum values occurring over a 30 minute period per day.

Table 1.27 Operational – ground vehicle equipment – mechanically active substances

Environmental parameter	Unit	Classification		
		5S1	5S2	5S3
Sand	g/m^3 of air	No	0.1	10
Dust sedimentation	$mg/(m^2{\cdot}h)$	1.0	3.0	3.0

Table 1.28 Operational – ground vehicle equipment – mechanical conditions

Environmental parameter	Unit	Classification							
		5M1		5M2			5M3		
Stationary sinusoidal vibration									
Displacement amplitude	mm	1.5		3.3			7.5		
Acceleration amplitude	m/s^2		5		10	15		20	40
Frequency range	Hz	2–9	9–200	2–9	9–200	200–500	2–8	8–200	200–500
Stationary vibration, random									
Acceleration spectral density	m/s^2	0.3	0.1	1		0.3	3		1
Frequency range	Hz	10–200	200–500	10–200		200–500	10–200		200–500
Non-stationary vibration including shock									
Shock response spectrum type I peak acceleration $\hat{a}$	m/s^2	50		100			300		
Shock response spectrum type II peak acceleration $\hat{a}$	m/s^2	No		300			1000		
Impact from foreign bodies	J	No		5			20		

Table 1.29 Operational – ground vehicle equipment – contaminating fluids

Environmental parameter	Classification		
	5F1	5F2	5F3
Motor oil	No	No	Yes
Gearbox oil	No	No	Yes
Hydraulic oil	No	Yes	Yes
Transformer oil	No	Yes	Yes
Brake oil	No	Yes	Yes
Cooling fluid	No	Yes	Yes
Grease	No	Yes	Yes
Fuel	No	No	Yes
Battery electrolyte	No	Yes	Yes

1.4.3.4 Shipborne equipment

Table 1.30 Operational – shipborne equipment: climatic conditions

Environmental parameter	Unit	Classification						
		6K1	6K2	6K3	6K4	6K5	6K6	6K7
Low temp. air	°C	+5	−25	−25	−25	−40	+5	−20
Low temp. water	°C	0	0	0	0	0	+15	+15
High temp. air	°C	+40	+40	+55	+70	+70	+55	+70
High temp. surfaces	°C	None	None	None	+70	+70	+70	+70
High temp. water	°C	+30	+35	+35	+35	+35	+35	+35
Gradual change of temp. air to air	°C	None	−25/+20	−25/+40	−25/+40	−25/+40	+5/+40	−20/+40
	°C/min		1	3	3	3	3	3
Change of temp. air to water	°C	None	None	None	+40/+5	+40/+5	+40/+15	+40/+15
Humidity not combined with rapid temp.	%	95	95	95	95	95	95	95
changes	°C	+30	+35	+35	+45	+45	+35	+45
Humidity combined with rapid temp. changes,	%	None	None	95	95	95	95	95
air/air at high relative humidities	°C			−25/+35	−25/+35	−25/+35	+5/+30	−20/+35
Humidity combined with rapid temp. changes,	g/m^3	None	None	None	60	60	60	60
air/air at high water content	°C				+70/+15	+70/+15	+70/+15	+70/+15
Low relative humidity	%	10	10	10	10	10	10	10
	°C	+30	+30	+30	+30	+30	+30	+30
Movement of surrounding air	m/s	No	No	No	30	50	50	50
Precipitation, rain	mm/min	None	None	None	6	15	15	15
Solar radiation	W/m^2	No	700	700	1120	1120	1120	1120
Radiation, heat	W/m^2	No	600	1200	1200	1200	1200	1200
Water from other sources (not rain)	m/s	None	0.3	0.3	3	10	10	10
Wetness	None	No	Wet surfaces	Wet surfaces	Wet surfaces	Wet surfaces	Wet surfaces	Wet surfaces

Table 1.31 Operational – shipborne equipment – biological conditions

Environmental parameter	Unit	Classification	
		6B1	6B2
Flora, in air	None	Negligible	Presence of mould, fungus, etc.
Fauna, in air	None	Negligible	Presence of rodents or other animals harmful to products

Table 1.32 Operational – shipborne equipment – chemically active substances

Environmental parameter	Unit	Classification		
		6C1	6C2	6C3
Salt mist	None	No	Yes	
Sulphur dioxide	mg/m^3	0.1	1.0	1.0
	cm^3/m^3	0.037	0.37	0.37
Hydrogen sulphide	mg/m^3	0.01	0.5	0.5
	cm^3/m^3	0.0071	0.36	0.36
Nitrogen oxides (expressed in equivalent values of nitrogen dioxides)	mg/m^3	0.1	1.0	1.0
	cm^3/m^3	0.052	0.52	0.52
Ozone	mg/m^3	0.01	0.01	0.1
	cm^3/m^3	0.005	0.005	0.05
Hydrogen chloride	mg/m^3	0.1	0.1	0.5
	cm^3/m^3	0.066	0.066	0.33
Hydrogen fluoride	mg/m^3	0.003	0.003	0.03
	cm^3/m^3	0.0036	0.0036	0.036
Ammonia	mg/m^3	0.3	0.3	3.0
	cm^3/m^3	0.42	0.42	4.2
Sea salts in water	kg/m^3	Negligible	Negligible	30

Table 1.33 Operational – shipborne equipment – mechanically active substances

Environmental parameter	Unit	Classification		
		6S1	6S2	6S3
Sand	g/m^3 of air	None	0.1	10
Dust sedimentation	mg/(m^2·h)	Negligible	3.0	3.0
Soot deposit	None	None	Soot	Soot

Table 1.34 Operational – shipborne equipment – mechanical conditions

Environmental parameter	Unit	Classification						
		6M1	6M2		6M3		6M4	
Stationary sinusoidal vibration								
Displacement amplitude	mm	None	1.5		1.5		1.5	
Acceleration amplitude	m/s^2	None		10		20		50
Frequency range	Hz	None	2–13	13–100	2–18	18–200	2–28	28–200
Non-stationary vibration including shock								
Shock response spectrum type I peak acceleration $\hat{a}$	m/s^2	50	100		100		100	
Shock response spectrum type II peak acceleration $\hat{a}$	m/s^2	100	300		300		300	
Shock response spectrum type III peak acceleration $\hat{a}$	m/s^2	None	None		500		500	
Angular deviation, static condition								
Rotation around x-axis (list) angle	Degree	15	15		15		15	
Rotation around y-axis (list) angle	Degree	10	10		10		10	
Angular deviation, dynamic condition								
Rotation around x-axis (roll)								
Angle	Degree	22.5	22.5		22.5		22.5	
Frequency	Hz	0.14	0.14		0.14		0.14	
Rotation around y-axis (pitch)								
Angle	Degree	10	10		10		10	
Frequency	Hz	0.2	0.2		0.2		0.2	
Rotation around z-axis (yaw)								
Angle	Degree	4	4		4		4	
Frequency	Hz	0.05	0.05		0.05		0.05	
Steady state acceleration								
x-direction (surge)	m/s^2	5	5		5		5	
y-direction (sway)	m/s^2	6	6		6		6	
z-direction (heave)	m/s^2	10	10		10		10	

1.4.3.5 Portable equipment

Table 1.35 Operational – portable equipment – climatic conditions

Environmental parameter	Unit	Classification						
		7K1	7K2	7K3	7K4	7K5	7K6	7K7
Low temp. air	°C	+5	−5	−25	−40	−65	+5	−20
Low temp. water	°C	+40	+45	+70	+70	+85	+40	+55
Low relative humidity	%	5	5	5	5	4	30	4
High relative humidity	%	85	95	100	100	100	100	100
Low absolute humidity	g/m^3	1	1	0.5	0.1	0.003	6	0.9
High absolute humidity	g/m^3	25	29	48	62	78	36	27
Rapid change of air temperature	°C/°C	+5/+25	−5/+25	−25/+30	−40/+30	−65/+30	+5/+30	−20/+30
Low air pressure	kPa	70	70	70	70	30	70	70
High air pressure	kPa	106	106	106	106	106	106	106
Rate of change of air pressure	kPa/min	Negligible	Negligible	Negligible	Negligible	6	6	6
Solar radiation	W/m^2	700	700	1120	1120	1120	1120	1120
Radiation, heat	None	Select from the following table						
Movement of surrounding air	m/s	Select from the following table						
Condensation	None	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation, rain	None	No	No	Yes	Yes	Yes	Yes	Yes
Rain intensity	mm/min	None	None	6	6	15	15	15
Low rain temperature	°C	None	None	+5	+5	+5	+5	+5
Water from other sources (not rain)	None	Select from the following table						
Ice and frost formation	None	No	Yes	Yes	Yes	Yes	Yes	Yes

Table 1.36 Operational – portable equipment – special climatic conditions

Environmental parameter	Class	Unit	Special condition Z
High air temperature	7Z14	°C	+55
Low air temperature	7Z15	°C	84
Heat radiation	7Z1	None	Negligible
	7Z2	None	Heat radiation, e.g. near room heating systems
	7Z3	None	Heat radiation, e.g. near room heating systems or commercial ovens/furnaces
Movement of surrounding air	7Z4	m/s	5
	7Z5	m/s	10
	7Z6	None	30
	7Z7	None	50
Water from sources other than rain	7Z8	None	Negligible
	7Z9	None	Dripping water
	7Z10	None	Spraying water
	7Z11	None	Splashing water
	7Z12	None	Water jets
	7Z13	None	Water waves

Table 1.37 Operational – portable equipment – biological conditions

Environmental parameter	Unit	Classification		
		7B1	7B2	7B3
Flora	None	No	Presence of mould, fungus, etc.	Presence of mould, fungus, etc.
Fauna	None	No	Presence of rodents or other animals harmful to products. Excludes termites	Presence of rodents or other animals harmful to products. Including termites

Table 1.38 Operational – portable equipment – chemically active substances

Environmental parameter	Unit	Classification			
		7C1	7C2	7C3	7C4
Sea salt	None	Negligible	Conditions of salt mist		
Sulphur dioxide	mg/m^3	0.1	1.0 (0.3)	10 (5.0)	40 (13)
Hydrogen sulphide	mg/m^3	0.01	0.5 (0.1)	10 (3.0)	70 (14)
Chlorine	mg/m^3	0.1	0.3 (0.1)	1.0 (0.3)	3.0 (0.6)
Hydrogen chloride	mg/m^3	0.1	0.5 (0.1)	5.0 (1.0)	5.0 (1.0)
Hydrogen fluoride	mg/m^3	0.003	0.03 (0.01)	2.0 (0.1)	2.0 (0.1)
Ammonia	mg/m^3	0.3	3.0 (1.0)	35 (10)	175 (35)
Ozone	mg/m^3	0.01	0.1 (0.05)	0.3 (0.1)	2.0 (0.2)
Nitrogen oxides (expressed in equivalent values of nitrogen dioxides)	mg/m^3	0.1	1.0 (0.5)	9.0 (3.0)	20 (10)

Table 1.39 Operational – portable equipment – mechanically active substances

Environmental parameter	Unit	Classification		
		7S1	7S2	7S3
Sand	mg/m^3	30	300	10 000
Dust suspension	mg/m^3	0.2	5.0	20
Dust sedimentation	$mg/(m^2{\cdot}h)$	1.5	20	80

Table 1.40 Operational – portable equipment – mechanical conditions

Environmental parameter	Unit	Classification								
		7M1			7M2			7M3		
Stationary sinusoidal vibration										
Displacement amplitude	mm	3.5			3.5			7.5		
Acceleration amplitude	m/s^2		10	15		10	15		20	40
Frequency range	Hz	2–9	9–200	200–500	2–9	9–200	200–500	2–8	8–200	200–500
Stationary vibration, random										
Acceleration spectral density	m^2/s^3	1	0.3		1	0.3		3	1	
Frequency range	Hz	10–200	200–2000		10–200	200–2000		10–200	200–2000	
Non-stationary vibration including shock										
Shock response spectrum type I peak acceleration $\hat{a}$	m/s^2	100			100				300	
Shock response spectrum type II peak acceleration $\hat{a}$	m/s^2	No			300				1000	
Free fall										
Mass less than 1 kg	m		0.025				0.25		1.0	
Mass 1 kg to 10 kg	m		0.025				0.1		0.5	
Mass 10 kg to 50 kg	m		0.025				0.05		0.25	
Mass more than 50 kg	m			To be agreed between supplier and user						

1.5 Environmental application

Although the conditions affecting equipment mainly consist of the environment (ambient and created), consideration must also be given to where the equipment will be operating from and how it will be used.

For simplicity we have (within this book) broken these details down into two basic categories:

- *Conditions*
  The environmental conditions that have been identified as having an effect on the electronic equipment (Table 1.41).
- *Situations*
  The main uses of electronic equipment (Table 1.42).

1.5.1 Environmental conditions

There are eight basic conditions that have a direct effect on electronic equipment. These are:

Table 1.41 Basic environmental conditions

Climatic
- ambient temperature
- solar radiation
- condensation
- relative atmospheric humidity
- atmospheric pressure
- wind
- precipitation (i.e. rain, snow and hail)
- altitude

Mechanical
- vibration
- shock (sinusoidal and random)

Electrical
- electromagnetic environment (EMC and EMI)
- susceptibility and generation
- transients (spikes and surges)
- power supplies
- earthing and bonding

Biological
- animals
- humans (vandalism)
- vegetation

Externally generated influences
- temperature
- precipitation (e.g. water spray)
- pressure changes (e.g. tunnels)
- air movement
- dust

Ergonomic aspects
- protecting the health of the operator
- the comfort of the operator
- achieving maximum task effectiveness

Chemical
- pollution and contamination
- dangerous substances
- corrosion
- resistance to solvents

General
- safety
- reliability
- maintainability
- components
- waste
- earthquakes
- flammability and fire hazardous areas
- design of equipment

1.5.2 Equipment situations

Obviously not all equipment will be fully operational all of the time and so various equipment 'situations' also have to be considered.

Table 1.42 Environmental equipment conditions

Operational	Storage	Transportation	Shipborne
• when installed and operational • when installed and not in use	• when in storage	• when being transported	

Chapter 2

Ambient temperature

2.1 Guidance

2.1.1 What is ambient temperature?

Temperature, humidity, rainfall, wind velocity and the duration of sunshine all affect the climate of an area. These elements are in turn the result of the interaction of a number of determining causes, such as latitude, altitude, wind direction, distance from the sea, relief, and vegetation. Elements and their determining causes are similarly interrelated which also contribute to temperature changes, for example the length of day is a factor which helps to determine temperature; however, the duration of actual sunshine is an element with far-reaching effects on plant and animal life.

Of all the elements that have an effect on man and equipment none is more vital to living organisms than temperature. Temperature has a large influence on where humans live and in the areas where they work. Protective housing or artificial heat sources may overcome low temperatures (and high altitudes); similarly cooling devices and reflective coatings protect equipment from high temperatures. Temperature is therefore a particularly important aspect of the environment and its accurate measurement and statement are matters requiring careful attention.

There are two possible sources from which the temperature at the Earth's surface may be derived. The first, and most important, source of temperature is the sun (heat rays from the sun are the most important manifestation of solar energy) and the second is the interior of the Earth.

The ambient temperature at any given time is the temperature of the air measured under standardised conditions and with certain recognised precautions against errors introduced by radiation from the sun or other heated bodies. Temperature figures with respect to climate are generally 'shade' temperatures (i.e. the temperature of the air measured with due precautions taken to exclude the influence of the direct rays of the sun) and it is usual for the temperature to be much higher in direct sunshine. Many mountain areas have air temperatures in the region of zero in winter but the

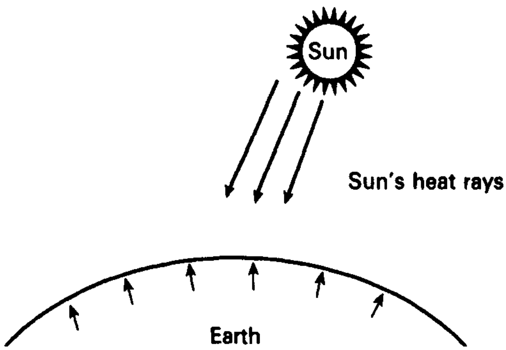


Fig. 2.1 Temperature sources at the Earth's surface

presence of bright sunshine produces a feeling of warmth and permits the wearing of light clothing.

Seasonal fluctuations in temperature do not pass below ground deeper than 60–80 ft. Below that depth borings and mineshafts indicate that the temperature increases (downwards) depending on the geographical position, location and depth. On average, however, a rise of about 1°F may be taken for each 64 ft of descent. Assuming that this rate of increase is maintained, it stands to reason that the interior of the Earth must be excessively hot and, therefore, it must warm the surface to some extent. It is not possible to determine the precise influence of this temperature increase but it has an effect on tunnels at a depth greater than 80 ft. As the heat from the core is virtually negligible on the surface of the Earth (compared with that of the sun), it has not been considered here and the only source of heat that has been taken into account is the sun.

The difference between summer and winter temperatures of any locality is known as the 'annual range of temperature' of that locality. It is the difference between the highest and lowest temperatures ever experienced at

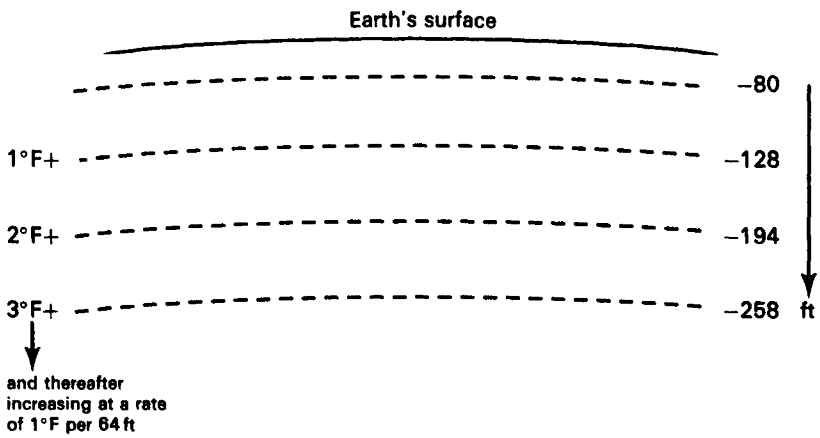


Fig. 2.2 Temperature changes below the Earth's crust

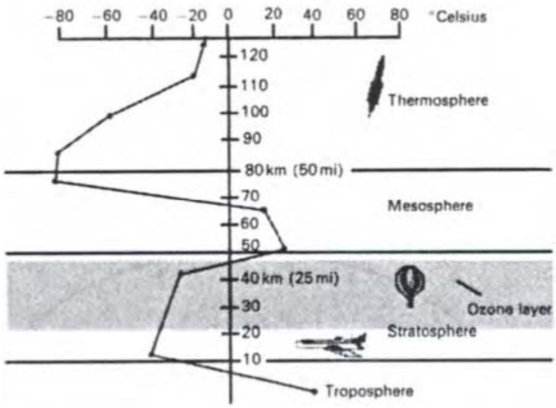


Fig. 2.3 Temperature changes above the Earth's surface (reproduced from Microsoft Encarta 98 Encyclopedia Deluxe edition)

the place in question (it may also be referred to as the 'absolute range of temperature'). The maximum and minimum temperatures are not the same every year and, should their average over a series of years be taken, it would be known as the 'mean annual extreme range'.

Although air near the surface, especially at night, may be cooler than the air just above it there is generally a gradual falling off of temperature from the ground level up. Over thousands of feet this cooling averages 1°F per 300 ft and thus at approx. 25–55 000 ft (five to 10 miles) above the ground the temperature will be down to 55–60°F below zero. Above this the air temperature ceases to fall off regularly, in fact it may even rise for a bit. Usually, however, it remains fairly constant and is, on this account, sometimes referred to as the isothermal layer. To meteorologists and airmen it is known as the stratosphere. The lower layers of the atmosphere, where temperature falls off with height, commonly go by the name of the troposphere. The boundary layer between the two is called the tropopause.

2.1.2 Introduction

When equipment has been installed without any protection it can be expected to be exposed to more extreme air temperatures and more severe combinations of air temperatures and relative humidities than a similar piece of equipment that has been installed or housed in a temperature controlled environment.

In addition to open air temperature, temperature stresses on equipment depend on a number of other environmental parameters (e.g. solar radiation, heating from adjacent equipment and air velocity, etc.) and these must be taken into account when designing and manufacturing equipment.

The performance of equipment is also influenced and limited by the internal temperature of the equipment. Internal temperatures, in turn, depend on the external ambient conditions and the heat generated within the device itself. Indeed, whenever a temperature gradient exists within a system formed by a device and its surrounding environment, a process of heat transfer will ensue.

Thus in any generic (or system specific) specification or standard related to ambient temperature it is necessary to consider the:

- *operating temperature range* – the specified operating temperature for the equipment which must always be the lowest and the highest ambient temperature expected to be experienced by the equipment during its normal operation;
- *storage temperature range* – the specified storage temperature that is always the lowest and the highest ambient temperature that the equipment is expected to experience (with the power turned off) during storage or from exposure to climatic extremes.

Note: The equipment is not normally expected to be capable of operating at these extreme temperatures, merely survive them without damage.

Note: The use of the words 'shall' and 'should' in the context of national, European and international specifications is normally accepted as 'mandatory' and 'preferable', respectively.

2.1.3 Test standards

The following are the most frequently used ambient temperature tests that equipment is required to pass.

IEC 68.2.1	Environmental testing procedures – Test A: Cold
IEC 68.2.2	Environmental testing procedures – Test B: Dry heat
IEC 68.2.14	Environmental testing procedures – Test N: Change in temperature
IEC 68.2.41	Environmental testing procedures – Tests Z/BM: Combined dry heat/low air pressure
IEC 68.2.61	Environmental testing procedures – Test Z/ABDM: Climatic sequence

2.1.4 Other related standards and specifications

IEC 68.1	Environmental testing procedures – General and guidance
IEC 68.2.13	Environmental testing procedures – Test M: Low air pressure
IEC 68.2.28	Environmental testing procedures – Guidance: Damp heat tests
IEC 68.2.3	Environmental testing procedures – Test Ca: Damp heat, steady state

IEC 68.2.30	Environmental testing procedures – Test Db and guidance: Damp heat cyclic (12 + 12 hour cycle)
IEC 68.2.33	Environmental testing procedures – Guidance on change of temperature tests
IEC 68.2.38	Environmental testing procedures – Test Z/AD: Composite temperature/humidity cyclic test
IEC 68.2.39	Environmental testing procedures – Test Z/AMD: Combined sequential cold, low air pressure and damp heat test. (*Note:* mainly for high altitude applications)
IEC 68.2.40	Environmental testing procedures – Test Z/AM: Combined cold low air pressure tests
IEC 68.2.50	Environmental testing procedures – Test Z/Afc: Combined cold vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.2.51	Environmental testing procedures – Test Z/BFc: Combined dry heat vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.2.56	Environmental testing procedures – Test Cb: Damp heat, steady state, primarily for equipment
IEC 68.3.1/1A	Environmental testing procedures – Background information – Cold and dry heat tests (and supplement)
IEC 68.3.2	Environmental testing procedures – Background information – Combined temp./low air pressure tests
IEC 68.4.4	Environmental testing procedures – Information for specification writers – Test summaries
IEC 721.2.1	Classification of environmental conditions – Environmental conditions appearing in nature – Temperature and humidity
IEC 721.2.3	Classification of environmental conditions – Environmental conditions appearing in nature – Air pressure
IEC 721.3.0	Classification of environmental conditions – Classification of groups of environmental parameters and their severities – Introduction

2.2 Typical contract requirements – ambient temperature

2.2.1 Introduction

The requirement for equipment to conform to various environmental specifications is becoming commonplace in today's contracts. More and more specifications are being used to describe the various conditions that equipment is likely to experience when being used, stored or whilst in transit.

The following are the most common environmental requirements found in modern contracts concerning ambient temperature.

2.2.2 Temperature ranges

Equipment has to be designed and manufactured to meet the full performance specification requirement for the selected temperature category. Typical ranges are shown in Tables 2.1 to 2.3 (see pages 46 to 50) which have been extrapolated from IEC 721. Deviations from these temperature tables are normally subject to agreement between purchaser and supplier.

2.2.3 Temperature increases

The design of equipment should always take into account temperature increases within cubicles and equipment cases so as to ensure that the components do not exceed their specified temperature ranges.

2.2.4 Temperature variations

Rapid external ambient temperature variations resulting from moving equipment through tunnels, etc. (e.g. railway mounted equipment) should be taken into account. It should be noted that it is normal for the rate of change of external temperature to be assumed to be 3°C/sec with a maximum variation of 40°C.

2.2.5 Temperature stresses

In addition to open air temperature, temperature stresses on equipment caused by other environmental parameters (e.g. solar radiation, air velocity and heating from adjacent equipment) need to be considered.

2.2.6 Operational requirements

The following are normal operating requirements found in most contracts:

- the specified operating temperatures are the lowest and the highest ambient temperatures expected to be experienced by equipment during normal operation;
- when equipment is turned on it is expected to operate within the temperature ranges stipulated and be fully operational within a specified time after initial turn-on unless otherwise specified;
- the permissible limit temperatures of the operating equipment are not allowed to be exceeded as a result of the temperature rise occurring in operation (including temporary acceleration).

Note: The limit temperature of operating equipment is normally the maximum or minimum temperature at which no 'disadvantageous change or deformation of operating equipment' occurs. Ambient temperature is the temperature closest to the element (i.e. where it is positioned).

2.2.7 Storage

After storage equipment will be expected to function in accordance with the procuring specification, without failure and be capable of passing the high and low level temperature tests as well as the temperature shock tests.

The specified storage temperatures are normally the lowest and highest ambient temperatures that the sample is expected to experience (with the power turned off) during storage or exposure to climatic extremes. The equipment is not expected to be capable of operating at these extreme temperatures, but to survive them without damage.

2.2.8 Peripheral units

For peripheral units (measuring transducers, etc.) or situations where equipment is in a decentralised configuration, ambient temperature ranges are frequently exceeded. In these cases the actual temperature occurring at the location of the equipment concerned needs to be used in the design.

2.2.9 Installation

When equipment is installed in a controlled climatic environment, provided the equipment is not required to operate outside of those conditions, the temperature range can normally be agreed between purchaser and supplier.

2.2.10 Tests

2.2.10.1 Production configuration

All proposed candidate equipment, components or other articles will need to be tested in their production configuration without the use of any additional external devices that have been added expressly for the purpose of passing temperature testing.

2.2.10.2 Procuring specifications

When tested, the sample (component, equipment or other article) will be expected to perform as stipulated in the procuring specification and over the designated temperature range.

2.2.10.3 Test methods

Test methods for determining the suitability of a specimen normally include:

IEC 68.2.1	Environmental testing procedures – Test A: Cold
IEC 68.2.14	Environmental testing procedures – Test N: Change in temperature
IEC 68.2.2/2A	Environmental testing procedures – Test B: Dry heat (plus supplement)
IEC 68.2.41	Environmental testing procedures – Test Z/BM: Combined dry heat/low air pressure
IEC 68.2.61	Environmental testing procedures – Test Z/ABDM: Climatic sequence

Note: Other tests can be specified from those shown in Section 2.4.

2.3 Values and ranges

Guidance on geographical values and ranges of temperature (i.e. limits of statistical open-air climate) has been taken from the latest issue of the IEC 721 standard. These figures are based on observations over a period of not less than 10 years and represent conditions frequently met by products whilst being transported, stored, installed or used.

Except where stated, all values given represent the maximum and minimum temperature requirements for that particular equipment, location and situation.

Deviation from the temperature table is normally subject to acceptance by demonstration that the equipment is suitable for service and by agreement between the purchaser and the supplier.

2.3.1 Ship environment

The ship environment (as described in IEC 721.3.6) classifies groups of environmental parameters and their severities that a product is subjected to when permanently or temporarily installed aboard a ship, including:

- ships propelled by mechanical means, including mobile offshore units (see also IEC 92.10);
- ships not propelled by mechanical means (including sailing boats and liferafts).

The classes defined in this standard are applicable to all sizes of ships from pleasure craft to trawlers, ferry boats, icebreakers, cargo ships (including tankers) whilst operating in:

- inland waterways (i.e. canals, rivers, lakes);
- coastal waters;
- oceans.

Table 2.1 Ambient temperature – storage

Installation location	IEC 721 class	Low air temp.	High air temp.	Rate of change of temp. averaged over a period of 15 minutes
		°C	°C	°C
Fully air conditioned enclosed locations, with air temperature and humidity control	1K1	+20	+25	0.1
Fully air conditioned, temperature controlled, enclosed locations, without humidity control	1K2	+5	+40	0.5
Fully enclosed locations without air temperature or humidity control	1K3	−5	+45	0.5
Partially weather protected locations without air temperature or humidity control[1]	1K4	−25	+55	0.5
Partially weather protected locations without air temperature or humidity control[1]	1K5	−40	+70	1.0
Partially weather protected locations without air temperature or humidity control[1]	1K6	−55	+70	1.0
Restricted non-weather protected locations[1]	1K7	−20	+35	0.5
Moderate non-weather protected locations[1]	1K8	−33	+40	0.5
Worldwide non-weather protected locations[1]	1K9	−65	+55	0.5
Non-weather protected locations with tropical damp climates (rainforests)	1K10	+5	+40	0.5
Non-weather protected locations with tropical dry climates (deserts)	1K11	−20	+55	0.5

Note
1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

Table 2.2 Ambient temperature – transportation

Installation location	IEC 721 class	Low air temp.	High air temp. (ventilated)	High air temp. (unventilated)	Change of temp. air/air	Change of temp. air/water
		°C	°C	°C	°C	°C
Weather protected heated and ventilated	2K1	+5	+40	N/A	N/A	N/A
Weather protected and ventilated but unheated in general climates excluding cold and cold temperate climates	2K2	−25	+40	+60	−25/+25	N/A
Non-weather protected, unventilated and unheated in general climates excluding cold and cold temperate climates	2K3	−25	+40	+70	−25/+30	+40/+5
Non-weather protected, unventilated and unheated in general climates including cold temperate climates	2K4	−40	+40	+70	−40/+30	+40/+5
Non-weather protected conditions worldwide	2K5	−65	+55	+85	−65/+30	+55/+5
Non-weather protected conditions excluding cold and cold temperate climates	2K5H	−25	+55	+85	−25/+30	+55/+5
Non-weather protected conditions including cold and cold temperate climates	2K5L	−65	+40	+70	−65/+30	+40/+5
Non-weather protected conditions covering tropical damp climates (rainforests)	2K6	+5	+40	+70	+5/+30	+40/+5
Non-weather protected conditions covering tropical dry climates (deserts)	2K7	−20	+55	+85	−20/+30	+55/+5

Note
1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

Table 2.3 Ambient temperature – operational

Installation location	IEC 721 class	Low air temp.	High air temp.	Rate of change of temp.	Change of temp. air/air
		°C	°C	°C/min	°C
Stationary use at weather protected, fully air conditioned locations with temperature and humidity control	3K1	+20	+25	0.1	–
Stationary use at weather protected, temperature controlled locations with partial humidity control	3K2	+15	+30	0.5	–
Stationary use at weather protected, temperature controlled locations with no humidity control	3K3	+5	+40	0.5	–
Stationary use at weather protected temperature controlled locations with no humidity control	3K4	+5	+40	0.5	
Stationary use at weather protected locations with no temperature or humidity control	3K5	–5	+45	0.5	–
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K6	–25	+55	0.5	
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K7	–40	+70	1.0	
Stationary use at partially weather protected locations with no temperature or humidity control, not exposed to solar radiation[1]	3K7L	–40	+40	1.0	
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K8	–55	+70	1.0	
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K8H	–25	+70	1.0	
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K8L	–55	+55	1.0	
Stationary use at partially weather protected locations in tropical damp climates (rainforest)	3K9	+5	+40	1.0	

continued

Stationary use at partially weather protected locations in tropical dry climates (desert)	3K10	−20	+55	1.0	
Stationary use at non-weather protected restricted locations[1]	4K1	−20	+35	0.5	–
Stationary use at non-weather protected moderate locations[1]	4K2	−33	+40	0.5	
Stationary use at non-weather protected general locations[1]	4K3	−60	+40	0.5	
Stationary use at non-weather protected worldwide locations[1]	4K4	−65	+55	0.5	
Stationary use at non-weather protected locations, low air temperature, low absolute humidity[1]	4K4H	−20	+55	0.5	
Stationary use at non-weather protected locations, high air temperature, low relative humidity, high absolute humidity[1]	4K4L	−65	+35	0.5	
Stationary use at non-weather protected locations in tropical damp climates (rainforests)	4K5	+5	+40	0.5	
Stationary use at non-weather protected locations in tropical dry climates (deserts)	4K6	−20	+55	0.5	
Ground vehicle installations with products weather protected, ventilated and heated	5K1	+5	+40	–	–
Ground vehicle installations with products weather protected (or partially weather protected), heated (or unheated), unventilated	5K2	−25	+40	–	−25/+30
Ground vehicle installations, unventilated, subject to wet surfaces and solar radiation	5K3	−40	+40		−40/+30
Ground vehicle installations, unventilated, subject to sprays, jets of water and solar radiated	5K4	−65	+55		−65/+30
Ground vehicle installations, unventilated, subject to sprays, jets of water and solar radiation in low temperature climates	5K4H	−25	+55		−25/+30
Ground vehicle installations, unventilated, subject to sprays, jets of water and solar radiation in high temperature climates	5K4L	−65	+40	−65/+30	
Installations in totally weather protected, heated and ventilated ship environments, not exposed to solar radiation	6K1	+5	+40	–	–
Installations in totally weather protected, heated and ventilated ship environments, excluding cold climates	6K2	−25	+40	1	−25/+20

continued

Table 2.3 (*cont.*)

Installation location	IEC 721 class	Low air temp. °C	High air temp. °C	Rate of change of temp. °C/min	Change of temp. air/air °C
Installations in totally weather protected, heated and ventilated ship environments, near to heat dissipating equipment	6K3	−25	+55	3	−25/+40
Installations in non-weather protected, unventilated heated ship environments, excluding cold climates	6K4	−25	+70	3	−25/+40
Installations in non-weather protected, unventilated, unheated ship environments, including cold climates	6K5	−40	+70	3	−25/+40
Shipborne installations in tropical damp climates (rainforests)	6K6	+5	+55	3	+5/+40
Shipborne installations in tropical dry climates (deserts)	6K7	−20	+70	3	−20/+40
Portable and non-stationary use at direct transfer between temperature controlled weather protected environments, without humidity control	7K1	+5	+40	–	+5/+25
Portable and non-stationary use at or direct transfer between weather protected environments without humidity or temperature control	7K2	−5	+45	–	−5/+25
Portable and non-stationary use at or direct transfer between partially weather protected restricted environments[1]	7K3	−25	+70	–	−25/+30
Portable and non-stationary use at or direct transfer between partially weather protected moderate environments[1]	7K4	−40	+70	–	−40/+30
Portable and non-stationary use at or direct transfer between partially weather protected worldwide environments[1]	7K5	−65	+85	–	−65/+30
Portable and non-stationary use in tropical damp climates (rainforests)	7K6	+5	+40	–	+5/+30
Portable and non-stationary use in tropical climates (deserts)	7K7	−20	+55	–	−20/+30

Note
1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

2.3.2 Environmental conditions in tropical areas

In the tropics (i.e. between 23°27′ south and 23°27′ north) it is normal to find daytime high temperatures, frequently combined with high precipitation. There are very few changes but the tropical climate extends from warm damp climatic conditions (in tropical rainforests at the equator) to a warm dry climate (in the deserts near the tropics).

The basic environmental conditions found in the tropics fall into two categories, balanced and extreme.

Balanced conditions:

- minimum daily temperature fluctuations of less than 1°C. Annual temperature fluctuations of no more than 6°C;
- daylight periods between 10.5 and 15.5 hours;
- uniform intensity of solar radiation;
- abundant fauna.

Extreme conditions:

- precipitation – rainfall the whole year round near the equator, heavy rainfall during certain periods of the year near the tropics;
- tropical cyclones in sea areas – wind velocities of 30 m/s with peaks attaining more than 60 m/s, for example in typhoons in the Western Pacific and in hurricanes in the Caribbean Sea;
- unfavourable soil conditions – erosion of humus and minerals in areas with heavy rainfalls;
- rapid drying of soil in the desert – as a result of high temperatures and strong winds;
- lush vegetation in tropical rainforests;
- less dense vegetation in mountain forests;
- green areas of savannahs and steppes;
- absence of vegetation in the desert.

2.4 Tests

This section details some of the test standards which may be applied to equipment and contains:

- a list of the most used environmental tests that a purchaser will normally require a manufacturer to adhere to;
- a list of other related standards and specifications;
- a brief description of the most common tests.

Note: Full details of each of these recommended tests are contained in the relevant ISO, IEC or other standard. A complete list of these standards is supplied in the reference section of this book. Copies of all these standards may be obtained from any National Standards Organisation.

2.4.1 Cold temperature test (IEC 68.2.1 Test A)

Standard No.	IEC 68.2.1
Title	Environmental testing procedures – Test A: Cold
Summary	Contains: • Test Aa: Cold for non-heat dissipating specimen with sudden change of temperature; • Test Ab: Cold for non-heat dissipating specimen with gradual change of temperature; • Test Ad: Cold for heat dissipating specimen with gradual change of temperature. Standard temperatures from −65°C to +5°C. Applicable to all electrical and electronic components of which the terminations or integral mounting devices are liable to be submitted to stresses during normal assembly or handling operations.
Equiv. Std	Technically equivalent to AS 1099:PT2AA Technically equivalent to AS 1099:PT2AB Technically equivalent to AS 1099:PT2AD Identical to BS EN 60068 PT2-1 Identical to DIN EN 60068 PT2-1 Identical to DIN IEC 68 PT2-1 Identical to EN 60068 PT2-1 Identical to HD 323.2.1 Identical to NEN 10068-2-1 Identical to NFC 20-701 Identical to NF EN 60068-2-1 Identical to SEN 43 16 01
Ref. Stds	IEC 68.1 Environmental testing procedures – General and Guidance IEC 68.3.1 Environmental testing procedures – Background information – Cold and dry heat tests

2.4.1.1 Introduction

Whilst air temperatures around −25°C are often recorded in Central Europe, in some of the more uninhabited regions (e.g. Switzerland) minimum temperatures often go down to −40°C. Granted operational equipment will rarely be subjected to such severe conditions, but some electronic equipment may occasionally be stored or installed for several weeks before actually being brought into service and could quite likely be exposed to these extreme conditions.

One problem to be contended with is that when temperatures as low as −40°C are reached, many failures can occur due to the different coefficient of thermal expansion of the various materials, for instance:

- electronic capacitors may become unstable;

- the capacitance of metallised paper and paper capacitors will drop slightly;
- the capacitances of mica capacitors (depending on their size) will increase to one and a half or even twice their original value;
- protective coatings become brittle.

2.4.1.2 Purpose of this test

The purpose of test IEC 68.2.1 is to:

- determine the suitability of heat generating and non heat generating equipment during operation, storage, or whilst being transported at extremely low temperatures;
- provide a procedure to determine the effect of subjecting samples of equipment (that are intended to be used or stored at low temperatures) to sudden changes of temperature.

The cold tests are subdivided into two categories as shown in Figure 2.4.

2.4.1.3 General conditions

An item of equipment is considered heat dissipating only if the hottest point on its surface, measured in free air conditions (i.e. with no forced air circulation) is more than 5°C above the ambient temperature of the surrounding atmosphere after temperature stability has been reached.

Note: No external heating measures are permitted in order for the sample to pass this test.

2.4.1.4 Test conditions

IEC 68.2.1 provides details of cold (i.e. low temperature) tests for sudden and gradual changes of temperature, for both heat dissipating and non-heat dissipating samples.

Samples shall be turned on and be fully operational (including displays) within the specified time (according to the procuring specification) at the specified temperature.

Samples must be capable of being fully operational (according to the procuring specification) after temperature shock testing.

2.4.1.5 Other standards

Other standards that are frequently referred to when testing for low temperatures include:

IEC 68.2.39	Environmental testing procedures – Test Z/AMD: Combined sequential cold, low air pressure and damp heat test
IEC 68.2.40	Environmental testing procedures – Test Z/AM: Combined cold low air pressure tests

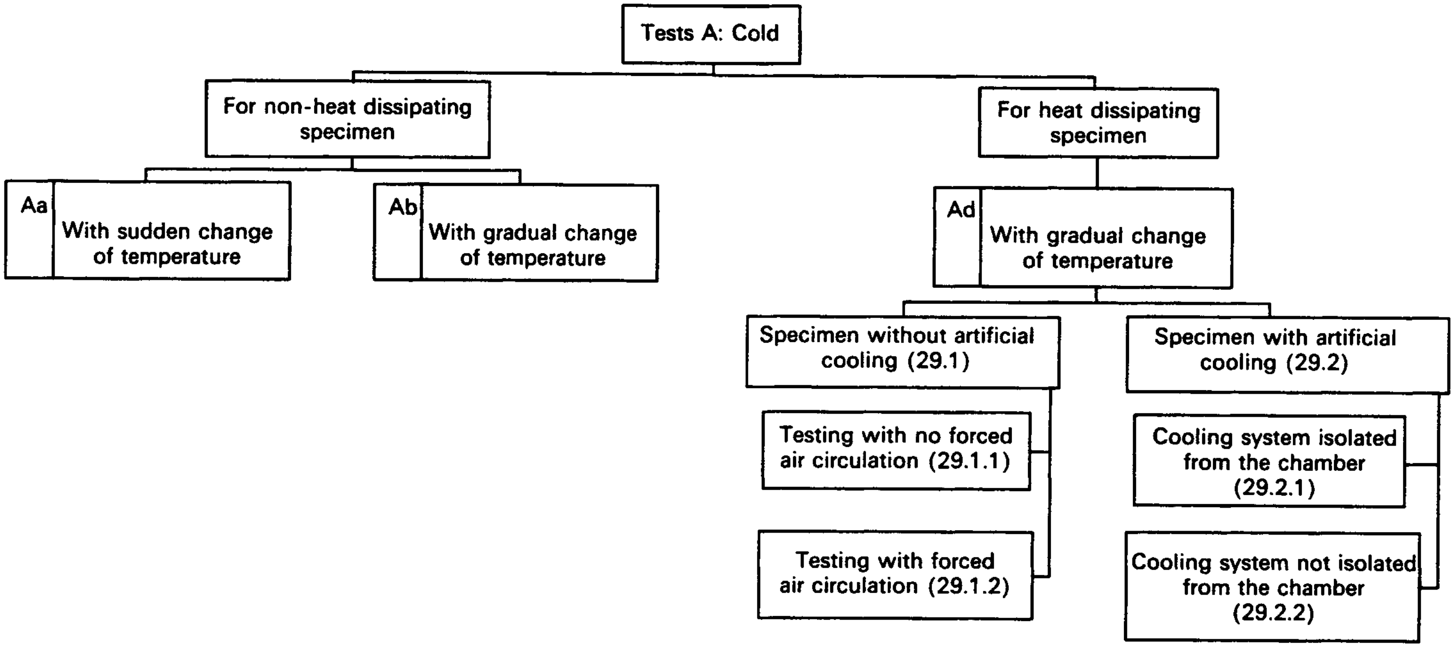


Fig. 2.4 Diagrammatic representation of the various cold test procedures (reproduced from the equivalent standard BS 60068 PT2.1 by kind permission of the BSI)

IEC 68.2.50	Environmental testing procedures – Test Z/AFc: Combined cold vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens

2.4.2 Dry heat test (IEC 68.2.2. Test B)

Standard No. IEC 68.2.2 (includes first supplement 68.2.2A)
Title Environmental testing procedures – Test B: Dry heat
Summary Contains:

- Test Ba: Dry heat for non-heat dissipating specimen with sudden change of temperature;
- Test Bb: Dry heat for non-heat dissipating specimen with gradual change of temperature;
- Test Bc: Dry heat for heat dissipating specimen with sudden change of temperature;
- Test Bd: Dry heat for heat dissipating specimen with gradual change of temperature.

Equiv. Std
Technically equivalent to AS 1099:PT2BA
Technically equivalent to AS 1099:PT2BB
Technically equivalent to AS 1099:PT2BC
Technically equivalent to AS 1099:PT2BD
Identical to BS EN 60068 PT2-2
Identical to DIN EN 60068 PT2-2
Identical to DIN IEC 68 PT2-2
Identical to EN 60068 PT2-2
Identical to HD 323.2.2
Identical to NEN 10068-2-2
Identical to NFC 20-702
Identical to NF EN 60068-2-2
Identical to SEN 43 16 02

Ref. Stds
IEC 68.1 Environmental testing procedures – General and Guidance
IEC 68.3.1 Environmental testing procedures – Background information – Cold and dry heat tests

2.4.2.1 Introduction

Dry heat is a particular problem for almost all types of electronic equipment as it accelerates the development of chemical processes, thus speeding up the ageing of materials. In extreme cases semiconductors will often attain the conductive properties of metals (i.e. electrons are raised into the conduction band) and occasionally the internal temperature of electronic equipment will reach values where materials with a low melting point may begin to soften or flow (e.g. the protective wax of 'sweating' resistors).

Whilst the chief source of heat is the sun, losses due to power dissipation must also be considered.

2.4.2.2 *Purpose of this test*

The purpose of test IEC 68.2.2 is to:

- determine the suitability of heat generating and non-heat generating samples for operation at high temperatures;
- determine the suitability of heat generating and non-heat generating samples to survive storage at high temperatures;
- determine the ageing effects of high temperature on electronic equipment;
- provide a procedure to determine the effect of subjecting electronic equipment whilst operational (or stored at high temperature) to sudden changes of temperature.

The dry heat tests are subdivided into categories as shown in Figure 2.5.

2.4.2.3 *General conditions*

No external cooling methods are allowed in order to pass this test.

It is appreciated that certain difficulties may arise due to the fact that heat transfer is associated with temperature gradients and that the temperature of the medium surrounding the device will vary in space. It is a requirement, therefore, that the 'ambient temperature' of the surrounding atmosphere is accurately defined and for this purpose:

- the yearly average external open-air temperature is conventionally taken as 25°C;
- the yearly average external temperature inside equipment housing or 'cubicles' is conventionally taken as 55°C.

External air temperatures in special locations (such as satellite terminals on top of buildings) may exceed the normal open-air temperature.

2.4.2.4 *Test conditions*

IEC 68.2.2 provides details of dry heat (i.e. high temperature) tests for both sudden and gradual changes of temperature, in both heat dissipating and non-heat dissipating electronic equipment.

Note: An item of equipment is considered heat dissipating only if the hottest point on its surface, measured in free air conditions (i.e. with no forced air circulation), is more than 5°C above the ambient temperature of the surrounding atmosphere after temperature stability has been reached.

It is not uncommon for equipment (especially when installed inside cubicles) to endure short-term start-up thermal conditions of up to 10°C over the steady state temperature range. If this does occur, then the full performance ratings may be relaxed if this is acceptable (and agreed with the end user) for the type of service required.

Samples are normally required to be capable of being fully operational (according to the procuring specification) after temperature shock testing

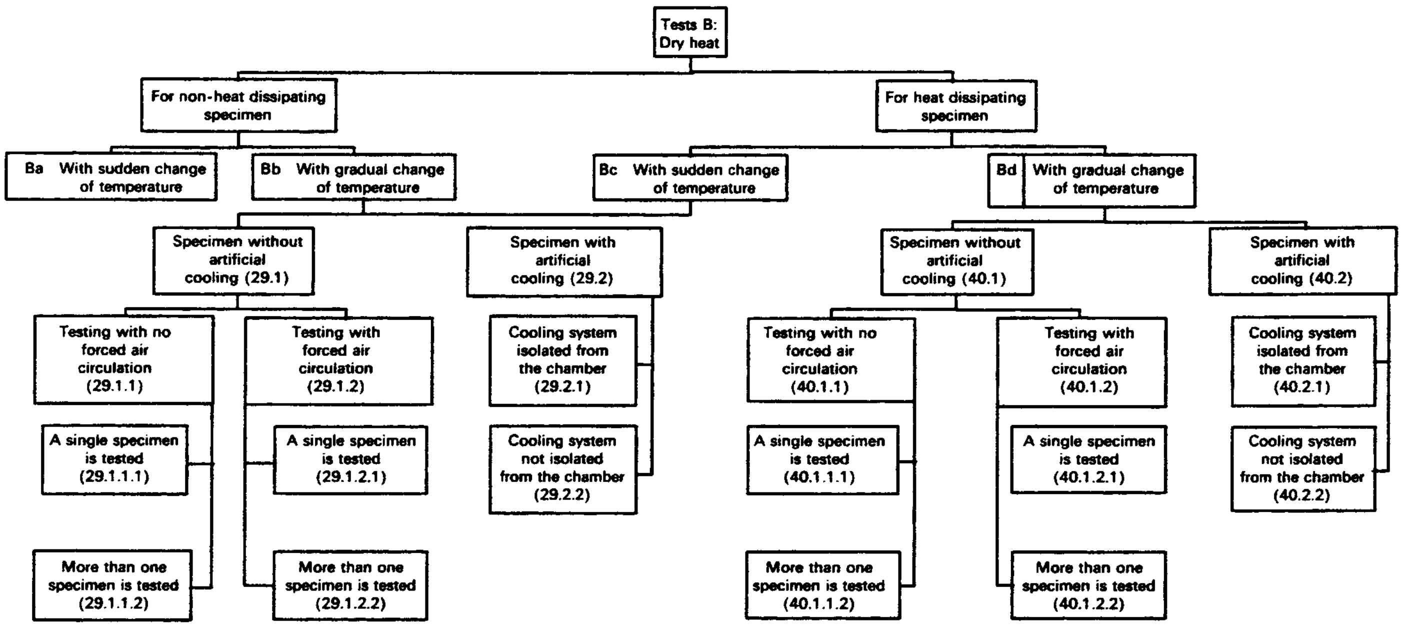


Fig. 2.5 Diagrammatic representation of the various dry heat test procedures (reproduced from the equivalent standard BS EN 60068.2.2 by kind permission of the BSI)

and to be fully operational (including displays) within 30 seconds of being switched on, at the specified temperature.

2.4.2.5 Other standards

Other standards that could be considered are:

IEC 68.2.51	Environmental testing procedures – Test Z/BFc: Combined cold vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.3.1	Environmental testing procedures – Background information – Cold and dry heat tests

2.4.3 Change of temperature test (IEC 68.2.14 Test N)

Standard No.	IEC 68.2.14
Title	Environmental testing procedures – Test N: Change of temperature
Summary	Determines the ability of components, equipment or other articles to withstand rapid changes of ambient temperature. The exposure times adequate to accomplish this will depend upon the nature of the specimen.
Equiv. Std	Technically equivalent to AS 1099:PT2N Technically equivalent to AS 1099:PT2NA Technically equivalent to AS 1099:PT2NB Technically equivalent to AS 1099:PT2NC Identical to BS 2011:PT2.1N(1985) Identical to DIN IEC 68 PT2-14 Identical to HD 323.2.14 Identical to NEN 10068-2-14 Identical to NFC 20-714 Identical to SEN 43 16 13
Ref. Stds	IEC 68.2.1 Environmental testing procedures – Tests A: Cold IEC 68.2.2 Environmental testing procedures – Tests B: Dry heat IEC 68.2.33 Environmental testing procedures – Guidance on change of temperature tests

2.4.3.1 Introduction

Electronic equipment will normally only experience gradual changes of temperature and internal components will normally only have to tolerate relatively slower changes of temperature than those experienced by the external surfaces.

Rapid changes of temperature may, however, be expected:

- during manufacture;
- when equipment is being transported and/or stored;

- when equipment is transported from a warm indoor environment into a cold air conditioned environment or vice versa (see also Chapter 4);
- when equipment is externally mounted;
- when equipment is suddenly cooled by rain or immersed in cold water;
- when a cooling system is switched on;
- when high temperature gradients have built up in equipment after switching on (e.g. in the vicinity of high wattage resistors).

2.4.3.2 Purpose of this test

The purpose of test IEC 68.2.14 is to:

- determine the ability of samples to withstand rapid changes of ambient temperature;
- stress samples in order to determine whether they have been properly designed and/or manufactured.

2.4.3.3 General

The change of temperature (or temperature shock) test is intended to determine the effect of a change of temperature (or a succession of changes of temperature) on samples. It is *not* intended that the test should show effects that are due only to low or high temperatures as described in paragraphs 2.4.1 and 2.4.2.

Notes: Quick changes of temperature (i.e. temperature gradients) may result in the destruction of electronic components, due to mechanical stresses.

Equipment manufacturers normally recommend that the number of switching-on operations are kept to a minimum and that the equipment is always pre-heated whenever possible.

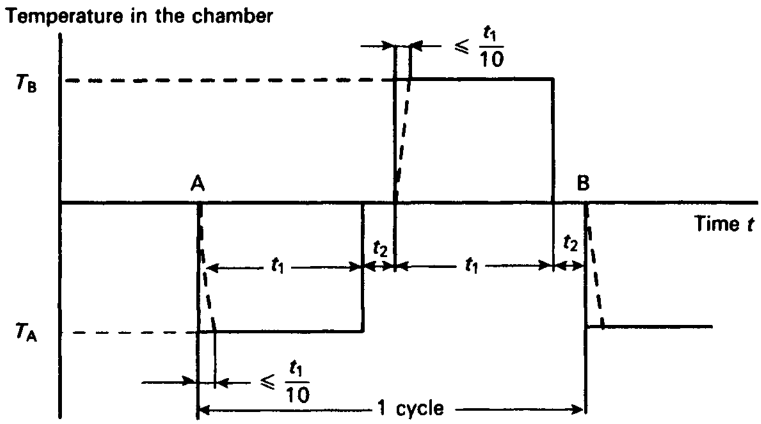
2.4.3.4 Test conditions

Samples are subjected to temperature shock testing as specified in IEC 68.2.14 (depicted in Figure 2.6), by alternate and rapid exposure to low and high temperatures in air, or in a suitable inert gas.

During the test:

- the severity of the test is a combination of two temperatures chosen from IEC 68.2.1 and IEC 68.2.2;
- the transition time and the number of shock cycles are as specified in IEC 68.2.14;
- the sample is *not* required to operate during testing;
- the sample must be capable of being fully operational (according to the procuring specification) after completion of temperature shock testing.

Verification of good temperature design of all installed equipment shall be agreed between the purchaser and supplier. This shall include:



A = start of first cycle
B = end of first cycle and start of second cycle
Note: The dotted curve is explained in Sub-clause 1.3.1.5

Fig. 2.6 Ambient temperature – temperature shock testing (reproduced from the equivalent standard BS 2011 Part 2.1N:1985 by kind permission of the BSI)

- geometrical characteristics of subassemblies;
- localisation of the main emitting elements;
- thermal profile;
- characteristics of the cooling system.

2.4.3.5 Other standards

Other standards that could be considered are:

IEC 68.2.33	Environmental testing procedures – Guidance on change of temperature tests
IEC 68.3.1	Environmental testing procedures – Background information – Cold and dry heat tests

2.4.4 Combined dry heat/low air pressure test (IEC 68.2.41 Test Z/BM)

Standard No.	IEC 68.2.41
Title	Environmental testing procedures – Test Z/BM: Combined dry heat/low air pressure test
Summary	Applicable to both heat dissipating and non-heat dissipating specimens. The object of the test is to determine the ability of components or equipment or other articles to be stored and used under a simultaneous combination of high temperature and low air pressure. Details the

	preferred combinations of temperature, air pressure and duration.
Equiv. Std	Identical to BS 2011:PT2.1Z/BM(1977) Identical to DIN IEC 68 PT2-41 Identical to HD 323.2.41 Identical to NEN 10068-2-41

2.4.4.1 Introduction

Components, equipment or other articles whilst operational (and particularly whilst in transit) are frequently subjected to a simultaneous combination of high temperature and low air pressure.

2.4.4.2 Purpose of this test

The purpose of test IEC 68.2.41 is to:

- provide a standard test procedure that can be used to determine the suitability of a sample (heat dissipating or non-heat dissipating) that is intended to be used or stored in a combination of high temperature and low air pressure;
- describe a composite test aimed at determining the suitability of a specimen to a simultaneous combination of high temperature and low air pressure.

2.4.4.3 General

This test is a combination of high temperature (paragraph 2.4.2) and low air pressure tests (paragraph 5.4.1) and can be used to test heat dissipating equipment in their operational state as well as non-heat dissipating equipment in their operational or stored states.

2.4.4.4 Test conditions

In this test the specimen is first exposed to a high temperature and then (with the temperature value maintained) the air pressure within the test chamber is reduced. The severity of the test is a combination of temperature, air pressure and duration of exposure.

2.4.4.5 Other standards

Other standards that could be considered are:

IEC 68.2.51	Environmental testing procedures – Test Z/BFc: Combined dry heat vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.3.1	Environmental testing procedures – Background information – Cold and dry heat tests
IEC 68.3.2	Environmental testing procedures – Background information – Combined temperature/low air pressure tests

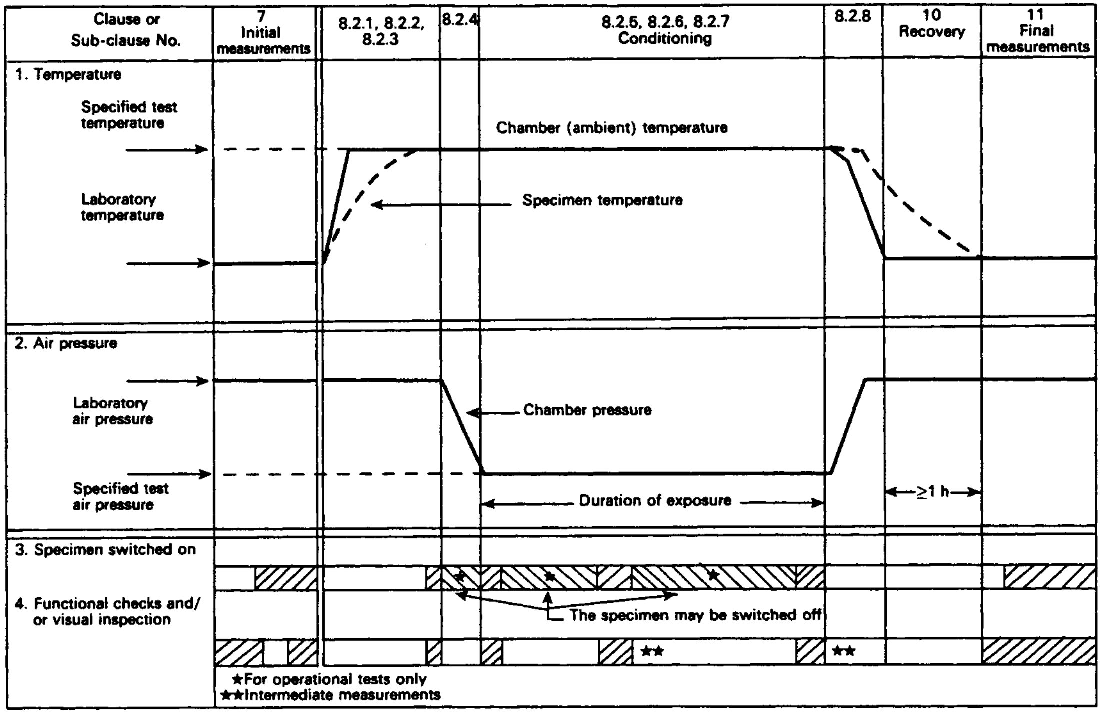


Fig. 2.7 Test profile for non-heat dissipating specimens (reproduced from the equivalent standard BS 2011 Part 2.1Z/BM;1977 by kind permission of the BSI)

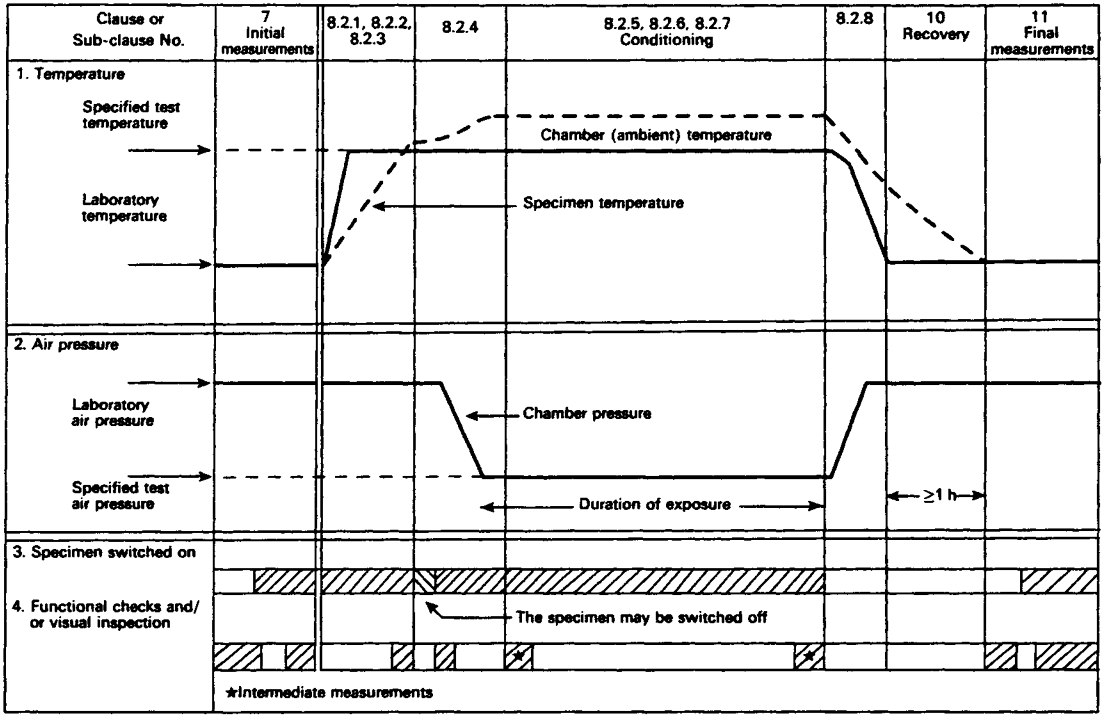


Fig. 2.8 Test profile for heat dissipating specimens (reproduced from the equivalent standard BS 2011 Part 2.1Z/BM;1977 by kind permission of the BSI)

2.4.5 Climatic sequence test (IEC 68.2.61. Test Z/ABDM)

Standard No.	IEC 68.2.61
Title	Environmental testing procedures – Test methods – Test Z/ABDM: Climatic sequence
Summary	Describes in detail a composite test specifying a 'climatic sequence' for specimens of products (primarily components), that is based on clause 7 of IEC 68.1, and it includes guidance in informative annexes for specification writers and those performing the test.
Equiv. Std	Similar to BS 2011:PT2.1Z/ABDM(1983) Identical to BS EN 60068 PT2-61 Identical to DIN EN 60068 PT2-61 Identical to EN 60068 PT2-61 Identical to NEN 10068-2-61 Identical to NFC 20-761 Identical to NF EN 60068-2-61

2.4.5.1 Introduction

Electronic equipment whilst in use (and particularly during transit) can be frequently subjected to environmental conditions consisting of a sequence of temperature, humidity and low air pressure environmental stresses.

2.4.5.2 Purpose of this test

The purpose of test IEC 68.2.61 is to determine the suitability of electronic equipment when subjected to environmental conditions consisting of a sequence of high temperature, low temperature, humidity and (when required) low air pressure environmental stresses.

2.4.5.3 General

This test is frequently specified to follow other tests involving mechanical stress (e.g. tests for the robustness of terminations, solderability, shock and vibration) and is used as a means of determining whether the sealing of a specimen has been damaged by such stress.

2.4.5.4 Test conditions

IEC 68.2.61 describes a composite test for assessing the suitability of samples to a 'climatic sequence' of tests as shown in Figure 2.9.

In this test the specimen is first exposed to a high temperature and then a cycle of damp heat. This is immediately followed by a low temperature test so that any moisture which has entered either the specimen or via surface cracks in its seals will be frozen and cause further damage.

Low air pressure is then followed by further exposure to cyclic damp heat conditions and (if required) the severity of the test can be increased by

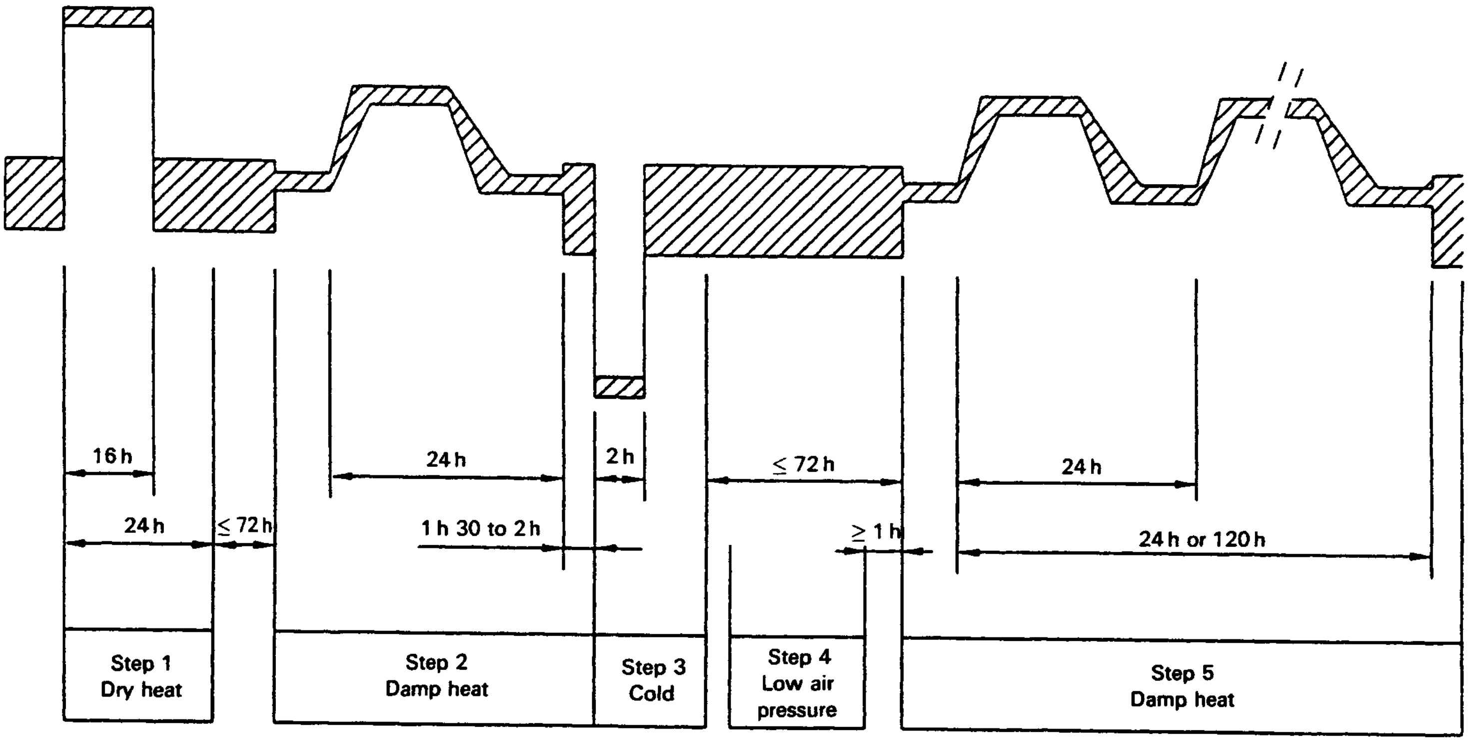


Fig. 2.9 Diagrammatic sequence of the progress of the climatic sequence (reproduced from the equivalent standard BS EN 60068.2.61 by kind permission of the BSI)

completing a low temperature test in between each of the five final damp heat cycles.

2.4.5.5 Other standards

IEC 68.2.1	Environmental testing procedures – Test A: Cold
IEC 68.2.13	Environmental testing procedures – Test M: Low air pressure
IEC 68.2.2/2A	Environmental testing procedures – Test B: Dry heat (and supplement)
IEC 68.2.28	Environmental testing procedures – Guidance – Damp heat tests
IEC 68.2.30	Environmental testing procedures – Test Db and guidance: Damp heat, cyclic (12 + 12 hour cycle)

Chapter 3

Solar radiation

3.1 Guidance

3.1.1 What is solar radiation?

Of all the factors that control the weather, the sun is by far the most powerful, and practically everything that occurs on the Earth is controlled, directly or indirectly, by it. The sun affects the places humans inhabit, in the kind of homes that are built, the work that is done, and the equipment that is used.

Less than one-millionth of the energy emitted from the sun's surface travels the ninety-odd million miles to reach this planet. The sun's energy crosses those miles in the form of short electromagnetic radio waves, identical in nature to those used in broadcasting, which pass through the atmosphere and are absorbed by the Earth's surface. These waves warm the Earth's surface and are then re-radiated back to space. The wavelength of the energy emitted by the Earth is very much longer than that emitted by the sun, because the Earth is much cooler than the sun. These longer waves are not able to pass through the atmosphere as freely as short waves. A large proportion of the energy emitted by the Earth is absorbed by the water vapour and water droplets in the lower atmosphere which in turn is re-radiated back to Earth. Thus the Earth plays the part of a receiving station absorbing short electromagnetic waves and converting them into longer electromagnetic waves, while the atmosphere acts as a trap containing most of the longer electromagnetic waves before they are lost to space.

Radiation from the sun consists of rays of three differing wavelengths, heat rays, actinic rays and light rays. Heat rays and actinic rays are intercepted by solid bodies and produce peculiar effects in varying degrees according to the nature of the surface on which they fall. The light rays are responsible for daylight and both light rays and actinic rays are necessary for the life processes of plants. The heat ray's most important manifestation is temperature. Although latitude determines

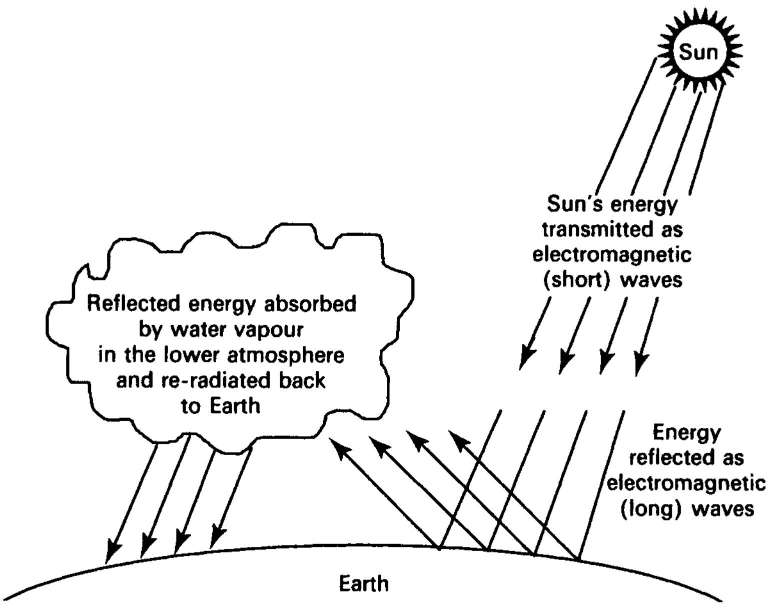


Fig. 3.1 Solar radiation – energy

the intensity of insolation this, together with the length of day, influences the duration of sunshine and therefore the temperature.

Radiant energy can be reflected from solid surfaces and intensified by that reflection. For example, reflection from walls is frequently used for ripening peaches and pears. Reflection from bare ground can also assist in the ripening of melons and other creeping plants, while reflection from water surfaces enhances the 'climatic reputation' of waterside resorts. However, radiant energy can also cause damage to equipment as heat rays can warm the material or its surrounding environment to dangerous levels and photochemical degradation of materials can be caused by the ultraviolet content of solar radiation.

3.1.2 Introduction

On cloudless nights when atmospheric radiation is very low, objects exposed to the night sky will attain surface temperatures below that of the surrounding air temperature. For example, a horizontal disc thermally insulated from the ground and exposed to the night sky during a clear night can attain a temperature of −14°C when the air temperature is 0°C and the relative humidity is close to 100%. The lowest possible values of atmospheric radiation during clear nights are shown in Figure 3.3. These values are of assistance when determining the 'under temperature' of components.

The Sun's electromagnetic radiation consists of a broad spectrum of

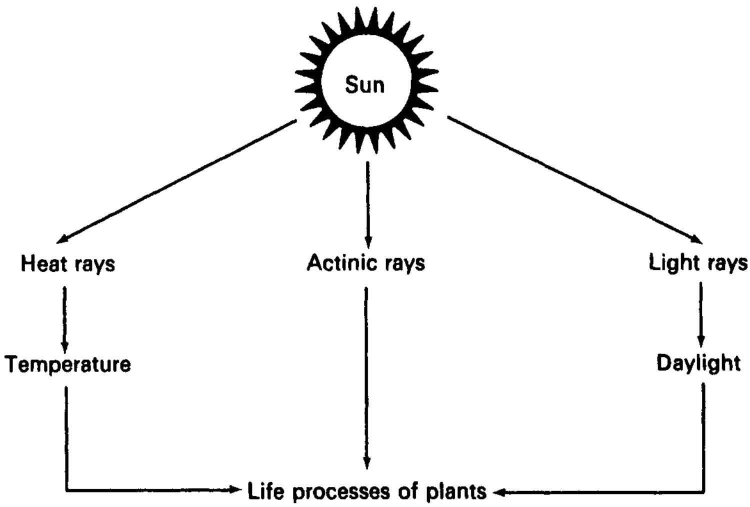


Fig. 3.2 Sun's radiation – rays

light ranging from ultraviolet to near infrared. Owing to the distance of the sun from the Earth, solar radiation appears on the Earth's surface as a parallel beam and the highest (maximum) level of radiation occurs at noon on a cloudless day at a surface perpendicular to the sun.

Most of the sun's energy reaches the surface of the Earth in the 0.3–0.4 μm range and the density of the solar radiated power (or irradiance – expressed in watts per square metre) is dependent on the content of aerosol particles, ozone and water vapour in the air. The actual amount of irradiance will vary considerably with geographical latitude and type of climate (i.e. temperature, humidity, air velocity, etc.).

Having said that, an object subjected to solar radiation will obtain a temperature depending on the surrounding ambient air temperature, the intensity of radiation, the air velocity, the incidence angle of the radiation on the object, the duration of exposure, the thermal properties of the object itself (e.g. surface reflectance, size, shape, thermal conductance and specific heat) together with other factors such as wind and heat conduction to mountings and surface absorbency, etc.

3.1.2.1 Photochemical degradation of material

One of the biggest problems caused by solar radiation is the photochemical degradation of most organic materials which in turn causes the elasticity and plasticity of certain rubber compounds and plastic materials to be affected and can, in exceptional cases, make optical glass opaque.

Although solar radiation can bleach out colours in paints, textiles, paper, etc. (a major consideration when trying to read the colour coding

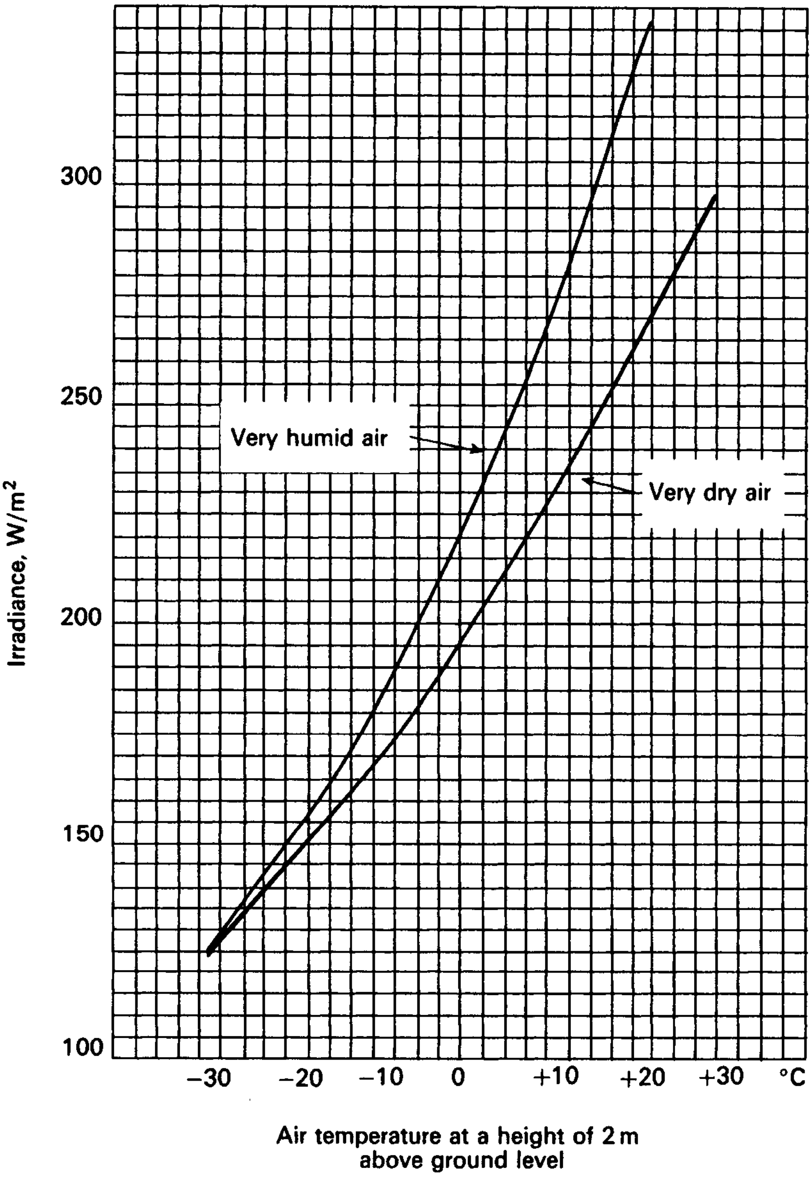


Fig. 3.3 Lowest values of atmospheric radiation during clear nights (reproduced from the equivalent standard BS 7527 Section 2.4;1991 by kind permission of the BSI)

of components), by far the most important effect is the heating of materials.

The combined effect of solar radiation, atmospheric gases, temperature and humidity changes, etc. are often termed 'weathering' and result in the

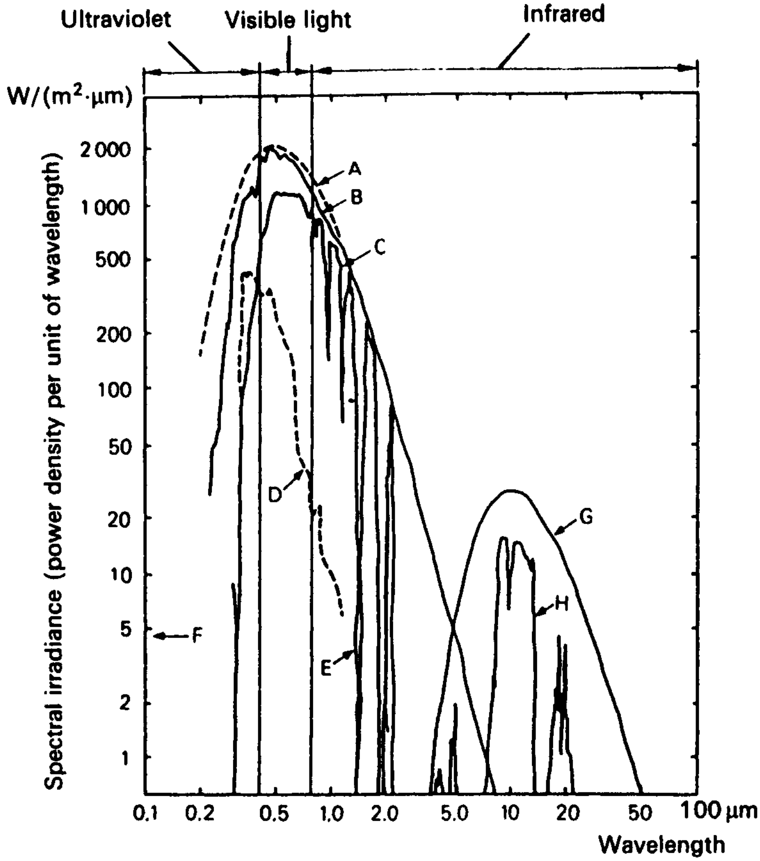


Fig. 3.4 Spectra of electromagnetic radiation from the sun and surface of the Earth (reproduced from the equivalent standard BS 7527 Section 2.4;1991 by kind permission of the BSI)

'ageing' and ultimate destruction of most organic materials, e.g. plastics, rubbers, paints, timber, etc.

Typical defects caused by weathering are:

- rapid deterioration and breakdown of paints;
- cracking and disintegration of cable sheathing;
- fading of pigments;
- bleaching out of colours in paints, textiles and paper.

3.1.2.2 Effects of irradiance

To guard against the effects of irradiance, the following guidelines should be considered when locating electronic equipment:

- the sun should be allowed to shine only on the smallest possible casing surfaces;

Table 3.1 Mean daily extraterrestrial global irradiation (kWh/m^2) (reproduced from the equivalent standard BS 7527 Section 2.4;1991 by kind permission of the BSI)

Latitude	June	December	Annual
90 N	12.47	0.00	4.17
85 N	12.42	0.00	4.20
80 N	12.28	0.00	4.30
75 N	12.05	0.00	4.49
70 N	11.72	0.00	4.76
65 N	11.40	0.11	5.16
60 N	11.40	0.65	5.71
55 N	11.48	1.36	6.29
50 N	11.56	2.16	6.87
45 N	11.61	3.00	7.42
40 N	11.61	3.85	7.93
35 N	11.56	4.72	8.40
30 N	11.44	5.57	8.82
25 N	11.26	6.40	9.19
20 N	11.00	7.20	9.49
15 N	10.68	7.96	9.73
10 N	10.30	8.68	9.90
05 N	9.84	9.34	10.01
00	9.33	9.95	10.04
05 S	8.76	10.50	10.01
10 S	8.13	10.98	9.90
15 S	7.46	11.39	9.73
20 S	6.74	11.73	9.49
25 S	5.99	12.00	9.19
30 S	5.21	12.19	8.82
35 S	4.41	12.32	8.40
40 S	3.60	12.37	7.93
45 S	2.79	12.37	7.41
50 S	2.01	12.31	6.86
55 S	1.27	12.22	6.29
60 S	0.60	12.13	5.71
65 S	0.10	12.12	5.16
70 S	0.00	12.45	4.75
75 S	0.00	12.80	4.48
80 S	0.00	13.05	4.30
85 S	0.00	13.20	4.20
90 S	0.00	13.25	4.16

- windows should be avoided on the sunny side of rooms housing electronic equipment;
- heat sensitive equipment parts must be protected by heat shields made, for instance, of polished stainless steel or aluminium plate;
- air conditioning plant and cooling fans (when used) in rooms housing electronic equipment should be efficient and reliable;
- convection flow should sweep across the largest possible surfaces of materials with good conduction properties.

Figures 3.5 to 3.7 are world maps produced by the IEC/BSI and show levels of relative global irradiation for June, December and the global

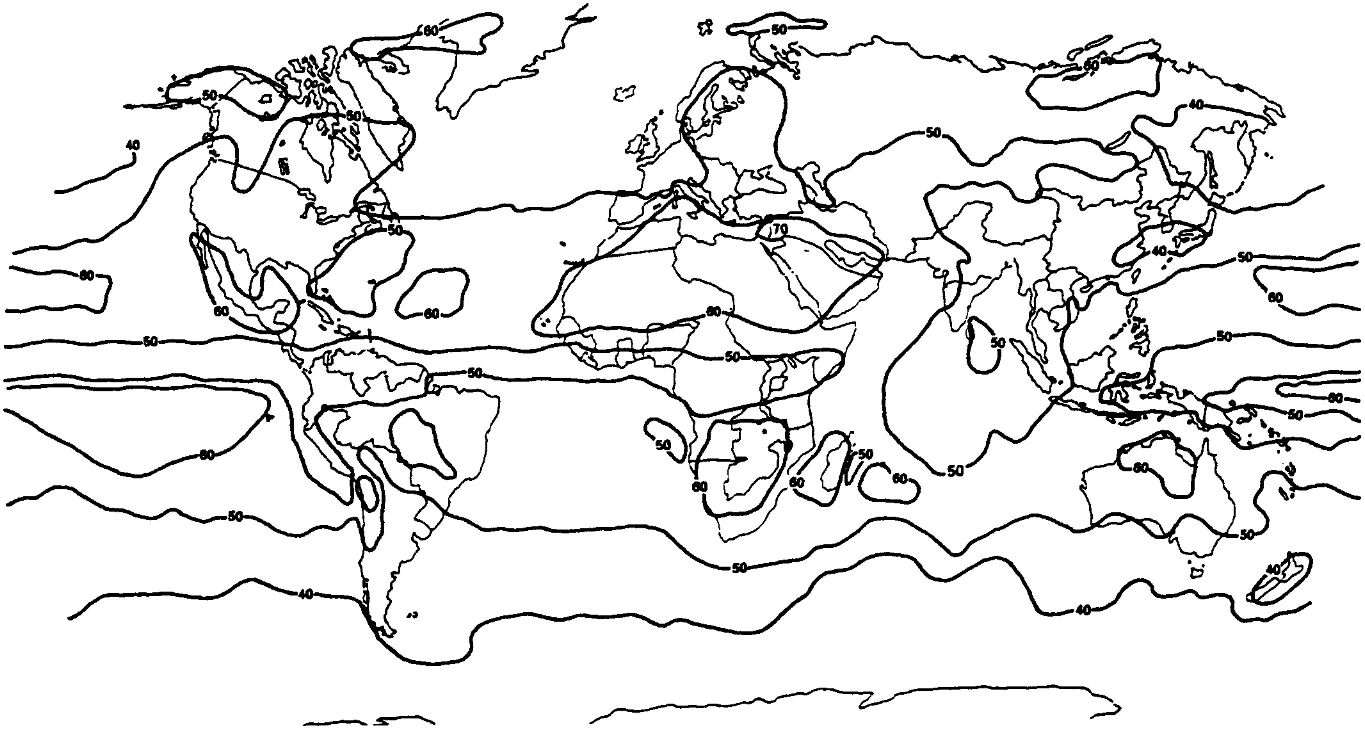


Fig. 3.5 Mean relative global irradiation for the month of June (in percent) (reproduced from BS 7527; Section 2.4; 1991 by kind permission of BSI)

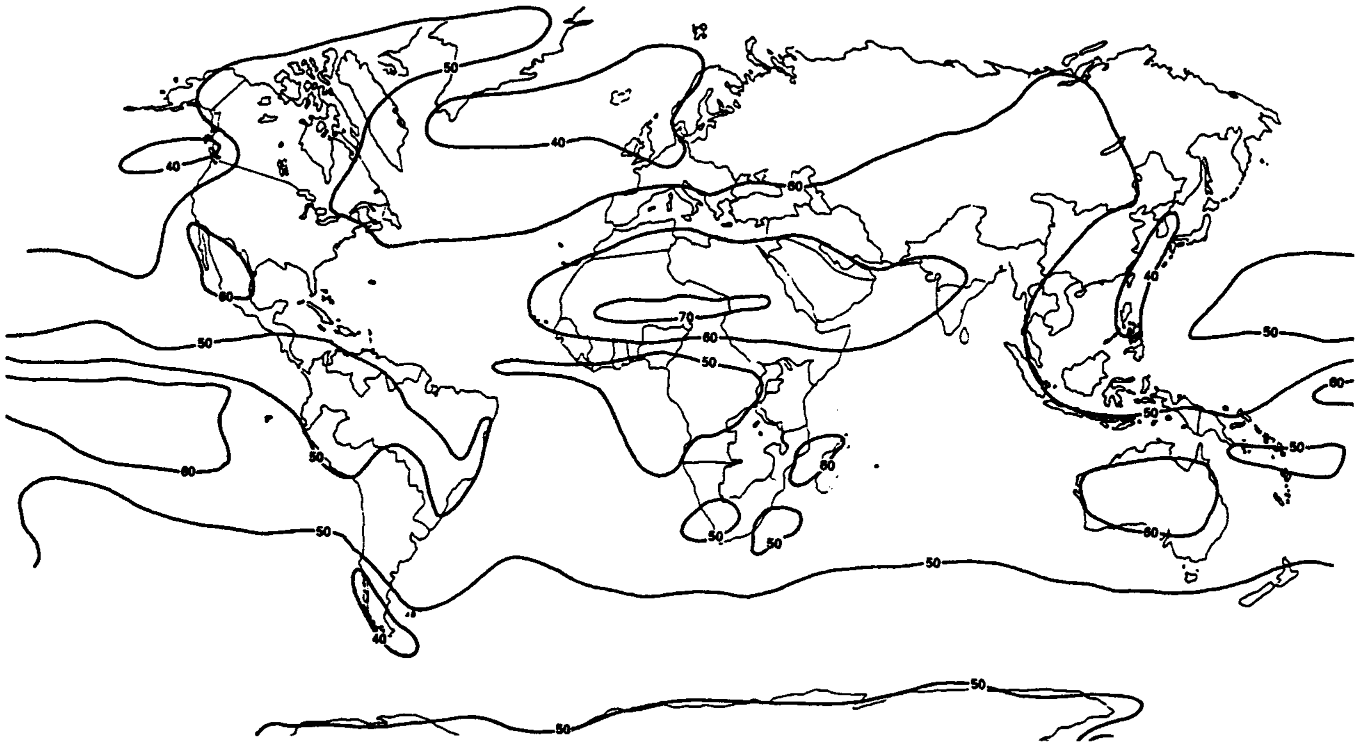


Fig. 3.6 Mean relative global irradiation for the month of December (in percent) (reproduced from BS 7527; Section 2.4; 1991 by kind permission of BSI)

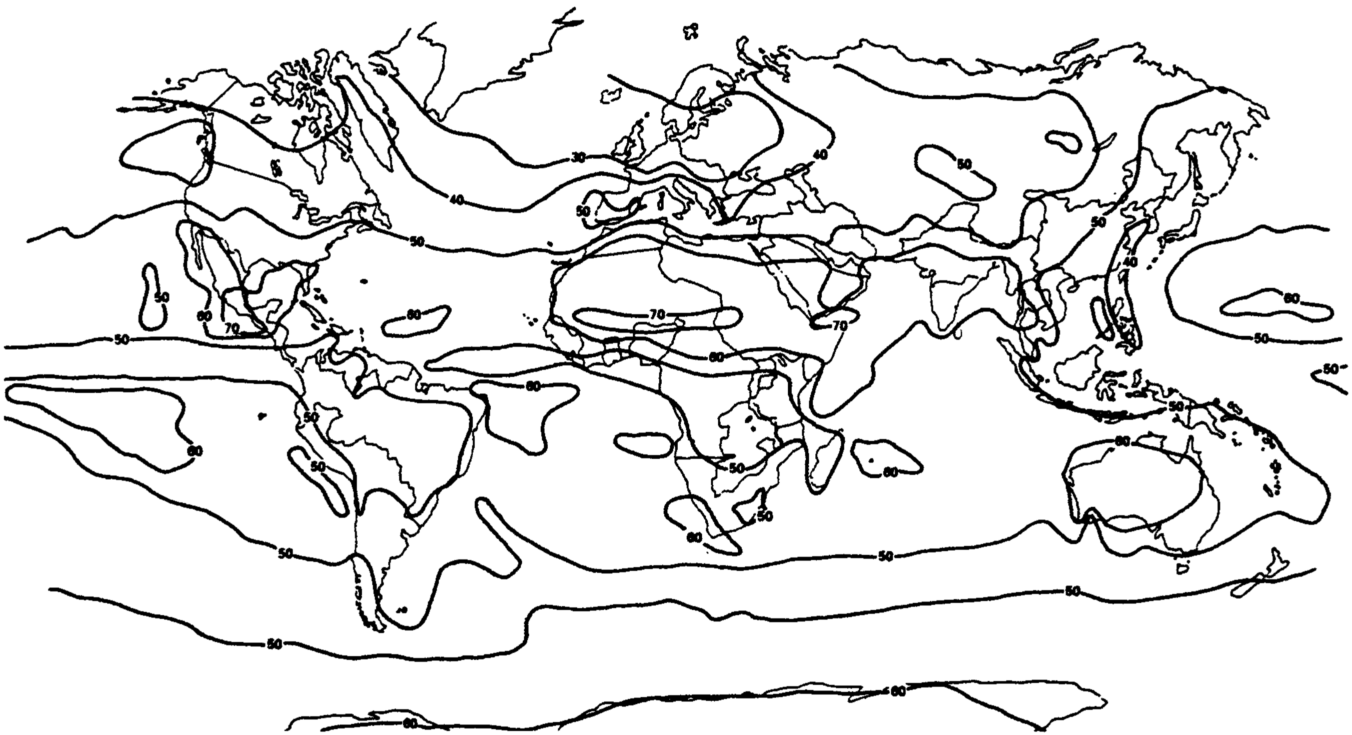


Fig. 3.7 Mean relative global irradiation for the year (in percent) (reproduced from BS 7527; Section 2.4; 1991 by kind permission of BSI)

mean irradiance for the year. These values have been derived from satellite measurements and give an indication of the intensity of the sun's rays.

3.1.2.3 Heating effects

As stated before, probably the most important effect of solar radiation heating is mainly caused by the short-term, high intensity radiation around noon on cloudless days. Typical peak values of irradiance are shown in Table 3.2.

Table 3.2 Typical peak values of irradiance in W/m^2 from a cloudless sky

Area	Large cities	Flat land	Mountainous areas
Subtropical climates and deserts	700	750	1180
Other areas	1050	1120	1180

Note
In December the monthly mean average of daily irradiation will reach approximately 10.8 kWh/m^2 close to the South Pole, because of the duration of daylight. Outside of the Antarctic area, daily levels reach approximately 8.4 kWh/m^2. The highest annual mean averages of daily global irradiation (up to 6.6 kWh/m^2) are mainly found in desert areas.

As equipment (if fully exposed to solar radiation) in an ambient temperature such as 35–40°C can attain temperatures in excess of 60°C, one has to consider an equipment's outside surface. To a major extent the surface reflectance of an object affects its temperature rise from solar heating and changing the finish from a dark colour to a gloss white can cause a considerable reduction in temperature. Conversely, a pristine finish that has been designed to reduce temperature, can be expected to deteriorate in time and result in an increase in temperature.

Another problem found in most of today's materials is that they are also selective reflectors, i.e. their spectral reflectance factor changes with wavelength. For example, paints are, in general, poor infrared reflectors although they may be very efficient as a visible warning. Care should, therefore, be taken when selecting materials and finishes for equipment casings.

3.1.3 Test standards

The following is the most used specification for solar radiation:

IEC 68.2.5	Environmental testing procedures – Test Sa: Simulated solar radiation at ground level

3.1.4 Other related standards and specifications

EN 50125	Railway applications – Environmental conditions for rolling stock equipment
G. Major *et al.*	*World maps of relative global radiation.* World Meteorological Organisation, Technical Note No. 172, Annex. WMO-No. 557, Geneva (1981).
IEC 68.2.9	Environmental testing procedures – Guidance for solar radiation testing
IEC 721.2.4	Classification of environmental conditions – Environmental conditions appearing in nature – Solar radiation and temperature
ISO 4892	Methods of testing plastics – Optical and colour properties, weathering

3.2 Typical contract requirements – solar radiation

3.2.1 Introduction

More and more modern day contracts are stipulating adherence to environmental specifications. These specifications describe the various conditions that are likely to be experienced by equipment when in storage, transit or use. In addition, as equipment is likely to be exposed to great extremes of solar radiation because of their function (e.g. equipment housed in direct sunlight must be able to function equally well in the radiation from the sun as the shade of tunnels and buildings), it is important that manufacturers and suppliers are aware of the requirements from an equipment point of view.

It is usual, therefore, to find that the general requirements for installing electronic equipment include the following stipulations:

- the sun should be allowed to shine only on the smallest possible casing surfaces and the convection flow should sweep across the largest possible surfaces of materials with good conduction properties;
- windows should be avoided on the sunny side of rooms housing electronic equipment;
- air conditioning plant and cooling fans (when used) in rooms housing electronic equipment shall be efficient and reliable.

3.2.1.1 Severity of solar radiation

Normally the customer or end user will define the severity (i.e. the amount of) solar radiation to which products are liable to be exposed during transportation, storage and use in accordance with the values and ranges shown in Section 3.3.

3.2.1.2 Effects of solar radiation

The following are some of the requirements frequently found in contracts:

- equipment that is exposed to the effect of solar radiation shall remain unaffected;
- heat sensitive parts of equipment shall be protected by heat shields made, for instance, of polished stainless steel or aluminium plate.

3.2.1.3 Production configuration

A normal contract requirement is that all proposed candidate equipment, components or other articles have to be tested in their production configuration without the use of any additional external devices that have been added expressly for the purpose of passing solar radiation testing.

3.2.1.4 Procuring specifications

Procuring specifications frequently require that when tested, the sample (component, equipment or other article) shall perform as stipulated in the procuring specification and over the designated range.

3.2.1.5 Test methods

When a contract requires a test to be performed to prove the equipment's capability of withstanding solar radiation, the usual standard quoted is IEC 68.2.5 (see Test 3.4.1).

The type of instrument considered most suitable for monitoring irradiance is a 'pyrometer' which is used for measuring combined solar and sky radiation on a horizontal plane.

3.3 Values and ranges

Guidance on geographical values and ranges of solar radiation has been taken from the latest issue of the IEC 721 standard. These figures are based on observations over a period of not less than 10 years and represent conditions frequently met by products whilst being transported, stored, installed or used.

Except where stated, all values given represent the maximum and minimum solar radiation experienced by a particular piece of equipment in a particular location and situation.

Deviation from the solar radiation tables is normally subject to acceptance by demonstration that the equipment is suitable for service.

Table 3.3 Solar radiation – storage

Installation location	IEC 721 class	Solar radiation W/m^2
Fully air conditioned enclosed locations, with air temperature and humidity control	1K1	500
Fully air conditioned, temperature controlled, enclosed locations without humidity control	1K2	700
Fully enclosed locations without air temperature or humidity control	1K3	700
Partially weather protected locations without air temperature or humidity control[1]	1K4	1120
Partially weather protected locations without air temperature or humidity control[1]	1K5	1120
Partially weather protected locations without air temperature or humidity control[1]	1K6	1120
Restricted non-weather protected locations[1]	1K7	1120
Moderate non-weather protected locations[1]	1K8	1120
Worldwide non-weather protected locations[1]	1K9	1120
Non-weather protected locations with tropical damp climates (rainforests)	1K10	1120
Non-weather protected locations with tropical dry climates (deserts)	1K11	1120

Note
1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

Table 3.4 Solar radiation – transportation

Installation location	IEC 721 class	Solar radiation W/m^2
Weather protected heated and ventilated	2K1	700
Weather protected, ventilated but unheated in general climates excluding cold and cold temperate climates	2K2	700
Non-weather protected, unventilated and unheated in general climates excluding cold and cold temperate climates	2K3	1120
Non-weather protected, unventilated and unheated in general climates including cold and temperate climates	2K4	1120
Non-weather protected conditions worldwide	2K5	1120
Non-weather protected conditions excluding cold and cold temperate climates	2K5H	1120
Non-weather protected conditions including cold temperate climates	2K5L	1120
Non-weather protected conditions covering tropical damp climates (rainforests)	2K6	1120
Non-weather protected conditions covering tropical dry climates (deserts)	2K7	1120

Table 3.5 Solar radiation – operational

Installation location	IEC 721 class	Solar radiation W/m²
Stationary use at weather protected, fully air conditioned locations with temperature and humidity control	3K1	500
Stationary use at weather protected, temperature controlled locations with partial humidity control	3K2	700
Stationary use at weather protected, temperature controlled locations with no humidity control	3K3	700
Stationary use at weather protected, temperature controlled locations with no humidity control	3K4	700
Stationary use at weather protected locations with no temperature control and a wide range of relative humidity	3K5	700
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K6	1120
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K7	1120
Stationary use at partially weather protected locations with no temperature or humidity control, not exposed to solar radiation	3K7L	None
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K8	1120
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K8H	1120
Stationary use at partially weather protected locations with no temperature or humidity control	3K8L	1120
Stationary use at partially weather protected locations in tropical damp climates (rainforest)	3K9	1120
Stationary use at partially weather protected locations in tropical dry climates (desert)	3K10	1120
Stationary use at restricted non-weather protected locations[1]	4K1	1120
Stationary use at moderate non-weather protected locations[1]	4K2	1120
Stationary use at general non-weather protected locations[1]	4K3	1120
Stationary use at worldwide non-weather protected locations[1]	4K4	1120
Stationary use at worldwide non-weather protected locations, low air temperature, low absolute humidity[1]	4K4H	1120
Stationary use at worldwide non-weather protected locations, high air temperature, low relative humidity, high absolute humidity[1]	4K4L	1120
Stationary use at non-weather protected locations in tropical damp climates (rainforests)	4K5	1120
Stationary use at non-weather protected locations in tropical dry climates (deserts)	4K6	1120
Ground vehicle installations with products weather protected, ventilated and heated	5K1	None
Ground vehicle installations with products weather protected (or partially weather protected), heated (or unheated), unventilated	5K2	700
Ground vehicle installations, unventilated, subject to wet surfaces and solar radiation	5K3	1120
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation	5K4	1120

continued

Table 3.5 *(cont.)*

Installation location	IEC 721 class	Solar radiation W/m^2
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation in low temperature climates	5K4H	1120
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation in high temperature climates	5K4L	1120
Ground vehicle installations in tropical damp climates (rainforests)	5K5	1120
Ground vehicle installations in tropical dry climates (deserts)	5K6	1120
Installations in totally weather protected, heated and ventilated ship environments, not exposed to solar radiation	6K1	Negligible
Installations in totally weather protected, heated and ventilated ship environments, excluding cold climates	6K2	700
Installations in totally weather protected, heated and ventilated ship environments, near to heat dissipating equipment	6K3	700
Installations in non-weather protected, unventilated, heated ship environments, excluding cold climates	6K4	1120
Installations in non-weather protected, unventilated, unheated ship environments, including cold climates	6K5	1120
Shipborne installations in tropical damp climates (rainforests)	6K6	1120
Shipborne installations in tropical dry climates (deserts)	6K7	1120
Portable and non-stationary use at or direct transfer between temperature controlled weather protected environments, without humidity control	7K1	700
Portable and non-stationary use at or direct transfer between weather protected environments without humidity or temperature control	7K2	700
Portable and non-stationary use at or direct transfer between partially weather protected restricted environments[1]	7K3	1120
Portable and non-stationary use at or direct transfer between partially weather protected moderate environments[1]	7K4	1120
Portable and non-stationary use at or direct transfer between partially weather protected worldwide environments[1]	7K5	1120
Portable and non-stationary use in tropical damp climates (rainforests)	7K6	1120
Portable and non-stationary use in tropical dry climates (deserts)	7K7	1120

Note

1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

3.4 Tests

This section details some of the test standards which may be applied to equipment and contains:

- details of the most common environmental tests to which a purchaser will normally require a manufacturer to adhere;
- a list of other related standards and specifications;
- a brief description of the tests.

Note: Full details of all of these recommended tests are contained in the relevant ISO, IEC or other standard. A full list of these standards is supplied in the reference section of this book. Copies of all these standards may be obtained from any National Standards Organisation.

3.4.1 Simulated solar radiation at ground level test (IEC 68.2.5 Test Sa)

Standard No.	IEC 68.2.5
Title	Environmental testing procedures – Test Sa: Simulated solar radiation at ground level
Summary	The object of this test is to determine the effects (thermal, mechanical, chemical, electrical, etc.) produced on equipment and components as a result of exposure to solar radiation under the conditions experienced at the surface of the Earth.
Equiv. Std	Technically equivalent to AS 1099:PT2Sa Identical to BS 2011:PT2.1SA(1977) Identical to DIN IEC 68 PT2-5 Identical to HD 323.2.5 Identical to NEN 10068.2.5 Identical to NFC 20-705

3.4.1.1 Introduction

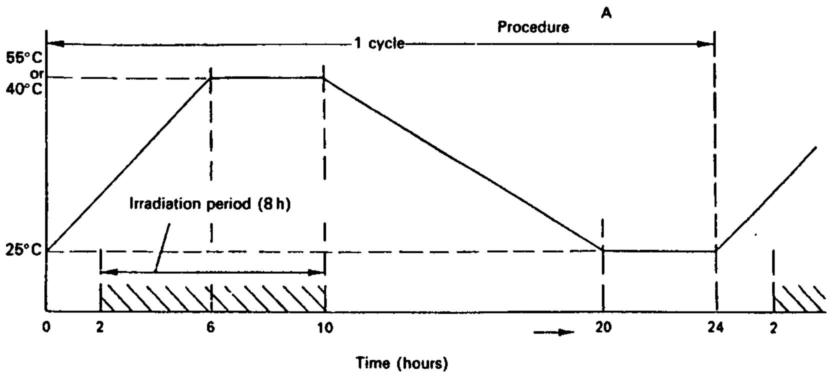
Components, equipment and other articles whilst being used or whilst in storage are frequently subjected to exposure to solar radiation under the conditions experienced at the surface of the Earth.

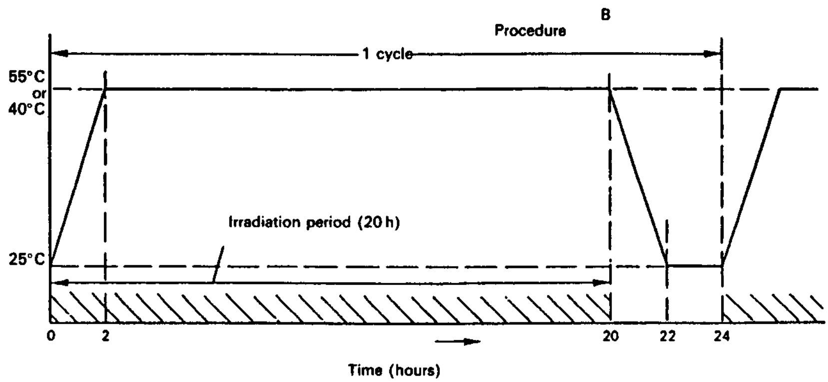
3.4.1.2 Purpose of this test

The purpose of this test is to determine the effect (e.g. thermal, mechanical, chemical and electrical, etc.) on a piece of equipment and/ or component as a result of exposure to solar radiation.

3.4.1.3 General

The temperature within the test enclosure during irradiation and dark periods must be controlled. In addition, differing humidity conditions (particularly condensation) can cause photochemical degradation of





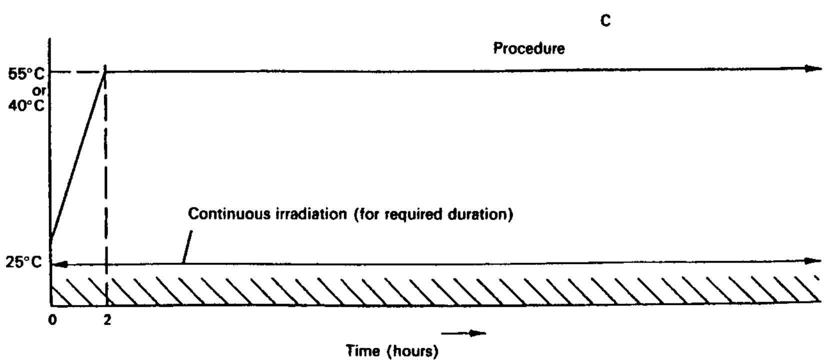


Fig. 3.8 Spectral energy distribution and permitted tolerances (reproduced from BS 2011:Part 2.1SA:1977 by kind permission of BSI)

Spectral region	Ultraviolet B*	Ultraviolet A	Visible			Infrared
Bandwidth	0.28 µm–0.32 µm	0.32 µm–0.40 µm	0.40 µm–0.52 µm	0.52 µm–0.64 µm	0.64 µm–0.78 µm	0.78 µm–3.00 µm
Irradiance	5 W/m^2	63 W/m^2	200 W/m^2	186 W/m^2	174 W/m^2	492 W/m^2
Tolerance	±35%	±25%	±10%	±10%	±10%	±20%

* Radiation shorter than 0.30 µm reaching the Earth's surface is insignificant

Fig. 3.9 Permitted tolerances for spectral energy distribution (reproduced from BS 2011: Part 2.1Sa: 1977 by kind permission of BSI) materials, paints, plastics, etc. Dust and other surface contamination may significantly change the absorption characteristics of irradiated surfaces. Ozone and other contaminating gases can significantly affect the degradation process.

In practice high solar radiation conditions are rarely accompanied by a complete absence of wind and so the cooling effect of air flowing over a piece of equipment should also be considered (e.g. an air flow of as little as 1 m per second can effect a reduction in temperature rise of over 20%).

3.4.1.4 Test conditions

Candidate equipment is subjected to the simulated solar radiation test as described in IEC 68.2.5 where the specimens are subjected to an irradiance of 1120 kW/m^2 (with the prescribed spectral distribution) taken from Figure 3.8.

Figure 3.9 shows the permitted tolerances for spectral energy distribution.

There are three types of test:

1. Procedure A
   A 24 h cycle, with 8 h irradiation and 16 h darkness – repeated as required. This test approximates to the most severe natural conditions.
2. Procedure B
   A 24 h cycle, with 20 h irradiation and 4 h darkness – repeated as required. This test is applicable where the principal interest is in degradation effects.
3. Procedure C
   Continuous irradiation as required. This is a simplified test for the assessment of heating effects on specimens with low thermal capacity.

Chapter 4

Humidity

4.1 Guidance

4.1.1 What is humidity?

The atmosphere is normally described as 'a shallow skin or envelope of gases surrounding the surface of the Earth which is made up of nitrogen, oxygen and a number of other gases which are present in very small quantities'. While the ratio of these components shows no appreciable variation either with latitude or altitude, the water vapour content of the atmosphere is subject to extremely wide fluctuations. The amount of water present in the air is referred to as humidity.

When air and water come into contact, they will exchange particles with each other (i.e. the air particles will pass into the water and water particles will pass into the air in the form of vapour). There is always a certain amount of water vapour present in the air and a certain amount of air present in water and there is always a constant movement between the two mediums.

When only a small amount of water vapour is present in the air, more particles of water will pass from the water into the air than from the air into the water and the water will gradually dry up or evaporate. Conversely, if the amount of water vapour in the air is large, then as many particles of vapour will pass from the air into the water as from the water into the air, and the water will not evaporate. In such a case the air is said to be 'saturated' or, in ordinary language, that it holds as much water vapour as it can contain.

Water vapour is collected in the air above the oceans and is carried by the wind towards the land masses. The amount of water vapour in the air varies greatly depending on the place and season. In general, evaporation is most rapid at high temperatures and slower at lower temperatures. We may, therefore, expect to find the greatest amount of water vapour over the oceans near the Equator and the smallest amount over the land in a cold region such as north-eastern Asia in winter. However, even when the surface is covered with snow and ice, water evaporation may take place and occasionally during a long frost, the snow will gradually disappear without melting.

Except for the water vapour present, the composition of the atmosphere near the surface of the Earth up to a height of some 2000 ft is practically uniform throughout the globe. However, at greater altitudes, i.e. above the atmospheric boundary known as the tropopause (which is found at an average height of about 25 000 ft in polar regions and rises to 55 000 ft over the Equator), there is practically no water vapour, or water, in any form.

4.1.2 Introduction

Temperature and the relative humidity of air (in varying combinations) are climatic factors which act upon a product during storage, transportation or operation. Humidity and the electrolytic damage resulting from moisture mostly affects plug points, soldered joints (in particular dry joints), bare conductors, relay contacts and switches. Humidity also promotes metal corrosion (see Chapter 7 – Pollutants and contaminants) owing to its electrical conductivity.

But in many cases, environmental influences such as mechanical and thermal stresses are merely the forerunner of the impending destruction of components by humidity – especially as the majority of electronic component failures are caused by water (Ref. 1).

In a recent report by the European Rail Research Institute (ERRI) the problems caused by humidity were discussed and part of that report provided the curve in Figure 4.1 as an example of how the water content of air varies with temperature. Water content (indicated by Relative Air Humidity – RAH or RH) corresponds to the ratio between the actual vapour pressure and the saturation vapour pressure. The water content varies with temperature.

Humidity (in the context of this book) covers Relative Humidity, Absolute Humidity, Condensation, Adsorption, Absorption and Diffusion and details of these 'subsets' are provided in the following paragraphs.

Note: At a fixed air pressure, the absolute air humidity (defined as the actual mass of water per unit of air volume in grams per cubic metre) is given by the air temperature (in degrees Celsius) and the relative air humidity (as a percentage).

4.1.2.1 Relative and Absolute Humidity and their effect on equipment performance

The performance of virtually all electronic equipment is influenced and limited by its internal temperature which, in turn, is dependent on the external ambient conditions and on the heat generated within the device itself. Fortunately, most electronic components (especially resistors) will

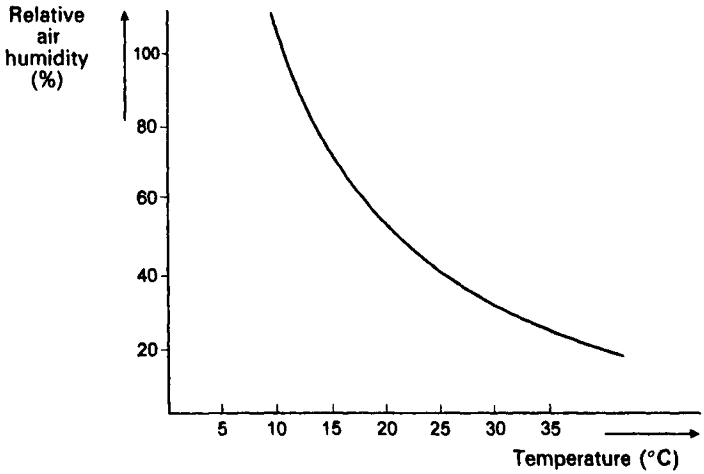


Fig. 4.1 Water content in air at different temperatures (reproduced by kind permission of ERRI)

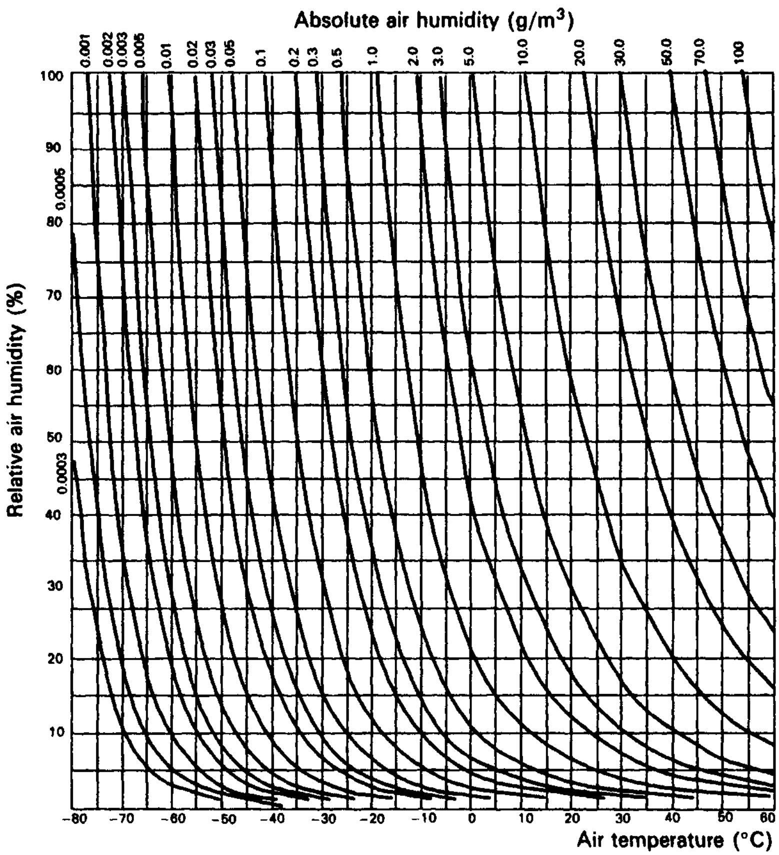


Fig. 4.2 Constitutional diagram for humid air (reproduced from the equivalent standard BS 7527 Section 2.1:1991 by kind permission of the BSI)

normally remain dry when under load owing to the amount of internal/external heat dissipation. Indeed, many components either have to be de-rated in order to improve their reliability or, for reasons of circuit function, only energised intermittently.

4.1.2.1.1 Externally mounted equipment

Equipment and components that are mounted in external cabinets or on the outside of a vehicles run the risk of coming into contact with water or water vapour (e.g. drifting snow, fog, dew, rain, spray water or water from hoses).

The equipment must, therefore, be adequately protected from such humidity in order to prevent the ingress of vapour into the system within the casing.

4.1.2.1.2 Housed equipment – humidity

In most locations (e.g. cabinets, equipment rooms, workshops and laboratories) although temperatures above 30°C may often occur, they are normally combined with a lower relative humidity than that found in the open air. In other rooms (e.g. offices), however, where several heat sources are present, temperatures and relative humidities can differ dramatically across the room.

The Sun also plays its part because in certain circumstances (such as when equipment is placed in an unventilated enclosure), the intense heat caused through solar radiation can generate relative humidities in excess of 95% when combined with:

- high relative humidity caused by the release of moisture from hygroscopic materials;
- the breathing and perspiration of human beings;
- open vessels containing water or other sources of moisture.

4.1.2.1.3 Equipment used in tunnels

When equipment is being transported through tunnels (e.g. when mounted on a train or vehicle) rapid external ambient temperature variations can result with a rate of change of external temperature of as much as 3°C/sec and with a maximum variation of 40°C. This can be a serious problem and must be considered when designing equipment.

4.1.2.2 Condensation

Condensation occurs on a specimen when its surface temperature is lower than that of the dew point (i.e. the temperature with a relative humidity of 100% at which condensation occurs). A direct relationship which can change electrical characteristics (e.g. decrease surface resistance, increase loss angle) thus exists between the absolute point at which atmospheric vapour condenses into droplets (i.e. the dew point), absolute humidity and vapour pressure.

If a piece of equipment has a low thermal time constant, condensation (normally found on the surface of the equipment) will occur only if the temperature of the air increases very rapidly, or if the relative humidity is very close to 100%. Sudden changes in temperature (particularly when equipment is mounted on a vehicle entering or leaving a tunnel) may cause water to condense on parts of equipment and leakage currents can occur.

4.1.2.3 Adsorption

Adsorption is the amount of humidity that may adhere to the surface of a material and depends on the type of material, the surface structure and the vapour pressure. This layer of water (no matter how small) can cause electrical short circuits and material distortion etc.

4.1.2.4 Absorption

The quantity of water that can be *absorbed* by a material depends largely on the water content of the ambient air. The speed of penetration of the water molecules generally increases with the temperature.

4.1.2.5 Diffusion

Water vapour can penetrate encapsulations of organic material (e.g. a capacitor or semiconductor) by way of the sealing compound and into the casing. This factor is frequently overlooked and can become a problem, especially as the moisture absorbed by an insulating material can cause a variation in a number of electrical characteristics (e.g. reduced dielectric strength, reduced insulation resistance, increased loss angle, increased capacitance).

4.1.2.6 Protection

The effects of humidity mainly depend on temperature, temperature changes and impurities in the air. There are three basic methods of protecting the active parts of electronic components from humidity:

- heating the surrounding air so that the relative humidity cannot reach high values; This method normally requires a separate heat source which (especially in the case of equipment mounted in external cabinets) usually means having to have a separate power supply. This method is disadvantaged by the reliability of the circuit being dependent on the efficiency of the heating.
- hermetically sealing components or assemblies using hydroscopic materials; This is an extremely difficult process as the smallest crack or split can allow moisture to penetrate the component particularly in the area of connecting wire entry points. Metal, glass and ceramic encapsulation do nevertheless produce very satisfactory results.
- ventilation and the use of moisture absorbing materials. Most water retaining materials and paint, etc. are suitable for the temporary

absorption of excessive high air humidity in the casing, which, because of the risk of pollution and dust penetration, cannot be fully ventilated (i.e. air exchange with the outside temperature is not possible).

4.1.3 Test standards

IEC 68.2.3	Environmental testing procedures – Test Ca: Damp heat, steady state
IEC 62.2.30	Environmental testing procedures – Test Db and guidance: Damp heat, cyclic (12 + 12 hour cycle)
IEC 68.2.38	Environmental testing procedures – Test Z/AD: Composite temperature/humidity cyclic test
IEC 68.2.56	Environmental testing procedures – Test Cb: Damp heat, steady state, primarily for equipment
IEC 68.2.61	Environmental testing procedures – Test Z/ABDM: Climatic sequence

4.1.4 Other related standards and specifications

EN 50123	Railway applications – d.c. switchgear for stationary installations in traction system – General
EN 50125	Railway applications – Environmental conditions for rolling stock equipment
EN 50155	Railway applications – Environmental conditions for non-rolling stock equipment
ERRI Question A118	Report No. 4. Use of electronic components in signalling
IEC 68.1	Environmental testing procedures – General and guidance
IEC 68.2.14	Environmental testing procedures – Test N: Change in temperature
IEC 68.2.2	Environmental testing procedures – Test B: Dry heat
IEC 68.2.28	Environmental testing procedures – Guidance: Damp heat tests
IEC 721.1	Classification of environmental conditions – Environmental parameters and their severities

4.2 Typical contract requirements – humidity

The requirement for equipment to conform to various environmental specifications is becoming commonplace in today's contracts. More and more specifications are being used to describe the various conditions that equipment is likely to experience when being used, stored or whilst in transit.

The following are the most common environmental requirements found in modern contracts concerning humidity.

4.2.1 External humidity levels

Equipment that is operated adjacent to the sea shore and therefore subject to extreme humidity must be able to function equally well as the same equipment housed in the low humidity of the desert.

Equipment should be designed and manufactured to meet the following external humidity levels (limit values), over the complete range of ambient temperature values as shown in Chapter 2.

Table 4.1 Humidity – External humidity levels

Duration	Limit value
Yearly average	75% relative humidity
On 30 days of the year, continuously	95% relative humidity
On the other days, occasionally	100% relative humidity
On the other days, occasionally	30 g/m^3 occurring in tunnels

Note:
Meteorological measurements made over many years have shown that, within Europe, a relative humidity greater (or equal to) 95% combined with a temperature above 30°C does not occur over long periods in free air conditions.

4.2.2 Condensation

Condensation has always been a problem when designing and using equipment and the humidity of air and the possible formation of condensed water must always be considered. The requirement most frequently stated in contracts is that 'operationally caused infrequent and slight moisture condensation shall not lead to malfunction or failure of the equipment'.

4.2.3 Indoor installations

Another contract requirement is that in all indoor installations, provision must be made for limiting the humidity of the ambient air to a maximum of 75% at −5°C.

4.2.4 Equipment being transported through tunnels

Rapid external ambient temperature variations resulting from equipment being transported through tunnels is a known problem and should always be taken into consideration. For the purpose of most specifications used in contracts, the rate of change of external temperature is normally assumed to be 3°C/sec with a maximum variation of 40°C.

4.2.5 Equipment installed in tunnels

Installations in tunnels may experience 100% humidity during start-up. Although this is normally specified as an abnormal operation, contracts (particularly railway contracts) nevertheless stipulate that suitable provisions must be incorporated to avoid incorrect operations. Normally these stipulations are agreed between purchaser and supplier and is part of the contract.

4.2.6 Equipment in cubicles and cases

Quite frequently, contracts will stipulate that the design of equipment shall always take into account temperature rises within cubicles and equipment cases in order to ensure that the components do not exceed their specified temperature ranges.

4.2.7 Peripheral units

For peripheral units (e.g. measuring transducers, etc.) or equipment employed in a decentralised configuration (i.e. where ambient temperature ranges are exceeded), contracts normally require that 'the actual temperature occurring at the location of the equipment concerned shall be utilised when designing equipment'.

4.2.8 Tests

4.2.8.1 Product configuration

Another normal requirement is that 'all proposed candidate equipment, components or other articles must be tested in their production configuration without the use of any additional external devices that have been added expressly for the purpose of passing humidity testing'.

4.2.8.2 Procuring specifications

When tested, it is usually a mandatory requirement for the sample (component, equipment or other article) 'to perform as stipulated in the procuring specification and over the designated humidity range'.

4.2.8.3 Test methods

Test methods for determining the suitability of specimens may be selected from:

IEC 68.2.3	Environmental testing procedures – Test Ca: Damp heat and tests
IEC 68.2.30	Environmental testing procedures – Test Db and guidance: Damp heat, cyclic (12 + 12 hour cycle)
IEC 68.2.38	Environmental testing procedures – Test Z/AD: Composite temperature/humidity test
IEC 68.2.39	Environmental testing procedures – Test Z/AMD: Combined sequential cold, low air pressure and damp heat test
IEC 68.2.56	Environmental testing procedures – Test Cb: Damp heat, steady state, primarily for equipment
IEC 68.2.61	Environmental testing procedures – Test Z/ABDM: Climatic sequence

4.3 Values and Ranges

Guidance on geographical values and ranges of humidity have been taken from the latest issue of IEC 721 standard. These figures are based on observations over a period of not less than 10 years and represent conditions frequently met by products whilst being transported, stored, installed or used.

Except where stated, all values given represent the maximum and minimum humidity experienced by a particular piece of equipment in a particular location and situation.

Deviation from the humidity tables shall be subject to acceptance by demonstration that the equipment is suitable for service.

4.4 Tests

This section details some of the test standards which may be applied to equipment and contains:

- details of the most used environmental tests that a purchaser will normally require a manufacturer to adhere to;
- a list of other related standards and specifications;
- a brief description of the more common tests.

Note: Full details of each of these recommended tests are contained in the relevant ISO, IEC or other standard. A complete list of these standards is supplied in the reference section of this book. Copies of all these standards may be obtained from any National Standards Organisation.

Table 4.2 Humidity – storage

Installation location	IEC 721 Class	Low relative humidity %	High relative humidity %	Low absolute humidity g/m³	High absolute humidity g/m³	Condensation
Fully air conditioned enclosed locations, with air temperature and humidity control	1K1	20	75	4	15	No
Fully air conditioned, temperature controlled, enclosed locations without humidity control	1K2	5	85	1	25	No
Fully enclosed locations without air temperature or humidity control	1K3	5	95	1	29	Yes
Partially weather protected locations without air temperature or humidity control[1]	1K4	10	100	0.5	29	Yes
Partially weather protected locations without air temperature or humidity control[1]	1K5	10	100	0.1	35	Yes
Partially weather protected locations without air temperature or humidity control[1]	1K6	10	100	0.02	35	Yes
Restricted non-weather protected locations[1]	1K7	20	100	0.9	22	Yes
Moderate non-weather protected locations[1]	1K8	15	100	0.26	25	Yes
Worldwide non-weather protected locations[1]	1K9	4	100	0.003	36	Yes
Non-weather protected locations with tropical damp climates (rainforests)	1K10	30	100	6	36	Yes
Non-weather protected locations with tropical dry climates (deserts)	1K11	4	100	0.9	27	Yes

Note

1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

Table 4.3 Humidity – transportation

Installation location	IEC 721 class	Relative humidity not combined with rapid temperature changes		Relative humidity combined with rapid temperature changes: air/air at high relative humidity		Absolute humidity combined with rapid temperature changes: air/air at high water content	
		%	°C	%	°C	g/m³	°C
Weather protected heated and ventilated	2K1	75	+30	N/A		N/A	
Weather protected, ventilated but unheated in general climates excluding cold and cold temperate climates	2K2	75	+30	N/A		N/A	
Non-weather protected, unventilated and unheated in general climates excluding cold and cold temperate climates	2K3	95	+40	95	−25/+30	60	+70/+15
Non-weather protected, unventilated and unheated in general climates including cold and temperate climates	2K4	95	+40	95	−40/+30	60	+70/+15
Non-weather protected conditions worldwide	2K5	95	+50	95	−65/+30	80	+85/+15
Non-weather protected conditions excluding cold and cold temperate climates	2K5H	95	+50	95	−25/+30	80	+85/+15
Non-weather protected conditions including cold temperate climates	2K5L	95	+45	95	−65/+30	60	+70/+15
Non-weather protected conditions covering tropical damp climates (rainforests)	2K6	95	+45	95	+5/+30	60	+70/+15
Non-weather protected conditions covering tropical dry climates (deserts)	2K7	95	+50	95	−20/+30	80	+85/+15

Table 4.4 Humidity – operational

Installation location	IEC 721 class	Low relative humidity %	High relative humidity %	Low absolute humidity g/m^3	High absolute humidity g/m^3	Condensation None
Stationary use at weather protected, fully air conditioned locations with temperature and humidity control	3K1	20	75	4	15	No
Stationary use at weather protected, temperature controlled locations with partial humidity control	3K2	10	75	2	22	No
Stationary use at weather protected, temperature controlled locations with no humidity control	3K3	5	85	1	25	No
Stationary use at weather protected temperature controlled locations with a wide range of relative humidity	3K4	5	95	1	29	Yes
Stationary use at weather protected locations with no temperature or humidity control	3K5	5	95	1	29	Yes
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K6	10	100	0.5	29	Yes
Stationary use at partially weather protected locations with no temperature or humidity control[1]	3K7	10	100	0.1	35	Yes
Stationary use at partially weather protected locations with no temperature or humidity control, not exposed to solar radiation	3K7L	10	100	0.1	35	Yes
Stationary use at partially weather protected locations with no temperature or humidity control	3K8	10	100	0.02	35	Yes
Stationary use at partially weather protected locations with no temperature or humidity control	3K8H	10	100	0.5	35	Yes
Stationary use at partially weather protected locations with no temperature or humidity control	3K8L	10	100	0.02	29	Yes

continued

Table 4.4 (*cont.*)

Stationary use at partially weather protected locations in tropical damp climates (rainforest)	3K9	30	100	6	36	Yes
Stationary use at partially weather protected locations in tropical dry climates (desert)	3K10	4	100	0.9	27	Yes
Stationary use at restricted non-weather protected locations[1]	4K1	20	100	0.9	22	Yes
Stationary use at moderate non-weather protected locations[1]	4K2	15	100	0.26	25	Yes
Stationary use at general non-weather protected locations[1]	4K3	15	100	0.03	36	Yes
Stationary use at worldwide non-weather protected locations[1]	4K4	4	100	0.003	36	Yes
Stationary use at non-weather protected locations, low air temperature, low absolute humidity[1]	4K4H	4	100	0.9	36	Yes
Stationary use at non-weather protected locations, high air temperature, low relative humidity, high absolute humidity[1]	4K4L	20	100	0.003	22	Yes
Stationary use at non-weather protected locations in tropical damp climates (rainforests)	4K5	30	100	6	36	Yes

continued

Table 4.4 (*cont.*)

Installation location	IEC 721 class	Low relative humidity		Relative humidity[2]		Relative humidity[3]		Relative humidity[4]		Relative humidity[5]		Condensation
		%	°C	%	°C	%	°C	%	°C	%	°C	None
Stationary use at non-weather protected locations in tropical dry climates (deserts)	4K6	4		100		0.9		27		Yes		
Ground vehicle installations with products weather protected, ventilated and heated, not exposed to solar radiation	5K1	10	+30	75	+30	No	No	No	No	No	No	N/A
Ground vehicle installations with products weather protected (or partially weather protected), heated (or unheated), unventilated	5K2	10	+30	95	+40	No	No	95	−25/+30	95	+10/+70	N/A
Ground vehicle installations, unventilated, subject to wet surfaces and solar radiation	5K3	10	+30	95	+45	95	+70	95	−40/+30	95	+10/+70	N/A
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation	5K4	10	+30	95	+50	95	+85	95	−65/+30	95	+10/+85	N/A
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation in low temperature climates	5K4H	10	+30	95	+50	95	+85	95	−25/+30	95	+10/+85	N/A

continued

Table 4.4 (*cont.*)

Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation in high temperature climates	5K4L	10	+30	95	+45	95	+70	95	−65/+30	95	+10/+70	N/A
Ground vehicle installations in tropical damp climates (rainforests)	5K5	10	+30	95	+45	95	+85	95	+5/+30	95	+10/+85	N/A
Ground vehicle installations in tropical dry climates (deserts)	5K6	10	+30	95	+50	95	+85	95	−20/+30	95	+10/+85	N/A

Table 4.4 (*cont.*)

Installation location	IEC 721 class	Low relative humidity		Humidity[6]		Humidity[7]		Humidity[8]		Condensation
		%	°C	%	°C	g/m³	°C	g/m³	°C	None
Installations in totally weather protected, heated and ventilated ship environments, not exposed to solar radiation	6K1	10	+30	95	+30	None		None		N/A
Installations in totally weather protected, heated and ventilated ship environments, excluding cold climates	6K2	10	+30	95	+35	None		None		N/A
Installations in totally weather protected, heated and ventilated ship environments, near to heat dissipating equipment	6K3	10	+30	95	+35	95	−25/+35	None		N/A
Installations in non-weather protected, unventilated heated ship environments, excluding cold climates	6K4	10	+30	95	+45	95	−25/+35	60	+70/+15	N/A
Installations in non-weather protected, unventilated, unheated ship environments, including cold climates	6K5	10	+30	95	+45	95	−25/+35	60	+70/+15	N/A
Shipborne installations in tropical damp climates (rainforests)	6K6	10	+30	95	+35	95	+5/30	60	+55/+15	N/A
Shipborne installations in tropical dry climates (deserts)	6K7	10	+30	95	+45	95	−20/+35	60	+70/+15	N/A

continued

Table 4.4 (*cont.*)

Portable and non-stationary use at or direct transfer between temperature controlled weather protected environments, without humidity control	7K1	5	85	1	25	N/A
Portable and non-stationary use at or direct transfer between weather protected environments without humidity or temperature control	7K2	5	95	1	29	N/A
Portable and non-stationary use at or direct transfer between partially weather protected restricted environments[1]	7K3	5	100	0.5	48	N/A
Portable and non-stationary use at or direct transfer between partially weather protected moderate environments[1]	7K4	5	100	0.1	62	N/A
Portable and non-stationary use at or direct transfer between partially weather protected worldwide environments[1]	7K5	4	100	0.003	78	N/A
Portable and non-stationary use in tropical damp climates (rainforests)	7K6	30	100	6	36	N/A
Portable and non-stationary use in tropical dry climates (deserts)	7K7	4	100	0.9	27	N/A

Notes

1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.
2 Relative humidity, not combined with rapid temperature changes, except in engine compartments of vehicles powered by internal combustion engines.
3 Relative humidity, not combined with rapid temperature changes, in engine compartments of vehicles powered by internal combustion engines.
4 Relative humidity, combined with rapid temperature changes, air/air at high relative humidities. Not in close proximity to refrigerated air conditioning systems.
5 Relative humidity combined with rapid temperature changes, air/air. At high relative humidities. In close proximity to refrigerated air conditioning systems.
6 Humidity, not combined with rapid temperature changes.
7 Humidity, combined with rapid temperature changes, air/air at high relative humidities.
8 Humidity, combined with rapid temperature changes, air/air at high water content.

4.4.1 Damp heat tests (IEC 68.2.3 Test Ca, IEC 68.2.30 Test Db and IEC 68.2.56 Test Cb)

4.4.1.1 Introduction

Whenever temperature gradients exist in a system, formed by an item of equipment (component, module or unit) and its surroundings, a process of heat transfer will ensue. This heat transfer, when considered in relation to the humidity of air, will probably result in condensed water.

4.4.1.2 Purpose of these tests

The three most common tests are:

- IEC 68.2.3 – whose purpose is to determine the suitability of components that have been subjected to long-term exposure to high humidity conditions when condensation is absent;
- IEC 68.2.30 – whose purpose is to determine the suitability of components, equipment or other articles for use and storage under conditions of high humidity combined with cyclic temperature changes;
- IEC 68.2.56 – whose purpose is to determine and observe the effects of high humidity at constant temperature without condensation, on electronic equipment over a prescribed period.

4.4.1.3 General

If a product is permanently placed outdoors for several years, it can be temporarily exposed to more extreme air temperatures and more extreme combinations of air temperatures and relative humidity than would normally be expected. The most severe deterioration is by corrosion which generally occurs when there is frequent condensation and/or re-evaporation. Increased humidity or temperature will accelerate this corrosive effect. When condensation or a high relative humidity is present, the joints between different metals or between a metal and a non-metallic material can be a source of corrosion. Testing is therefore essential to ensure a product can withstand the severe degradation that humidity can inflict.

4.4.1.4 Test conditions

Most contracts require that 'equipment shall be tested to ensure that it meets the requirements of IEC 68.2.3, IEC 68.2.30 and IEC 68.2.56'.

4.4.1.5 Other standards

IEC 68.2.28	Environmental testing procedures – Guidance: Damp heat tests
IEC 68.3.1	Environmental testing procedures – Background information – Cold and dry heat tests
IEC 721.2.1	Classification of environmental conditions – Environ-

	mental conditions appearing in nature – Temperature and humidity

4.4.2 Damp heat steady state test (IEC 68.2.3 Test Ca)

Standard No.	IEC 68.2.3
Title	Environmental testing procedure – Test Ca: Damp heat, steady state
Summary	Determines the suitability of equipment, components or other articles for storage and use under conditions of high relative humidity. The second impression (1985), incorporating Amendment No. 1 (1984), envisages a continuous test at a steady temperature of 40°C and a relative humidity of 93%. Standard test duration from 4 to 56 days.
Equiv. Std	Identical to AS 1099.2.3 Identical to BS 2011:PT2.1Ca(1977) Identical to DIN IEC 68 PT2-3 Identical to HD 323.2.3 Identical to NEN 10068-2-3 Identical to NFC 20-703 Identical to SEN 43 16 03

4.4.2.1 Introduction

Long-term exposure to humidity can have a severe effect on equipment, especially electronic components.

4.4.2.2 Purpose of this test

The purpose of this test is to determine the suitability of components and other electrotechnical equipment or articles for use and storage under conditions of high relative humidity.

4.4.2.3 General

In many cases this test is used to determine whether the electrical characteristics of a material can be maintained in a humid atmosphere, but the test may also be used to assess the protection to an equipment by encapsulation and to detect weaknesses in electrical products with regard to the diffusion of water vapour, etc.

4.4.2.4 Test conditions

Specimens are exposed to damp heat which is maintained at a temperature of 40°C and a relative humidity of 93% in accordance with IEC 68.2.3. The severity of the test may be chosen from the range 4, 10, 21 or 56 days.

4.4.2.5 Other standards

IEC 68.2.28	Environmental testing procedures – Guidance: Damp heat tests

4.4.3 Damp heat cyclic test (12+12 hour cycles) (IEC 68.2.30 Test Db)

Standard No.	IEC 68.2.30
Title	Environmental testing procedures Test Db and Guidance – Damp heat, cyclic (12 + 12 hour cycle)
Summary	The object of the test is to determine the suitability of components, equipment or other articles for use and/or storage under conditions of high humidity when combined with cyclic temperature changes.
Equiv. Std	Technically equivalent to AS 1099:PT2Db Identical to BS 2011:PT2.1Db (1981) Identical to DIN IEC 68 PT2-30 Identical to HD 323.2.30 Identical to NEN 10068-2-30 Identical to NFC 20-730 Similar to SEN 43 16 04

4.4.3.1 Introduction

Cyclic tests are required in all cases where the effects of condensation or the ingress and accumulation of water vapour by 'breathing' are found to occur.

4.4.3.2 Purpose of this test

The purpose of this test is:

- to determine the ability of electronic equipment to withstand the stresses occurring in a climate of relative humidity (with or without condensation) particularly with regard to variations of electrical and mechanical characteristics;
- to determine the suitability of electronic equipment for use and storage under conditions of high humidity combined with cyclic temperature changes which can produce condensation on the surface of the equipment.

4.4.3.3 General

Occasionally specimens may include hollow spaces where condensation can occur on internal surfaces. Two types of test are available, depending on whether moisture can penetrate a specimen owing to this so-called 'breathing effect'.

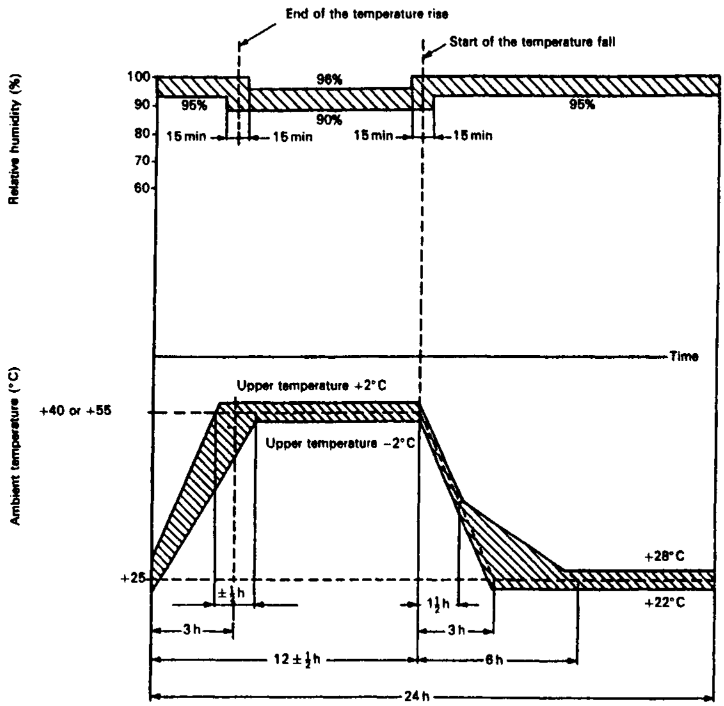


Fig. 4.3 Variant 1 (reproduced from the equivalent standard BS 7527 Section 2.1:1991 by kind permission of the BSI)

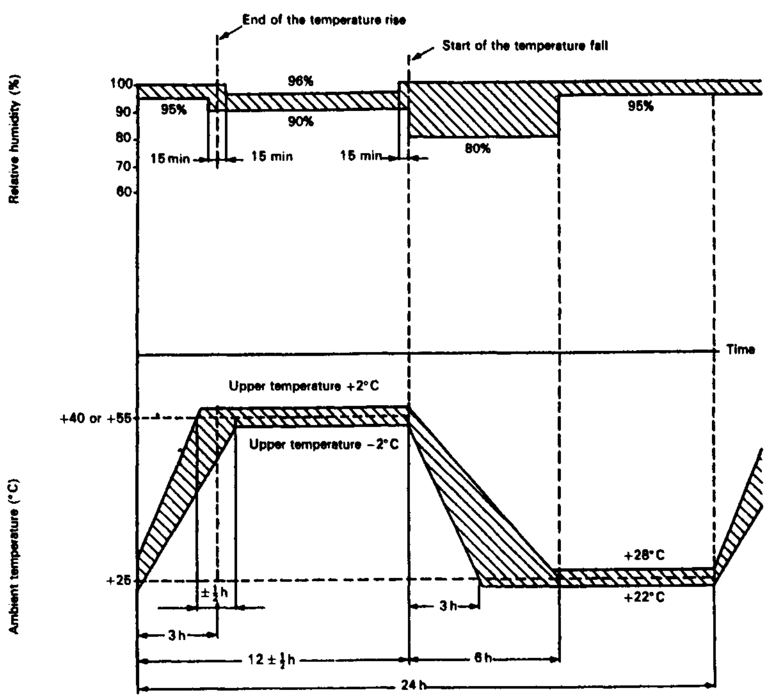


Fig. 4.4 Variant 2 (reproduced from the equivalent standard BS 7527 Section 2.1:1991 by kind permission of the BSI)

4.4.3.4 Test conditions

Candidate equipment will have to be subjected to at least one of the sequence of high humidity/cyclic temperature change tests as specified in IEC 68.2.30 and as shown in Figures 4.3. and 4.4.

The test comprises one or more temperature cycles in which the relative humidity is maintained at a high level (e.g. 95%). The severity of the test is determined by the upper temperature limit of the cycle and the number of cycles that a specimen is subjected to.

Further information on the application of damp heat tests including a comparison of steady state and cyclic tests can be found in IEC 68.2.28.

4.4.3.5 Other standards

IEC 68.2.28	Environmental testing procedures – Guidance: Damp heat tests

4.4.4 Composite temperature/humidity cyclic test (IEC 68.2.38 Test Z/AD)

Standard No.	IEC 68.2.38
Title	Environmental testing procedures – Test Z/AD: Composite temperature/ humidity cyclic test
Summary	Applicable to component type specimens. The object of the test is to determine in an accelerated manner the resistance to deteriorative effects of high temperature, humidity and cold conditions.
Equiv. Std	Technically equivalent to AS 1099:PT2Z/AD Technically equivalent to AS 1099:PT2Z/AM Identical to BS 2011:PT2.1Z/AD(1977) Identical to DIN IEC 68 PT2-38 Identical to HD 323.2.38 Identical to NEN 10068-2-38

4.4.4.1 Introduction

This standard deals with the deteriorative effects caused by heat, cold and water vapour on electronic equipment.

4.4.4.2 Purpose of this test

The purpose of this test is to determine, in an accelerated manner, the resistance of specimens to the deteriorative effects of high temperature, high humidity and cold conditions.

4.4.4.3 General

For non-operational tests the specimen is introduced into the chamber in an unpacked, switched off, 'ready to use' state in its normal position or as otherwise specified.

When operational tests are required, the specimen has to be switched on or be electrically loaded.

4.4.4.4 Test conditions

This is quite a brutal test as equipment is exposed, first to high relative humidity (which will produce an entry of moisture through 'breathing', into partially sealed containers) followed by low temperatures and then (as an option) subzero freezing in order to determine the effects of periodic icing (see Figures 4.5 and 4.6).

4.4.4.5 Other standards

IEC 68.2.28	Environmental testing procedures – Guidance: Damp heat tests

4.4.5 Damp heat steady state test – primarily for equipment (IEC 68.2.56 Test Cb)

Standard No.	IEC 68.2.56
Title	Environmental testing procedure – Test Cb: Damp heat, steady state, primarily for equipment
Summary	Determines the suitability of electrotechnical products, primarily for equipment, for use and storage under conditions of high humidity. This test is primarily intended to permit the observation of the effect of high humidity at constant temperature without condensation on the specimen over a prescribed period. Can be applied to non-heat dissipating and heat dissipating specimens.
Equiv. Std	Identical to BS 2011:PT2.1Cb (1990) Identical to DIN IEC 68 PT2-56 Identical to HD 323.2.56 Identical to NEN 10068-2-56

4.4.5.1 Introduction

This test is mainly used to determine the ability of an item of equipment to withstand high humidity conditions where condensation is absent.

4.4.5.2 Purpose of this test

The purpose of this test is to observe the effects of high humidity at constant temperature, on equipment over a prescribed period.

4.4.5.3 General

This test is particularly applicable to large equipment or equipment

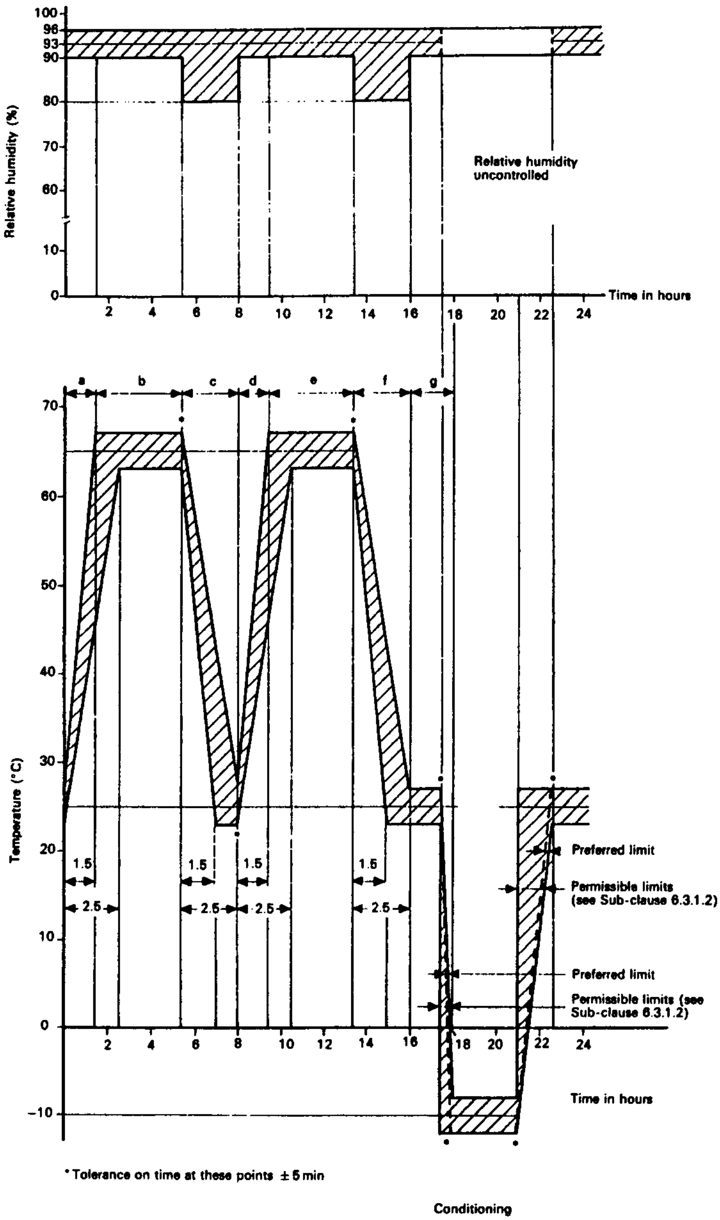


Fig. 4.5 Exposure to humidity followed by exposure to cold (reproduced from BS 7527 Section 2.1:1991 by kind permission of BSI)

having complex interconnections and normally the test equipment is external to the test chamber.

The test can be applied to both heat dissipating and non-heat dissipating equipment. When testing heat dissipating specimens the test

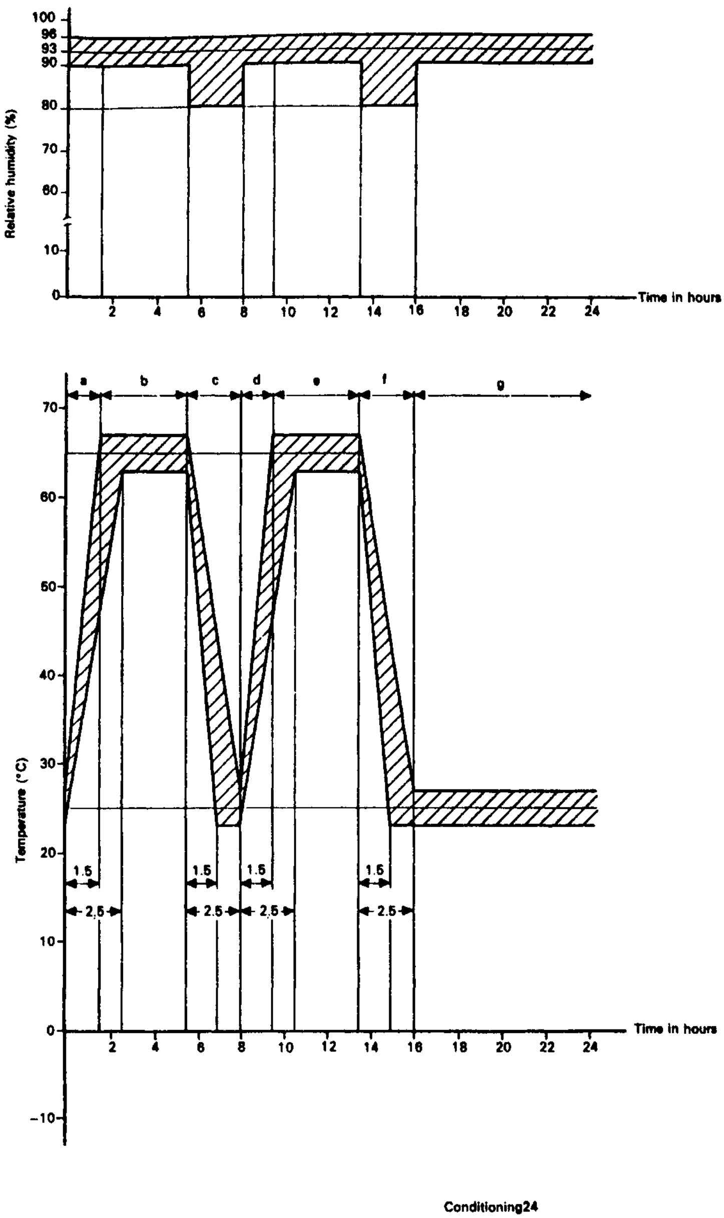


Fig. 4.6 Exposure to humidity not followed by exposure to cold (reproduced from BS 7527: Section 2.1:1991 by kind permission of BSI)

procedure ensures a good simulation of free air conditions and takes account of the effects of the specimen self-heating and the environment in the immediate vicinity of the specimen.

The test procedure is designed in such a way that condensation should not occur on the specimen, except in the case of active cooling devices which have a temperature below the dew point of the test atmosphere.

4.4.5.4 Test conditions

The test provides a number of preferred severities of high temperature, high humidity and test duration.

4.4.5.5 Other standards

IEC 68.2.28	Environmental testing procedures – Guidance: Damp heat tests

4.4.6 Climatic sequence test (IEC 68.2.61 Test Z/ABDM)

Standard No.	IEC 68.2.61
Title	Environmental testing procedures – Test methods – Test Z/ABDM: Climatic sequence
Summary	Describes in detail a composite test specifying a 'climatic sequence' for specimens of products, primarily components, that is based on clause 7 of IEC 68.1 and includes guidance (in informative annexes) for specification writers and those performing the test.
Equiv. Std	Similar to BS 2011:PT2.1Z/ABDM(1983) Identical to BS EN 60068 PT2-61 Identical to DIN EN 60068 PT2-61 Identical to EN 60068 PT2-61 Identical to NEN 10068-2-61 Identical to NFC 20-761

4.4.6.1 Introduction

This test deals with a range of environmental conditions to which equipment may be subjected in any combination.

4.4.6.2 Purpose of this test

The purpose of this test is to determine the suitability of specimens (primarily components) when subjected to environmental conditions consisting of a sequence of temperature, humidity and, where required, low air pressure environmental stresses.

4.4.6.3 General

This test is frequently specified to follow other tests involving mechanical stress (e.g. tests for robustness of terminations, solderability, shock and vibration) as a means of determining whether the sealing of a specimen has been damaged.

4.4.6.4 Test conditions

The test describes three types of composite test methods for determining the suitability of a specimen to a 'climatic sequence' of tests.

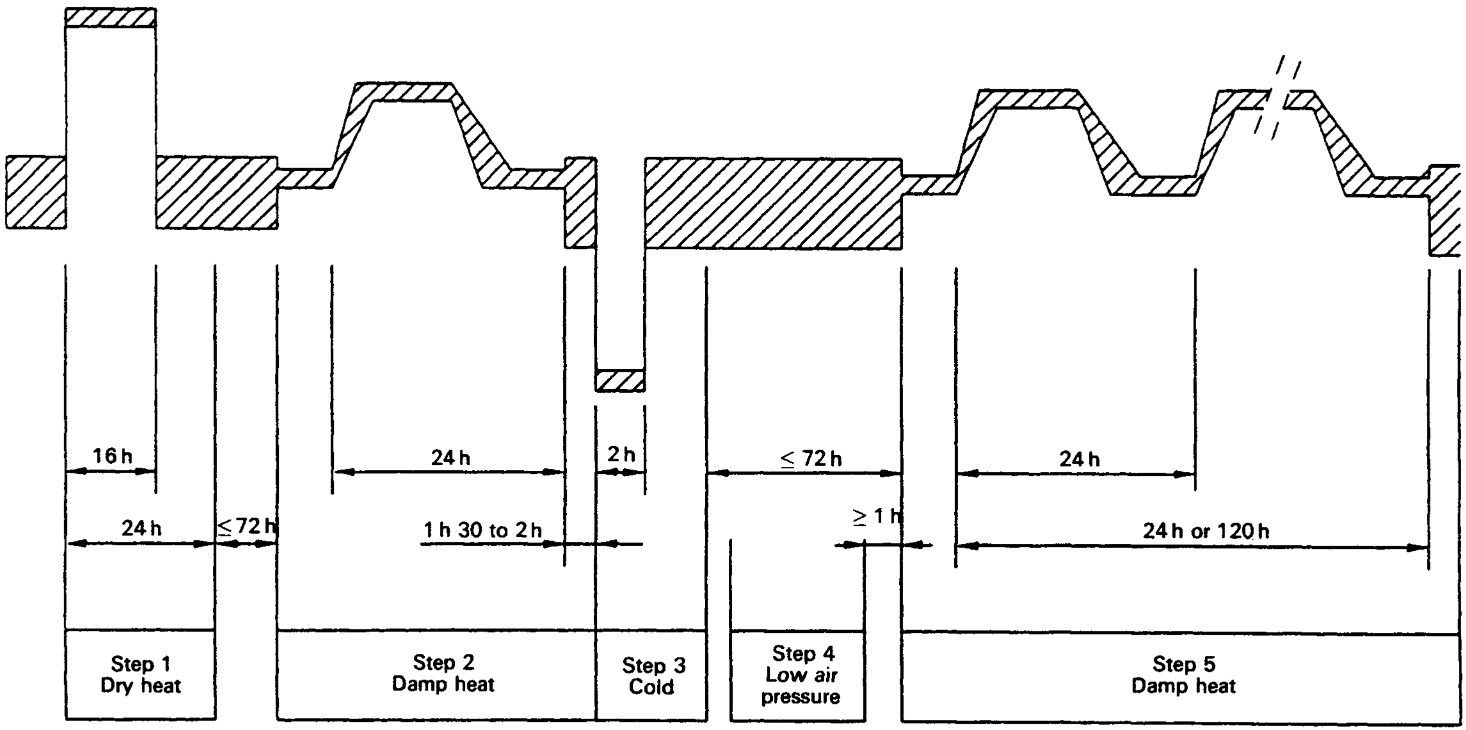


Fig. 4.7 Diagrammatic representation of the progress of the climatic sequence (reproduced from the equivalent standard BS 2011 Section 2.1:1983 by kind permission of the BSI)

Test method one is preferred (see Figure 4.7) and contains five steps of which one (low atmospheric temperature) is optional.

During this test the specimen is first exposed to a high temperature and then to a cycle of damp heat. This is immediately followed by a low temperature test so that any moisture which has entered, either the specimen or surface cracks in its seals, will be frozen and cause further damage. A low pressure test (optional) is then followed by further exposure to cyclic damp heat.

If required the severity of the test can be increased by completing a low temperature test in between each of the five final damp heat cycles.

4.4.6.5 Other Standards

IEC 68.2.39 Environmental testing procedures – Test Z/AMD: Combined sequential cold, low air pressure and damp heat test

IEC 68.2.39 provides details of a combined sequential cold, low air pressure and damp heat test which may also be used for evaluating samples. This test is primarily intended for components and equipment used in aircraft and for high altitude applications.

Chapter 5

Air pressure and altitude

5.1 Guidance

5.1.1 What is air pressure and altitude?

Air pressure, frequently referred to as atmospheric pressure, is 'the force exerted on a surface of an area caused by the Earth's gravitational attraction on the air vertically above that area'. Air pressure varies with altitude (i.e. elevation above mean sea level) and location. For instance at the equator where the tradewinds of both hemispheres converge, there is a low pressure zone (known as the ITCZ or International Conveyance Zone), which is characterised by high humidity.

5.1.2 Introduction

It is not widely appreciated that the location of equipment, especially with respect to its altitude above sea level, can affect the working of that equipment. But it is not just the height above sea level that has the most effect. Even air pressure variations at ground level have to be considered.

In the railway environment, when a train enters a tunnel it forces a pressure wave ahead of it which will travel at the velocity of sound to the opposite end of the tunnel where it will be reflected and return to meet the train at some point. This can become a particular problem, because the increasing intermittent pressure variations at the front of the train can produce a pressure difference sometimes more than double the value of the first pressure rise.

Owing to the way in which trains are designed, however, these air pressure variations will not affect the actual train itself (so much), but they will affect equipment such as electronic circuits that are mounted or installed in the tunnels. This is because air pressure variations (low and high) can indirectly affect the service life of most closed components (e.g. semiconductor elements and capacitors) by causing the packing and sealed housings to 'breathe' or rupture and thus promote destruction

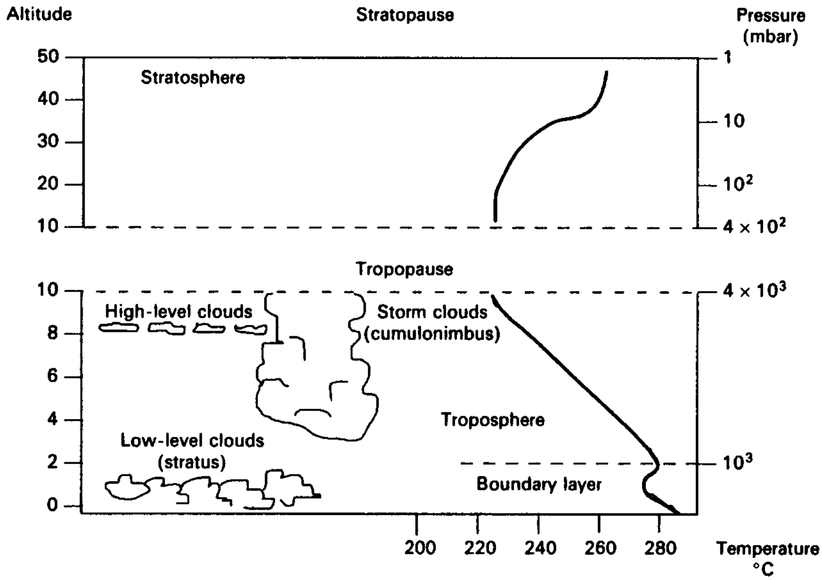


Fig. 5.1 Atmospheric structure

by leakage and/or penetration of humidity or atmospheric substances (e.g. sulphur emanating from rubber).

5.1.2.1 Low air pressure

At altitudes above sea level, low air pressure can cause:

- leakage of gases or fluids from gasket sealed containers;
- ruptures of pressurised containers;
- change of physical or chemical properties;
- erratic breakdown or malfunction of equipment from arcing or corona;
- decreased efficiency of heat dissipation by convection and conduction in air, that will affect equipment cooling (e.g. an air pressure decrease of 30% has been found to cause an increase of 12% in temperature);
- acceleration of effects due essentially to temperature (e.g. volatilisation of plasticisers, evaporation of lubricants, etc.).

5.1.2.2 High air pressure

High air pressure occurring in natural depressions and mines can have a mechanical effect on sealed containers and should always be borne in mind when designing equipment.

5.1.3 Test standards

IEC 68.2.13 Environmental testing procedures – Test M: Low air pressure

Table 5.1 Air pressure and altitude (reproduced with permission from ISO 2533)

Air pressure (kPa)	Air pressure (mbar)	Approximate altitude above sea level (m)
1	10	31 200
2	20	26 600
4	40	22 100
8	80	17 600
15	150	13 600
25	250	10 400
40	400	7 200
55	550	4 850
70	700	3 000

IEC 68.2.39 Environmental testing procedures – Test Z/AMD: Combined sequential cold, low air pressure and damp heat test

IEC 68.2.40 Environmental testing procedures – Test Z/AM: Combined cold heat/low air pressure tests

IEC 68.2.41 Environmental testing procedures – Test Z/BM: Combined dry heat/low air pressure

5.1.4 Other related standards and specifications

EN 50123 Railway applications – d.c. switchgear for stationary installations in traction systems – General

EN 50125 Railway applications – Environmental conditions for rolling stock equipment

EN 50155 Railway applications – Environmental conditions for non-rolling stock equipment

ERRI Question A118 Report No. 4. Use of electronic components in signalling

IEC 68.1 Environmental testing procedures Part 1 General

IEC 68.2.1 Environmental testing procedures – Test A: Cold

IEC 68.2.2 Environmental testing procedures – Test B: Dry heat

IEC 721.2.3 Classification of environmental conditions – Environmental conditions appearing in nature – Air pressure.

IEC 68.3.1/1A Environmental testing procedures – Background information – Cold and dry heat tests (and first supplement)

IEC 68.3.2 Environmental testing procedures – Background information – Combined temperature/low pressure tests

5.2 Typical contract requirements – air pressure and altitude

5.2.1 Introduction

The requirement for equipment to conform to various environmental specifications is becoming commonplace in today's contracts. More and more specifications are being used to describe the various conditions that equipment is likely to experience when being used, stored or whilst in transit.

The following are the most common environmental requirements found in modern contracts concerning air pressure and altitude.

5.2.1.1 Installation up to 2000 m above sea level

In view of the places in Europe where equipment can be installed (e.g. in the mountains of Switzerland or the depths of the Channel Tunnel), one of the frequent requirements is that equipment must be capable of working to an altitude (h) from −120 to 2000 m above sea level – which corresponds to an air pressure range from 110.4 to 74.8 kPa.

Table 5.2 indicates the correlation between altitude (relative to sea level) and corresponding air pressure.

5.2.1.2 Installations above 2000 m

For installations at a higher altitude than 2000 m, contracts usually stipulate that the temperature tests (carried out in laboratories at sea level) shall take into account an agreed correction factor.

5.2.1.3 Cross winds

Another normal contract requirement for vehicle mounted equipment is that the equipment needs to function correctly at cross winds of up to 15 m/s with gusts of 30 m/s and a duration of 1 second per gust. In exceptional cases wind speeds can reach a maximum of 50 m/s and these have to be catered for.

5.2.1.4 Pressure pulses

Contracts (particularly when considering railway requirements) will normally stipulate that pressure pulses caused by vehicles crossing or entering a tunnel must be taken into account.

Table 5.2 Classes of altitude relative to sea level

Classes	Altitude range relative to sea level (m)	Air pressure range (kPa)
1	From −120 to 1200	Between 110.4 and 80.8
2	From −120 to 1800	Between 110.4 and 74.8
3	From 0 to >1800	Between 92.2 and <74.8

5.2.2 Tests

All proposed candidate equipment, components or other articles need to be tested in their production configuration without the use of any additional external devices that have been added expressly for the purpose of passing air pressure testing.

When tested, the sample (component, equipment or other article) should perform as stipulated in the procuring specification and over the designated pressure range.

Test methods for determining the suitability of a specimen shall include:

IEC 68.2.13	Environmental testing procedures – Test M: Low air pressure
IEC 68.2.39	Environmental testing procedures – Test Z/AMD: Combined sequential cold, low air pressure and damp heat test
IEC 68.2.40	Environmental testing procedures – Test Z/AM: Combined cold low air pressure tests
IEC 68.2.41	Environmental testing procedures – Test Z/BM: Combined dry heat/low air pressure

5.3 Values and ranges

The normal value of air pressure at mean sea level is 101 kPa. Depending on meteorological conditions, air pressure at sea level may vary from approximately 95 to 107% of the aforementioned value.

In areas above sea level, air pressure is lower than it is at sea level.

Table 5.3 Normal air pressure related to altitudes above and below sea level

Altitude (m)		Air pressure (kPa)
30000		1.2
25000		2.5
20000		5.5
15000		12.0
10000		26.4
8000		35.6
6000		47.2
5000		54.0
4000		61.6
3000		70.1
2000		79.5
1000		89.9
0	Sea level	101.3
−400		106.2
−1000		113.9
−2000		127.8

Table 5.4 Air pressure and altitude – storage

Installation location	IEC 721 class	Low air pressure (kPa)	High air pressure (kPa)	Movement of surrounding air (m/s)
Fully air conditioned enclosed locations, with air temperature and humidity control	1K1	70	106	0.5
Fully air conditioned, temperature controlled, enclosed locations without humidity control	1K2	70	106	1.0
Fully enclosed locations without air temperature or humidity control	1K3	70	106	1.0
Partially weather protected locations without air temperature or humidity control[1]	1K4	70	106	1.0
Partially weather protected locations without air temperature or humidity control[1]	1K5	70	106	5.0
Partially weather protected locations without air temperature or humidity control[1]	1K6	70	106	5.0
Restricted non-weather protected locations[1]	1K7	70	106	Choice of either 30 or 50
Moderate non-weather protected locations[1]	1K8	70	106	Choice of either 30 or 50
Worldwide non-weather protected locations[1]	1K9	70	106	Choice of either 30 or 50
Non-weather protected locations with tropical damp climates (rainforests)	1K10	70	106	50
Non-weather protected locations with tropical dry climates (deserts)	1K11	70	106	50

Note
1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

Table 5.5 Air pressure and altitude – transportation

Installation location	IEC 721 class	Low air pressure (kPa)	Change of air pressure (kPa/min)	Movement of surrounding air (m/s)
Weather protected, heated and ventilated	2K1	70	No	No
Weather protected, ventilated but unheated in general climates excluding cold and cold temperate climates	2K2	70	No	No
Non-weather protected, unventilated and unheated in general climates excluding cold and cold temperate climates	2K3	70	No	20
Non-weather protected, unventilated and unheated in general climates including cold and temperate climates	2K4	70	No	20
Non-weather protected conditions worldwide	2K5	30	6	30
Non-weather protected conditions excluding cold and cold temperate climates	2K5H	30	6	30
Non-weather protected conditions including cold temperate climates	2K5L	30	6	30
Non-weather protected conditions covering tropical damp climates (rainforests)	2K6	30	6	30
Non-weather protected conditions covering tropical dry climates (deserts)	2K7	30	6	30

Table 5.6 Air pressure and altitude – operational

Installation location	IEC 721 class	Low air pressure (kPa)	High air pressure (kPa)	Movement of surrounding air (m/s)
Stationary use at weather protected, fully air conditioned locations with temperature and humidity control	3K1	70	106	0.5
Stationary use at weather protected, temperature controlled locations with partial humidity control	3K2	70	106	1.0
Stationary use at weather protected, temperature controlled locations with no humidity control	3K3	70	106	1.0
Stationary use at weather protected temperature controlled locations with no humidity control	3K4	70	106	1.0
Stationary use at weather protected locations with no temperature or humidity control	3K5	70	106	1.0
Stationary use at partially weather protected locations with no temperature or humidity control	3K6	70	106	1.0
Stationary use at partially weather protected locations with no temperature or humidity control	3K7	70	106	5.0
Stationary use at partially weather protected locations with no temperature or humidity control, not exposed to solar radiation	3K7L	70	106	5.0
Stationary use at partially weather protected locations with no temperature or humidity control	3K8	70	106	5.0
Stationary use at partially weather protected locations with no temperature or humidity control	3K8H	70	106	5.0
Stationary use at partially weather protected locations with no temperature or humidity control	3K8L	70	106	5.0
Stationary use at partially weather protected locations in tropical damp climates (rainforests)	3K9	70	106	5.0
Stationary use at partially weather protected locations in tropical dry climates (deserts)	3K10	70	106	5.0

continued

Stationary use at restricted non-weather protected locations[1]	4K1	70	106	Choice from 20, 30 or 50
Stationary use at moderate non-weather protected locations[1]	4K2	70	106	Choice from 20, 30 or 50
Stationary use at general non-weather protected locations[1]	4K3	70	106	Choice from 20, 30 or 50
Stationary use at worldwide non-weather protected locations[1]	4K4	70	106	Choice from 20, 30 or 50
Stationary use at non-weather protected locations, low air temperature, low absolute humidity[1]	4K4H	70	106	Choice from 20, 30 or 50
Stationary use at non-weather protected locations, high air temperature, low relative humidity, high absolute humidity[1]	4K4L	70	106	Choice from 20, 30 or 50
Stationary use at non-weather protected locations in tropical damp climates (rainforests)	4K5	70	106	50
Stationary use at non-weather protected locations in tropical dry climates (deserts)	4K6	70	106	50
Ground vehicle installations with products weather protected, ventilated and heated	5K1	70	N/A	None
Ground vehicle installations with products weather protected (or partially weather protected), heated (or unheated), unventilated	5K2	70	N/A	20
Ground vehicle installations, unventilated, subject to wet surfaces and solar radiation	5K3	70	N/A	20
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation	5K4	70	N/A	30
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation in low temperature climates	5K4H	70	N/A	30
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation in high temperature climates	5K4L	70	N/A	30
Ground vehicle installations in tropical damp climates (rainforests)	5K5	70	N/A	30
Ground vehicle installations in tropical dry climates (deserts)	5K6	70	N/A	30
Installations in totally weather protected, heated and ventilated ship environments, not exposed to solar radiation	6K1	N/A	N/A	Negligible
Installations in totally weather protected, heated and ventilated ship environments, excluding cold climates	6K2	N/A	N/A	Negligible
Installations in totally weather protected, heated and ventilated ship environments, near to heat dissipating equipment	6K3	N/A	N/A	Negligible

continued

Table 5.6 (*cont.*)

Installation location	IEC 721 class	Low air pressure (kPa)	High air pressure (kPa)	Movement of surrounding air (m/s)
Installations in non-weather protected, unventilated heated ship environments, excluding cold climates	6K4	N/A	N/A	30
Installations in non-weather protected, unventilated, unheated ship environments, including cold climates	6K5	N/A	N/A	50
Shipborne installations in tropical damp climates (rainforests)	6K6	N/A	N/A	50
Shipborne installations in tropical dry climates (deserts)	6K7	N/A	N/A	50
Portable and non-stationary use at or direct transfer between temperature controlled, weather protected environments, without humidity control	7K1	70	106	Choice from 5, 10, 30 or 50
Portable and non-stationary use at or direct transfer between weather protected environments without humidity or temperature control	7K2	70	106	Choice from 5, 10, 30 or 50
Portable and non-stationary use at or direct transfer between partially weather protected restricted environments[1]	7K3	70	106	Choice from 5, 10, 30 or 50
Portable and non-stationary use at or direct transfer between partially weather protected moderate environments[1]	7K4	70	106	Choice from 5, 10, 30 or 50
Portable and non-stationary use at or direct transfer between partially weather protected worldwide environments[1]	7K5	30	106	Choice from 5, 10, 30 or 50
Portable and non-stationary use in tropical damp climates (rainforests)	7K6	70	106	Choice from 5, 10, 30 or 50
Portable and non-stationary use in tropical dry climates (deserts)	7K7	70	106	Choice from 5, 10, 30 or 50

Note

1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

In areas below sea level (natural depressions, mines and cross channel) air pressure is higher than at sea level.

Notes: Values corresponding to the highest altitudes are given to take into account meteorological observation units and transportation by air. The altitude −400 m corresponds to the deepest natural depression in the world. For further information see ISO Standard 2533.

5.4 Tests

This section details some of the test standards which may be applied to equipment and contains:

- a list details of the most used environmental tests that a purchaser will normally require a manufacturer to adhere to;
- a list of other related standards and specifications;
- a brief description of the more common tests.

Note: Full details of each of these recommended tests are contained in the relevant ISO, IEC or other standard. A full list of these standards is supplied in the reference section of this book. Copies of all these standards may be obtained from any National Standards Organisation.

5.4.1 Low air pressure test (IEC 68.2.13 Test M)

Standard No.	IEC 68.2.13
Title	Environmental testing procedures – Test M: Low air pressure
Summary	Determines the ability of components, equipment or other articles to be stored, transported or used under low air pressure conditions.
Equiv. Std	Identical to AS 1099.2.13 Identical to BS 2011:PT2.1M(1984) Identical to DIN IEC 68 PT2-13 Identical to HD 323.2.13 Identical to NEN 10068-2-13 Identical to NFC 20-713 Identical to SEN 43 16 12

5.4.1.1 Introduction
This standard deals with low pressure tests at room temperature.

5.4.1.2 Purpose of this test
The purpose of this test is to determine the ability of components, equipment and other articles to be stored or used under low air pressure conditions.

5.4.1.3 General

For non-operational tests the specimen is introduced into the chamber in an unpacked, switched off, 'ready for use' state.

When operational tests are required, the specimen has to be switched on or be electrically loaded.

5.4.1.4 Test conditions

IEC 68.2.13 describes a test that can be used in order to measure the ability of components and equipment to be stored or used under low air pressure conditions. The test consists of introducing the specimen into the test chamber, reducing the chamber's air pressure and then maintaining these conditions according to the values specified. The severity of the test is dependent on the air pressure and the duration of the test (e.g. 5 min, 30 min, 2, 4 or 16 hours).

5.4.1.5 Other standards

IEC 68.2.40	Environmental testing procedures – Test Z/AM: Combined cold low air pressure tests
IEC 68.2.41	Environmental testing procedures – Test Z/BM: Combined dry heat/low air pressure

5.4.2 Combined sequential cold, low air pressure and damp heat test (IEC 68.2.39 Test Z/AMD)

Standard No.	IEC 68.2.39
Title	Environmental testing procedures – Test Z/AMD: Combined sequential cold, low air pressure and damp heat test
Summary	Applicable to components and equipment used in aircraft, particularly in zones that are unpressurised.
Equiv. Std	Technically equivalent to AS 1099:PT2Z/BM Identical to BS 2011:PT2.1Z/AMD(1977) Identical to DIN IEC 68 PT2-39 Identical to HD 323.2.39

5.4.2.1 Introduction

Although this test is primarily aimed at aviation applications, particularly during ascent and decent, if equipment is being transported by air in an unpressurised and non-temperature controlled zone the test could be important.

5.4.2.2 Purpose of this test

The purpose of this test is to simulate the conditions encountered within the unpressurised and non-temperature controlled zones of an aircraft during ascent and decent. The test provides a standard environmental test procedure consisting of the application of cold, low air pressure and damp heat.

5.4.2.3 General

Most non-heat dissipating components that incorporate elastomeric seals (such as a plug and socket connector) will experience hardening of the seals and contraction of materials as they become colder and may suffer failure of the seals (with consequent loss of internal pressure) as the surrounding air pressure decreases.

When an aircraft descends into a humid atmosphere and the air pressure increases once more, the cold components will suffer frosting and the humid atmosphere (or free water formed by the melting of the frost) can be driven into the component by the differential pressure and may be trapped inside by the seals as they recover their normal elasticity.

The same sequence could also cause water or ice to accumulate inside a piece of equipment that is fitted with an unsealed but closely fitting cover.

5.4.2.4 Test conditions

IEC 68.2.39 provides a standard environmental test procedure (consisting of the application of cold, low air pressure and damp heat) that simulates the conditions encountered within unpressurised and non-temperature controlled zones of an aircraft during ascent and decent.

5.4.2.5 Other standards

IEC 68.2.28	Environmental testing procedures – Guidance: Damp heat tests

5.4.3 Combined cold/low air pressure tests (IEC 68.2.40 Test Z/AM)

Standard No.	IEC 68.2.40
Title	Environmental testing procedures – Test Z/AM: Combined cold low air pressure tests
Summary	Applicable to both heat dissipating and non-heat dissipating specimens. The object of the test is to determine the ability of components or equipment or other articles to be stored and used under a simultaneous combination of low temperature and low air pressure.
Equiv. Std	Technically equivalent to AS 1099:PT2Z/AM Identical to BS 2011:PT2.1Z/AM(1977) Identical to DIN IEC 68 PT2-40 Identical to HD 323.2.40 Identical to NEN 10068-2-40

5.4.3.1 Introduction

Components, equipment or other articles whilst in use (and particularly whilst in store) are frequently subjected to a simultaneous combination of low temperature and low air pressure.

5.4.3.2 Purpose of this test

The purpose of this test is to provide a standard test procedure to determine the suitability of components, equipment or other articles (be they heat dissipating or non-heat dissipating) for use and/or storage under a combination of cold and low air pressure (with either a rapid or gradual change of temperature).

5.4.3.3 General

This test is a combination of low temperature (IEC 68.2.1) and low air pressure tests (IEC 68.2.13) and it can be used to test heat dissipating equipment in their operational state as well as non heat dissipating equipment in either an operational or stored state.

5.4.3.4 Test conditions

IEC 68.2.40 describes a composite test aimed at determining the susceptibility of a specimen to a simultaneous combination of low temperature and low air pressure, achieved by first exposing the specimen to a low temperature and then (with the temperature value maintained) reducing the air pressure in the test chamber.

The severity of the test is a combination of temperature, air pressure and duration of exposure as shown in Table 5.7.

Two types of test are catered for (see Figures 5.2. and 5.3) depending on whether the specimen is heat dissipating or not.

5.4.3.5 Other standards

IEC 68.2.1 Environmental testing procedures – Test A: Cold

IEC 68.2.13 Environmental testing procedures – Test M: Low air pressure

Table 5.7 Preferred combinations of temperature, air pressure and duration (reproduced from the equivalent standard BS 2011: Part 2.1 Z/AM 1977 by kind permission of the BSI)

Temperature (°C)	Air pressure		Duration (h)
	(kPa)	(mbar)	
−55	4	40	2
−55	15	150	2
−55	25	250	2
−55	40	400	2
−40	55	550	2–16
−25	55	550	2–16
−40	70	700	2–16

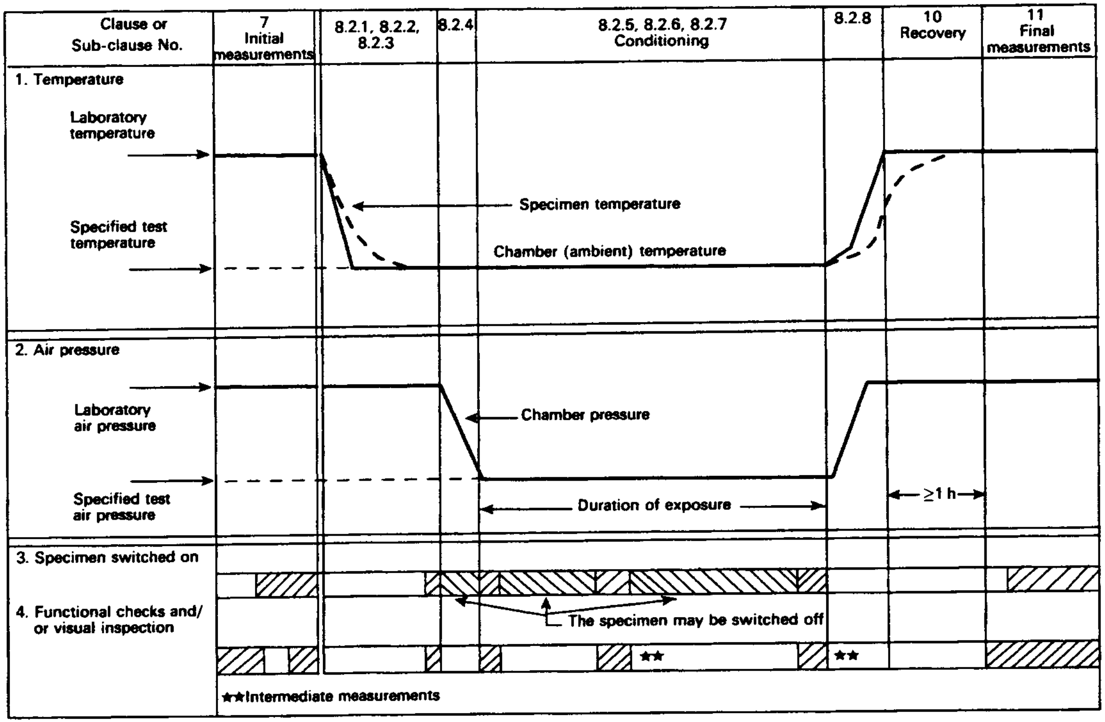


Fig. 5.2 Test profile for non-heat dissipating specimen (reproduced from the equivalent standard BS 2011: Part 2.1 Z/AM 1977 by kind permission of the BSI)

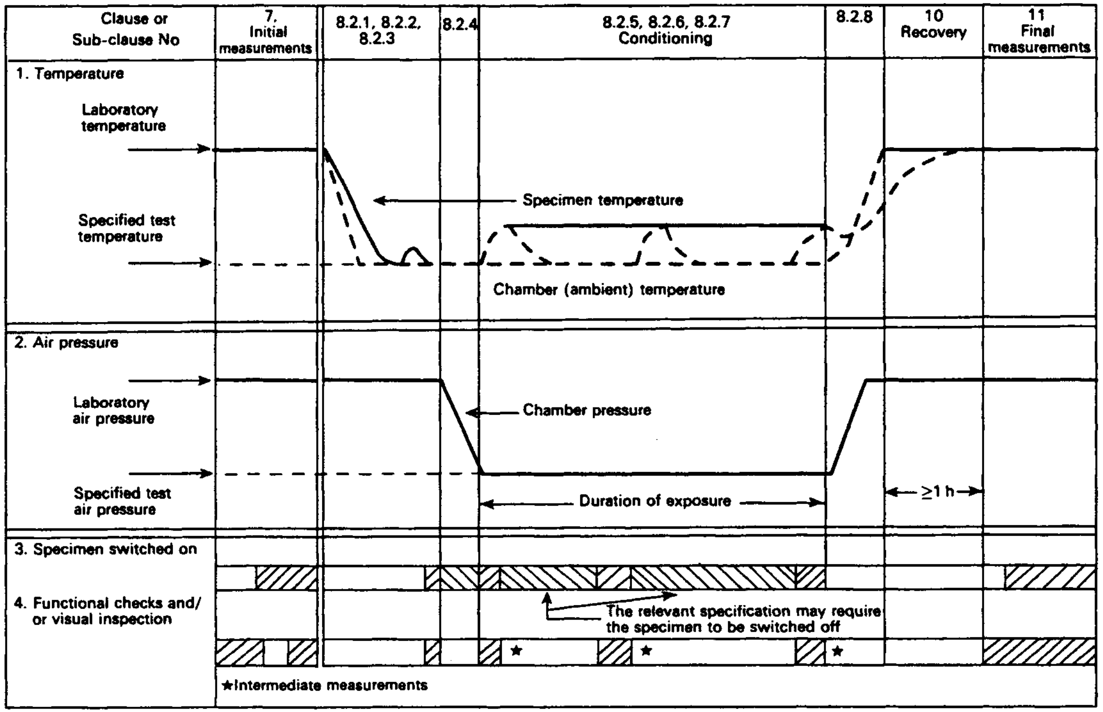


Fig. 5.3 Test profile for heat dissipating specimen (reproduced from the equivalent standard BS 2011: Part 2.1 Z/AM 1977 by kind permission of the BSI)

5.4.4 Combined dry heat/low air pressure test (IEC 68.2.41 Test Z/BM)

Standard No.	IEC 68.2.41
Title	Environmental testing procedures – Test Z/BM: Combined dry heat/low air pressure tests
Summary	Applicable to both heat dissipating and non-heat dissipating specimens. The object of the test is to determine the ability of components or equipment or other articles to be stored and used under a simultaneous combination of high temperature and low air pressure. Provides the preferred combinations of temperature, air pressure and duration.
Equiv. Std	Identical to BS 2011:PT2.1Z/BM(1977) Identical to DIN IEC 68 PT2-41 Identical to HD 323.2.41 Identical to NEN 10068-2-41 Identical to NEN 10068-2-41

5.4.4.1 Introduction

Components and equipment whilst in use (and particularly whilst in store) are frequently subjected to a simultaneous combination of high temperature and low air pressure.

5.4.4.2 Purpose of this test

The purpose of this test is to provide a standard test procedure to determine the suitability of components and equipment (heat dissipating or non-heat dissipating) for use and/or storage under a combination of high temperature and low air pressure.

5.4.4.3 General

This test is a combination of high temperature (IEC 68.2.2) and low air pressure (IEC 68.2.13) tests. It can be used to test heat dissipating equipment in their operational state and non-heat dissipating equipment in either an operational or stored state.

5.4.4.4 Test conditions

IEC 68.2.41 describes a composite test for judging the suitability of a specimen to a simultaneous combination of high temperature and low air pressure by first exposing it to a high temperature and then (with the temperature value maintained) reducing the air pressure in the test chamber.

The severity of the test is a combination of temperature, air pressure and duration of exposure as shown in Table 5.8.

Table 5.8 Preferred combinations of temperature, air pressure and duration (reproduced from the equivalent standard BS 2001: PT2:1 Z/BM 1977 by kind permission of the BSI)

Temperature (°C)	Air pressure (kPa)	Air pressure (mbar)	Duration (h)
155	4	40	2
85	4	40	2
155	15	150	2
85	15	150	2
55	15	150	2
55	25	250	2
55	40	400	2
55	55	550	2 or 16
55	70	700	2 or 16
40	55	550	2

5.4.4.5 Other test requirements

IEC 68.2.13 Environmental testing procedures – Test M: Low air pressure

IEC 68.2.2 Environmental testing procedures – Test B: Dry heat

Chapter 6

Weather and precipitation

6.1 Guidance

6.1.1 What is weather and precipitation?

Water is one of the most remarkable substances on the Earth. It is the substance that we most often see in all its three states: liquid (water), solid (ice) and gas (steam). No living organism can exist without water and as much as half the weight of plants and animals is made up of water. Water in the oceans makes up approximately 11 times the volume of the solid part of the Earth, in addition, that is, to water frozen in ice floes, in lakes, rivers, within the ground and in living plants and animals.

Water is a constantly moving cycle. As the sun beats down, some of the surface water is evaporated; this water vapour rises as part of the air and is moved along by the wind. Should it pass over a land mass it may become a cloud and as more moisture is attracted to the cloud or the clouds pass over rising ground the water particles become larger and fall as rain, sleet or snow. See Figures 6.1 and 6.2.

As the rain comes into contact with the ground there are several avenues open to it; it may be re-vaporised and return to the atmosphere, be absorbed by the ground or remain on the surface of the ground and run downhill forming streams and rivers which run into the sea and the cycle begins once more.

6.1.2 Introduction

6.1.2.1 Water

Water in all of its three forms is a major cause of failure in every application of electronic components. The humidity of the air and the possible formation of water particles must always be taken into consideration, especially as humidity possesses (almost without exception) a certain amount of electrical conductivity which increases the possibility of corrosion of metals. Similarly, the ingress of water followed by freezing within electronic equipment can result in malfunction.

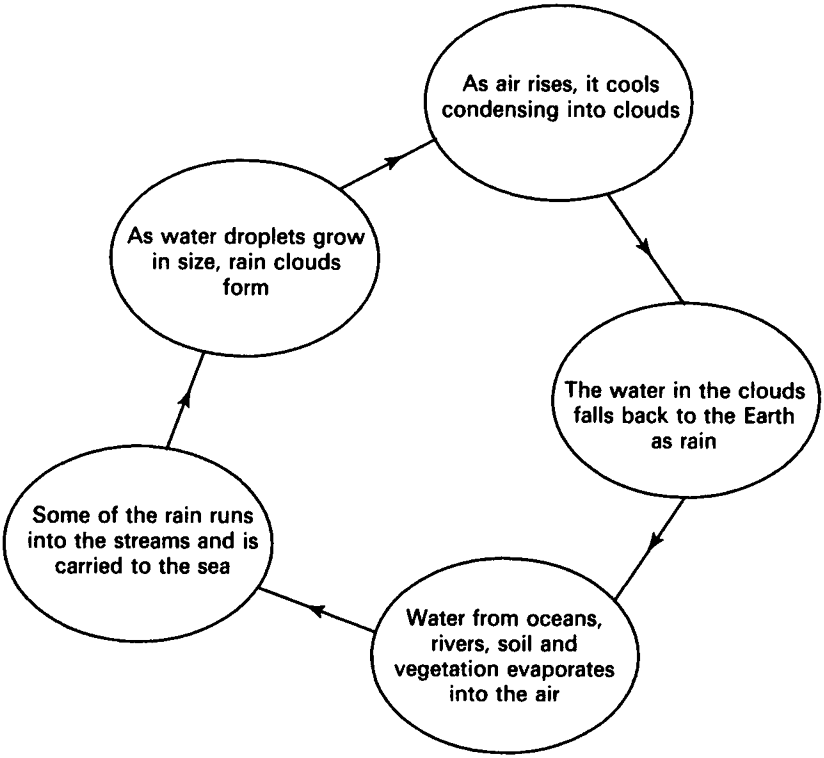


Fig. 6.1 The hydrological cycle

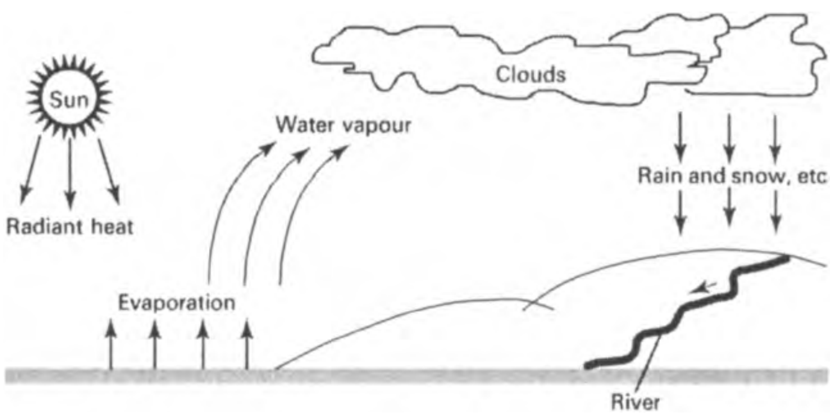


Fig. 6.2 Simplified water cycle

6.1.2.2 Salt water

Salt has an electrochemical effect on metallic materials (i.e. corrosion) which can damage and degrade the performance of equipment and/or parts that have been manufactured from metallic and/or non-metallic

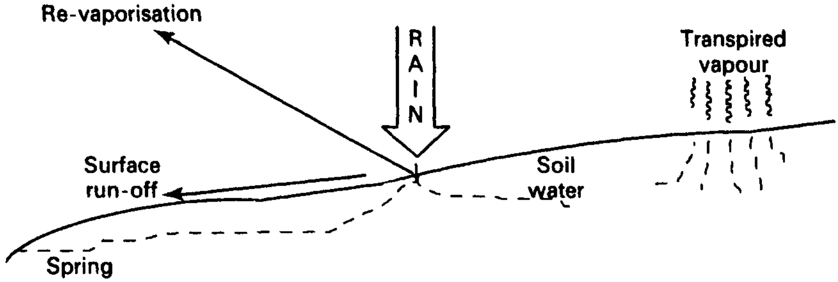


Fig. 6.3 The effect of rain

materials. Non-metallic materials can also be damaged by salt through a complex chemical reaction which is dependent on the supply of oxygenated salt solution to the surface of the material, its temperature and the temperature and humidity of the environment. This is particularly a problem in areas close to the sea or mountain ranges.

6.1.2.3 Ice and snow

Water in the form of ice can cause problems in the cooling of equipment, when it freezes and/or thaws in cracks, breaking cases, etc.

Powdered snow can easily be blown through ventilation ducts and then melt down in equipment compartments and cubicles: this can cause damp problems in critical systems if not prevented in the original construction.

6.1.2.4 Weathering

There are several types of weathering.

6.1.2.4.1 Exfoliation

During the day rocks are warmed by the sun and at night the surface can cool more rapidly than the underlying rocks. The outer skin of the rock then becomes tight and cracks, thus layers of the rock peel off, making mountains and hills, for example, become rounded or dome shaped. This exfoliation can have an effect on equipment that is sunk into rock faces or mounted on the surface of equipment.

6.1.2.4.2 Freeze thaw

When water freezes it turns to ice, expanding by about one-twelfth of its volume. If this water is in the joint or a crack in a casing then the space will become enlarged and the casing on either side will be forced apart. When the ice eventually thaws more water will penetrate into the crack and the cycle repeats itself with the crack constantly enlarging.

6.1.2.4.3 Chemical weathering

Water can pick up quantities of sulphur dioxide from the atmosphere and will form a weak solution of acid. This acid can attack certain equipment housings and the process whereby the housing is worn away is known as chemical weathering. Further details of the phenomenon can be found in Chapter 7, Pollutants and contaminants.

6.1.2.4.4 Erosion
As the wind blows over dry ground it collects grit and 'throws' it vigorously against the surfaces nearby. This grit acts in a similar way to sandpaper and gradually wears away the surface with which it comes into contact.

6.1.2.4.5 Mass movement
Once solids such as sedimentary rocks have been broken up, there is often a downwards movement of the particles which have been broken off. This 'soil creep' can gather momentum and can, in certain circumstances, submerge equipment.

6.1.3 Test standards

The primary purpose of water tests is to verify the ability of covers and seals to retain components and equipment in good working order. It may also be used, where necessary, under a standardised dropfield (i.e. water dropping onto the equipment under test conditions).

Tests are also required in order to determine the suitability of a component or a piece of equipment for use (or exposure) in a salt laden atmosphere and to test components or equipment designed to withstand a salt laden atmosphere.

Three basic tests are available. These are:

IEC 68.2.11	Environmental testing procedures – Test Ka: Salt mist
IEC 68.2.18	Environmental testing procedures – Test R and guidance: Water
IEC 68.5.52	Environmental testing procedures – Test Kb: Salt mist cyclic (sodium chloride solution)

6.1.4 Other related standards and specifications

IEC 34.5	Rotating electrical machines – Classification of degrees of protection provided by enclosures for rotating machines
IEC 68.2.17	Environmental testing procedures – Test Q: Sealing
IEC 68.2.3	Environmental testing procedures – Test Ca: Damp heat, steady state
IEC 144	Degrees of protection of enclosures for low voltage switchgear and controlgear
IEC 529	Classification of degrees of protection provided by enclosures

IEC 721.1	Classification of environmental conditions – Environmental parameters and their severities
IEC 721.2.2	Classification of environmental conditions – Environmental conditions appearing in nature – Precipitation and wind

6.2 Typical contract requirements – weather and precipitation

The requirement for equipment to conform to various environmental specifications is becoming commonplace in today's contracts. More and more specifications are being used to describe the various conditions that equipment is likely to experience when being used, stored or whilst in transit.

The following are the most common environmental requirements found in modern contracts concerning weather and precipitation.

6.2.1 Introduction

Equipment is often exposed to extremes of water and precipitation because of its function. For example, equipment that is operated adjacent to the sea shore or on mountain ranges and therefore subject to water and precipitation must be able to function equally well as the same equipment housed in arid deserts.

6.2.2 Operation

Most contracts will stipulate that 'all equipment shall be capable of operating during rain, snow, hail and be unaffected by ice, salt and water'. In particular this will concern:

6.2.2.1 Rain

A common contract requirement is that all equipment shall be capable of operating in rain and of preventing the penetration of rainfall at a minimum rate of 13 cm/h and an accompanying wind rate of 25 m/s.

The effect of rain should also be considered dependent on the equipment installation in conjunction with wind and vehicle movement. In these cases the rain rate to be taken into account is normally 6 mm/min (i.e. in accordance with Class 5K3 of IEC 721).

6.2.2.2 Snow and hail

Consideration should be given to the effect of all forms of snow and/or hail. The maximum diameter of the hailstones is conventionally taken as 15 mm, but larger diameters can occur on occasions.

6.2.2.3 Ice

Contracts normally recommend that the presence of ice should be considered on equipment installed outside of vehicles (e.g. trains, ships, etc.). In such conditions the performance of the equipment needs to be specified either in the product standard or by the purchaser.

6.2.2.4 Salt water

In accordance with most contracts, equipment should be capable of operating in (or be protected from) heavy salt spray, as would be experienced in seacoast areas and in the vicinity of salted roadways.

6.2.3 Tests

6.2.3.1 Production configuration

Normally found in contracts is a small notice stating that 'all proposed candidate equipment, components or other articles shall be tested in their production configuration without the use of any additional external devices that have been added expressly for the purpose of passing water and precipitation testing'.

6.2.3.2 Procuring specification

When tested, the sample (component, equipment or other article) should always perform as stipulated in the procuring specification when subjected to the designated severity of the test.

Test methods for determining the suitability of a specimen shall include:

IEC 68.2.11	Environmental testing procedures – Test Ka: Salt mist
IEC 62.18	Environmental testing procedures – Test R and guidance: Water
IEC 68.2.52	Environmental testing procedures – Test Kb: Salt mist cyclic (sodium chloride solution)

6.3 Values and ranges

Table 6.1 Water and precipitation – storage

Installation location	IEC 721 class	Rain intensity (mm/min)	Low rain temp. (°C)	Water from sources *other than rain* None	Formation of *ice and frost* None	Precipitation None
Fully air conditioned enclosed locations with air temperature and humidity control	1K1	None	None	No	No	No
Fully air conditioned, temperature controlled, enclosed locations without humidity control	1K2	None	None	No	No	No
Fully enclosed locations without air temperature or humidity control	1K3	None	None	Choice of dripping water, water jets or water waves	Yes	No
Partially weather protected locations without air *temperature or humidity control*[1]	1K4	None	None	Choice of dripping water, water jets or water waves	Yes	Yes
Partially weather protected locations without air temperature or humidity control[1]	1K5	None	None	Choice of dripping water, water jets or water waves	Yes	Yes
Partially weather protected locations without air temperature or humidity control[1]	1K6	None	None	*Choice of dripping water,* water jets or water waves	Yes	Yes
Restricted non-weather protected locations[1]	1K7	6	+5	Choice of dripping water, water jets or water waves	Yes	Yes
Moderate non-weather protected locations[1]	1K8	6	+5	Choice of dripping water, water jets or water waves	Yes	Yes
Worldwide non-weather protected locations[1]	1K9	15	+5	Choice of dripping water, water jets or water waves	Yes	Yes
Non-weather protected locations with tropical damp climates (rainforests)	1K10	15	+5	Choice of dripping water, water jets or water waves	No	Yes
Non-weather protected locations with tropical dry climates (deserts)	1K11	15	+5	Choice of dripping water, water jets or water waves	Yes	Yes

Note
1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

Table 6.2 Water and precipitation – transportation

Installation location	IEC 721 class	Water from sources other than rain (m/s)	Wetness None	Precipitation (mm/min)
Weather protected, heated and ventilated	2K1	No	No	No
Weather protected, ventilated but unheated in general climates excluding cold and cold temperate climates	2K2	No	No	No
Non-weather protected, unventilated and unheated in general climates excluding cold and cold temperate climates	2K3	1	Conditions of wet surfaces	6
Non-weather protected, unventilated and unheated in general climates including cold and temperate climates	2K4	1	Conditions of surfaces	6
Non-weather protected conditions worldwide	2K5	3	Conditions of wet surfaces	15
Non-weather protected conditions excluding cold and cold temperate climates	2K5H	3	Conditions of wet surfaces	15
Non-weather protected conditions including cold temperate climates	2K5L	3	Conditions of wet surfaces	6
Non-weather protected conditions covering tropical damp climates (rainforests)	2K6	3	Conditions of wet surfaces	15
Non-weather protected conditions covering tropical dry climates (deserts)	2K7	3	Conditions of wet surfaces	15

Table 6.3 Water and precipitation – operational

Installation location	IEC 721 class	Precipitation (mm/min)	Water from sources other than rain (m/s)	Formation of ice and frost None	Low rain temp. (°C)
Stationary use at weather protected, fully air conditioned locations with temperature and humidity control	3K1	No	No	No	–
Stationary use at weather protected, temperature controlled locations with partial humidity control	3K2	No	No	No	–
Stationary use at weather protected, temperature controlled locations with no humidity control	3K3	No	No	No	–
Stationary use at weather protected, temperature controlled locations with no humidity control	3K4	No	Choice of dripping, spraying or splashing water or water waves	No	–
Stationary use at weather protected locations with no temperature or humidity control	3K5	No	Choice of dripping, spraying or splashing water or water waves	Yes	–
Stationary use at partially weather protected locations with no temperature or humidity control	3K6	Yes	Choice of dripping, spraying or splashing water or water waves	Yes	–
Stationary use at partially weather protected locations with no temperature or humidity control	3K7	Yes	Choice of dripping, spraying or splashing water or water waves	Yes	–
Stationary use at partially weather protected locations with no temperature or humidity control, not exposed to solar radiation	3K7L	Yes	Choice of dripping, spraying or splashing water or water waves	Yes	–
Stationary use at partially weather protected locations with no temperature or humidity control	3K8	Yes	Choice of dripping, spraying or splashing water or water waves	Yes	–
Stationary use at partially weather protected locations with no temperature or humidity control	3K8H	Yes	Choice of negligible splashing water, water jets or water waves	Yes	–
Stationary use at partially weather protected locations with no temperature or humidity control	3K8L	Yes	Choice of negligible splashing water, water jets or water waves	Yes	–

continued

Table 6.3 (*cont.*)

Installation location	IEC 721 class	Precipitation (mm/min)	Water from sources other than rain (m/s)	Formation of ice and frost None	Low rain temp. (°C)
Stationary use at partially weather protected locations in tropical damp climates (rainforests)	3K9	Yes	Choice of negligible splashing water, water jets or water waves	No	–
Stationary use at partially weather protected locations in tropical dry climates (deserts)	3K10	Yes	Choice of negligible splashing water, water jets or water waves	Yes	–
Stationary use at non-weather protected restricted locations[1]	4K1	6	Choice of negligible splashing water, water jets or water waves	Yes	+5
Stationary use at non-weather protected moderate locations[1]	4K2	6	Choice of negligible splashing water, water jets or water waves	Yes	+5
Stationary use at non-weather protected general locations[1]	4K3	15	Choice of negligible splashing water, water jets or water waves	Yes	+5
Stationary use at non-weather protected worldwide locations[1]	4K4	15	Choice of negligible splashing water, water jets or water waves	Yes	+5
Stationary use at non-weather protected locations, low air temperature, low absolute humidity[1]	4K4H	15	Choice of negligible splashing water, water jets or water waves	Yes	+5
Stationary use at non-weather protected locations, high air temperature, low relative humidity, high absolute humidity[1]	4K4L	15	Choice of negligible splashing water, water jets or water waves	Yes	+5
Stationary use at non-weather protected locations in tropical damp climates (rainforests)	4K5	15	Choice of negligible splashing water, water jets or water waves	No	+5
Stationary use at non-weather protected locations in tropical dry climates (deserts)	4K6	15	Choice of negligible, splashing water, water jets or water waves	Yes	+5
Ground vehicle installations with products weather protected, ventilated and heated	5K1	No	No	–	–

Ground vehicle installations with products weather protected (or partially weather protected), heated (or unheated), unventilated	5K2	No	0.3	–	–
Ground vehicle installations, unventilated, subject to wet surfaces and solar radiation	5K3	6	1	–	–
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation	5K4	15	3	–	–
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation in low temperature climates	5K4H	15	3	–	–
Ground vehicle installations, unventilated, subject to sprays, jets and solar radiation in high temperature climates	5K4L	6	3	–	–
Ground vehicle installations in tropical damp climates (rainforests)	5K5	15	3	–	–
Ground vehicle installations in tropical dry climates (deserts)	5K6	15	3	–	–
Installations in totally weather protected, heated and ventilated ship environments not exposed to solar radiation	6K1	None	None	–	–
Installations in totally weather protected, heated and ventilated ship environments excluding cold climates	6K2	None	0.3	–	–
Installations in totally weather protected, heated and ventilated ship environments near to heat dissipating equipment	6K3	None	0.3	–	–
Installations in non-weather protected, unventilated heated ship environments, excluding cold climates	6K4	6	3	–	–
Installations in non-weather protected, unventilated, unheated ship environments including cold climates	6K5	15	10	–	–
Shipborne installations in tropical damp climates (rainforests)	6K6	15	10	–	–
Shipborne installations in tropical dry climates (deserts)	6K7	15	10	–	–

continued

Table 6.3 (*cont.*)

Installation location	IEC 721 class	Precipitation (mm/min)	Water from sources other than rain (m/s)	Formation of ice and frost None	Low rain temp. (°C)
Portable and non-stationary use at or direct transfer between temperature controlled, weather protected environments without humidity control	7K1	No	–	No	None
Portable and non-stationary use at or direct transfer between weather protected environments without humidity or temperature control	7K2	No	–	Yes	None
Portable and non-stationary use at or direct transfer between partially weather protected restricted environments[1]	7K3	6	–	Yes	+5
Portable and non stationary use at or direct transfer between partially weather protected moderate environments[1]	7K4	6	–	Yes	+5
Portable and non-stationary use at or direct transfer between partially weather protected worldwide environments[1]	7K5	15	–	Yes	+5
Portable and non-stationary use in tropical damp climates (rainforests)	7K6	15	–	Yes	+5
Portable and non-stationary use in tropical dry climates (deserts)	7K7	15	–	Yes	+5

Note
1 The choice of classification is dependent upon the type of climate in which the equipment will be installed.

6.4 Tests

This section details some of the test standards which may be applied to equipment and contains:

- a list of the most used environmental tests that a purchaser will normally require a manufacturer to adhere to;
- a list of other related standards and specifications;
- a brief description of the more common tests.

Note: Full details of each of these recommended tests are contained in the relevant ISO, IEC or other standard. A complete list of these standards is supplied in the reference section of this book. Copies of all these standards may be obtained from any National Standards Organisation.

6.4.1 Salt mist test (IEC 68.2.11 Test Ka)

Standard No.	IEC 68.2.11
Title	Environmental testing procedures – Test Ka: Salt mist
Summary	Compares the resistance to deterioration from salt mist of specimens of similar construction. It is useful for evaluating the quality and the uniformity of protective coatings.
Equiv. Std	Technically equivalent to AS 1099:PT2Ka Identical to BS 2011:PT2.1Ka(1982) Identical to DIN IEC 68 PT2-11 Identical to HD 323.2.11 Identical to NEN 10068-2-11 Identical to SEN 43 16 10

6.4.1.1 Introduction

Salt has an electrochemical effect on metallic materials (i.e. corrosion), which can damage and degrade the performance of equipment. Salt can also degrade the performance of parts manufactured using metallic and/ or non-metallic materials.

Non-metallic materials can be damaged by salt through a complex chemical reaction which is dependent on the supply of oxygenated salt solution to the surface of the test specimen, the temperature of the specimen and the temperature and humidity of the environment.

6.4.1.2 Purpose of this test

The purpose of this test is to:

- compare the resistance to deterioration from salt mist (prepared by dissolving sodium chloride (NaCl) in water) of specimens of similar construction;
- evaluate the quality and uniformity of protective coatings.

6.4.1.3 General

This test is not suitable as a general salt corrosion test or for the evaluation of individual specimens intended for use in salt laden atmospheres. For equipment and components, the tests detailed in IEC 68.2.52 are considered more appropriate as they provide more realistic conditions and enable a simpler form of testing for individual items.

6.4.1.4 Test conditions

IEC 68.2.11 provides details of tests aimed at comparing the resistance to deterioration from salt mist and for evaluating the quality and uniformity of protective coatings.

The salt used for the test shall be high quality sodium chloride with a pH value of solution between 6.5 and 7.2.

The equipment is placed, at a temperature of $35 \pm 2°C$, in a salt-mist chamber for 2 hours and is then placed in a moist chamber for the specified time. This procedure is then repeated for the specified number of times.

The relevant specification shall indicate the degree of strictness chosen from the range 16 h, 24 h, 2, 4, 14 or 28 days.

6.4.2 Water – falling drops, impacting water and immersion test (IEC 68.2.18 Test R)

Standard No.	IEC 68.2.18
Title	Environmental testing procedures – Test R and guidance: Water
Summary	Provides methods of tests applicable to electrotechnical products which, during transportation, storage or in service, may be subjected to falling drops, impacting water or immersion.
Equiv. Std	Identical to BS 2011:PT2.1R(1990) Identical to DIN IEC 68 PT2-18 Identical to NFC 20-718

6.4.2.1 Introduction

IEC 68.2.18 provides test methods applicable to electrotechnical products which, during transportation, storage or in service, may be subjected to falling drops of water, impacting water or immersion.

The structuring of test methods is shown in Figure 6.4 and is described briefly below.

The water tests described in IEC 68.2.18 are structured into three groups:

6.4.2.1.1 Falling drops (Test Ra)

Test Ra is a test with artificial rain. It is applicable to all electrotechnical products which during transportation, storage or in service may be

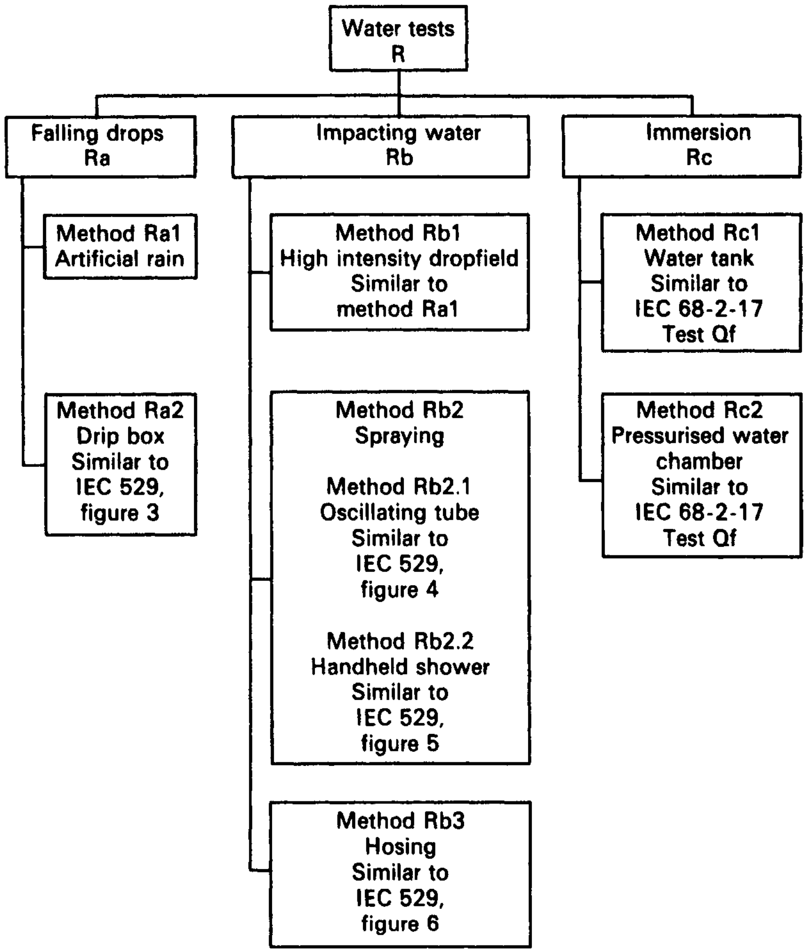


Fig. 6.4 Structuring of test methods (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

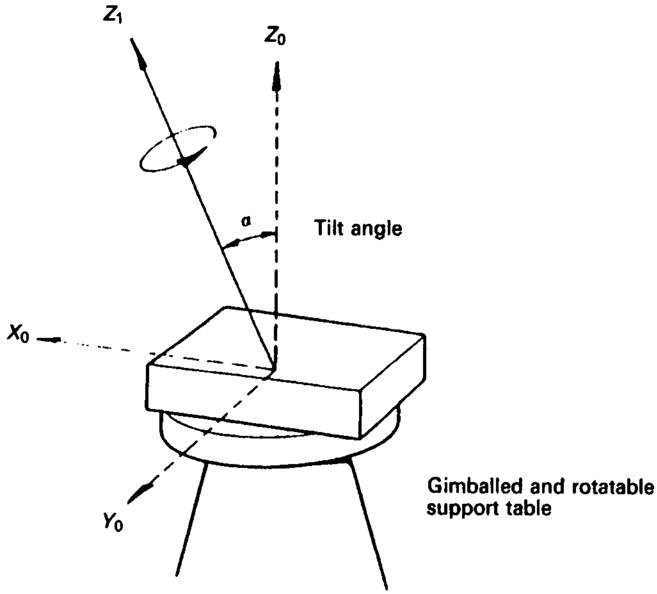
exposed to vertical falling drops either from rain, seepage or condensation.

This test is particularly relevant to electrotechnical products that may be placed outdoors and left unprotected from natural rain, or electrotechnical products which, although normally protected from falling rain, may be exposed to falling drops from condensation or leakage from upper surfaces.

Figure 6.5 is an example of the detail provided in Test 68.2.18.

6.4.2.1.2 Impacting water (Test Rb)

This test is aimed at considering the effects of water from cloud bursts,



Note: The support table shall be smaller than the specimen or be suitably perforated.

Fig. 6.5 Test Ra, definitions of angles and axes

heavy driving rain, sprinkler systems, spray from wheels, sluicing or breaking seas.

6.4.2.1.3 Immersion (Test Rc)

Test Rc is aimed at electrotechnical products which have been designed to be watertight and which, during transportation or in service, may be subjected to partial or complete submersion.

Test specimens are immersed in water to specified depths and/or equivalent pressures.

6.4.2.2 Purpose of these tests

The purpose of these tests is to verify the ability of covers and seals to maintain components and equipment in good working order under a standardised water dropfield or immersion.

6.4.2.3 General

The tests are intended to embrace all situations where water in liquid form is part of the micro-climate surrounding a product (e.g. rain, drizzle, hosing, immersion but excluding erosion resulting from high velocity water drops).

The range of water tests comprises some new methods based on a defined water intensity together with a number of well-established methods as given in IEC 529.

6.4.2.4 Test conditions

6.4.2.4.1 Test Ra: Falling drops

This test is applicable to electrotechnical products which, during transportation, storage or in service may be exposed to vertical falling drops, the origin of these being natural rain, seepage or condensation.

Whether an electrotechnical product tested separately has to function during conditioning or merely to survive conditions shall be clearly stated in the relevant specification.

There are two separate types of test within Test Ra:

6.4.2.4.1.1 Test Ra1: Artificial rain

Where the specimen is subjected to falling water drops simulating natural rain.

Table 6.4 Test Ra1: Artificial rain – test severity (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severities			
Intensity R (mm/h)	Associated dropsize D_{50} (mm)	Duration (min)	Spray or tilt angle ($\alpha°$)
10 ± 5	1.9 ± 0.2	10	0
100 ± 20	2.9 ± 0.3	30	30
400 ± 50	3.8 ± 0.4	60	60
		120	90

6.4.2.4.1.2 Test Ra2: Drip box

Where the specimen is mounted on a fixture which is placed under a drip box. The test specimen is then subjected to water drops which simulate falling water from condensation or leakage.

Table 6.5 Test Ra2: Drip box – test severity (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severities		
Drop falling height (m)	Tilt angle ($\alpha°$)	Duration (min)
0.2 ± 0.1	0	3
2.0 ± 0.5	15	10
	30	30
	45	60

6.4.2.4.2 Test Rb: Impacting water

This test is applicable to all electrotechnical products, which, during transportation, storage or in service, may be subjected to impacting water. The origin of this can be water from cloud bursts, heavy driving rain, sprinkler systems, spray from wheels, sluicing or breaking seas.

Whether an electrotechnical product tested separately has to function during conditioning or merely to survive conditions shall be clearly stated in the relevant specification.

There are a number of tests with Test Rb as follows:

6.4.2.4.2.1 Test Rb1: High intensity dropfield

The test specimen is mounted on an appropriate fixture and then subjected to a high intensity drop field.

Table 6.6 Test Rb1: High intensity dropfield – test severity (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severities		
Intensity R (mm/h)	Duration (min)	Tilt angle ($\alpha°$)
1000 ± 150	10	0
2000 ± 300	30	30
4000 ± 600	60	60
		90

6.4.2.4.2.2 Test Rb2: Oscillating tube and hand-held showerhead

This test is to simulate spray or splashing water, results of water action, or sprinkler systems.

The test specimen is mounted on an appropriate fixture and then subjected to impacting water generated from a semicircular oscillating tube or, if the specimen is too large, a hand-held showerhead is used.

Oscillating tube variant

The severity of the test depends upon the spray nozzle angle, water flow rate, tube oscillating angle and the duration. The values shall be selected from the following tables. There are two variants as shown in Tables 6.4 and 6.5.

Table 6.7 Test Rb2: Oscillating tube, variant 1 – test severity (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severities		
Spray nozzle angle ($\alpha°$)	Tube oscillating angle ($\beta°$)	Duration (min)
60°	±60°	3
90°	±180°	10
		30
		60

Note

Alternatively the tube oscillating arrangement $\alpha = 60°$ and $\beta = 60°$ can be replaced by a fixed nozzle angle semicircular tube under which the test specimen is rotated.

Table 6.8 Test Rb2: Oscillating tube, variant 2 – test severity (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severities		
Nozzle orifice diameter (mm)	Water flow per nozzle (dm^3/min)	Approximate supply pressure (kPa)
0.40	0.10 ± 0.0005	80
0.80	0.60 ± 0.03	400

Hand-held shower variant

The severity of this test depends upon whether or not a shield is used, and the duration of the test.

Table 6.9 Test Rb2: Hand-held shower – test severity (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Exposure (min/m^2)	Minimum test duration (min)
1	5
3	15
6	30

6.4.2.4.2.3 Test Rb3: Hosing

The test specimen is subjected to hosed water which is aimed at simulating wheel spray, sluicing or breaking seas. The severity of the test depends upon the choice of test nozzle, size, sluicing distance and test duration as shown below.

Table 6.10 Test Rb: Hosing – test severity – flow rates and nozzles (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severities – flow rates and nozzles		
Flow rate (dm^3/mm)	Approximate pressure supply (kPa)	Nozzle size (mm)
12.5 ± 1	30	6.3
75 ± 5	1000	6.3
100 ± 5	100	12.5

The distance from the nozzle to the specimen shall be 2.5 ± 0.05 m.

This distance may be reduced if necessary to ensure proper wetting when spraying upwards. At a distance of 2.5 m from the nozzle the substantial part of the water jet shall be within a circle of 40 mm for the 6.3 mm nozzle and 100 mm for the 12.5 mm nozzle.

Table 6.11 Test Rb3: Hosing – test severity – duration (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severity – test duration		
Exposure	Minimum test duration	Note
0.3	1	Only for 6.3 nozzle and 1000 kPa
1	3	
3	10	
10	30	

6.4.2.4.3 Test Rc: Immersion

This test is applicable to electrotechnical products which are designed to be watertight and which, during transportation or while in service, may be subjected to partial or complete immersion. Whether an electrotechnical product tested separately has to function during conditioning or merely to survive conditions shall be clearly stated in the relevant specification.

There are two tests associated with Test Rc, as follows:

6.4.2.4.3.1 Test Rc1: Water tank

The test specimen is subjected to a specified pressure by immersion in a water tank at a specified depth.

Table 6.12 Test Rc1: Water tank – test severity (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severities	
Head of water (m)	Duration (h)
0.15	0.5
0.40	2.0
1.0	24.0
2.0	
5.0	

6.4.2.4.3.2 Test Rc2: Pressurised water chamber

The test specimen is subjected to a specified pressure by immersion in a pressurised water chamber.

Table 6.13 Test Rc2: Pressurised water chamber – test severity (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Severities		
Overpressure (kPa)	Equivalent head of water (m)	Duration (h)
20	2	2
50	5	24
100	10	168
200	20	
500	50	
1 000	100	
2 000	200	
5 000	500	
10 000	1000	

Table 6.15 Typical characteristics of water with approximate values (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Dielectric constant	Pure water	80 at 25°C
Resistivity	Very pure water	200 000 Ω m
	Deionised water	500–5000 Ω m
	Mains supply	2.5 Ω m
Surface tension at 20°C		73×10^{-5} N/cm
Surface tension at 20°C	With 0.1 g/dm^3 wetting agent	43×10^{-5} N/cm
Surface tension at 20°C	With 0.5 g/dm^3 wetting agent	30×10^{-5} N/cm

Note

Normally fresh tap-water is used. If, however, a test is to be made in seawater this shall be noted in the relevant specification together with the characteristics of the seawater.

Table 6.14 Summary of test characteristics (reproduced from the equivalent standard to BS 2011:PT2.1R(1990) by kind permission of the BSI)

Procedure	Severities				Notes
	Intensity (mm/h)	Overpressure (kPa)	Duration (min)	Spray or tilt angle ($\alpha°$)	
Test Ra					
Method Ra1	10 ± 5	N/A	10	0	Artificial rain
	100 ± 20		30	15	
	400 ± 50		60	30	
			120	60	
				90	
Method Ra2	200–300	N/A	3	0	Drip box per appendix C
			10	15	
			30	30	
			60	45	
Test Rb					Intensity of falling water drops
Method Rb1	1000 ± 150	N/A	10	0	Not to be considered as artificial rain
	2000 ± 300		30	15	
	4000 ± 600		60	30	
				60	
				90	
Method Rb2.1	$n(0.07 \pm 0.005)$	c.50	3	60	Oscillating tube per appendix D
	$n(0.10 \pm 0.005)$	c.80	10	90	60° and c.180° oscillation
	$n(0.60 \pm 0.03)$ (dm^3/min)	c.400	30		*n* is number of nozzles
			60		
Method Rb2.2	10 ± 5 (dm^3/min)	c.90	5	60	Shower per appendix D.
			15	c. 180	
			30		

continued

Table 6.14 (*cont*)

Method Rb3	12.5 ± 1 75 ± 5 100 ± 5 (dm^3/min)	c.30 c.1000 c.100	1 3 10 30	c.180	Nozzle per Appendix D 6.3 mm or 12.5 mm diameter
	Head of water (m)	Overpressure (kPa)	Duration	Tilt angle (α°)	
Test Rc					
Method Rc1	0.15–0.40–1.0–2.0–5.0	N/A	30 min 2 h 24 h	N/A	Water tank
Method Rc2	2–5–10–20–50–100–200– 500–1000	20–50–100-200– 500–1000–2000– 5000–10 000	2 h 24 h 168 h	N/A	Pressurised water chamber

6.4.3 Salt mist (cyclic) test (IEC 68.2.52 Test Kb)

Standard No.	IEC 68.2.52
Title	Environmental testing procedures – Test Kb: Salt mist, cyclic (sodium chloride solution)
Summary	Deals with a test for determining the suitability of equipment or components for exposure or use in a salt laden atmosphere. The procedure of a test is split into a specified number of periods of spraying by a salt mist at a temperature of 15°C and 35°C, each followed by a storage under humid conditions at 40°C, 93% relative humidity. Under conditions of non-heat dissipation, the test is conducted on specimens.
Equiv. Std	Identical to BS EN 60068 PT2-52 Similar to DIN 40046(PT58) Identical to DIN EN 60068 PT2-52 Identical to EN 60068 PT2-52 Identical to HD 323.2.52 Identical to NEN 10068-2-52 Identical to NF EN 60068-2-52

6.4.3.1 Introduction

Salt has an electrochemical effect on metallic materials (i.e. corrosion), which can damage and degrade the performance of equipment. Salt can also degrade the performance of parts manufactured using metallic and/or non-metallic materials.

Non-metallic materials can also be damaged by salt through a complex chemical reaction (dependent on the supply of oxygenated salt solution to the surface of the test specimen), the temperature of the specimen and the temperature and humidity of the environment.

6.4.3.2 Purpose of this test

The purpose of this test is to:

- determine the suitability of a component or equipment for use or exposure in a salt laden atmosphere;
- test components or equipment designed to withstand a salt laden atmosphere;
- indicate deterioration of some non-metallic materials by assimilation of salts (apart from corrosive effects).

6.4.3.3 General

Test specimens are not energised during the spraying method and not normally during the storage period.

This test is accelerated compared with most service conditions.

6.4.3.4 Test conditions

IEC 68.2.52 provides details of the salt mist (cyclic) test aimed at evaluating the suitability of components and/or equipment being used in (or exposed to) a salt laden atmosphere.

The test procedure consists of spraying the components/equipment with a 5% sodium chloride (NaCl) salt mist solution for a specified time which is then followed by storage at a humid temperature of 40°C with 93% relative humidity.

The severity of the test is defined by the combination of the number of spraying periods and the duration of the storage under humid conditions following each spray.

Chapter 7

Pollutants and contaminants

7.1 Guidance

7.1.1 What are pollutants and contaminants?

Over the last 20 years environmental matters have become an area of widespread public concern particularly those concerning the issues of pollution and contaminants. Pollutants and contaminants come in many forms and can have an effect on the air, land or water courses and as pollutants move from one medium to another they may be deposited on equipment and equipment housing. They can cause extensive damage.

Pollution of the air can occur in both the troposphere and stratosphere. In the troposphere pollutants from chimneys (for example) are carried by the air and can be deposited over time and distance, thus having a limited life span before they are washed out or deposited on the ground, as shown in Figure 7.1. If pollutants are injected straight into the stratosphere (as with a volcanic eruption) they will remain there for some time and result in noticeable effects over the whole region.

The roughness of the ground produces turbulence in the air promoting the mixing of pollutants. In general, low wind speeds result in high pollutant concentrations.

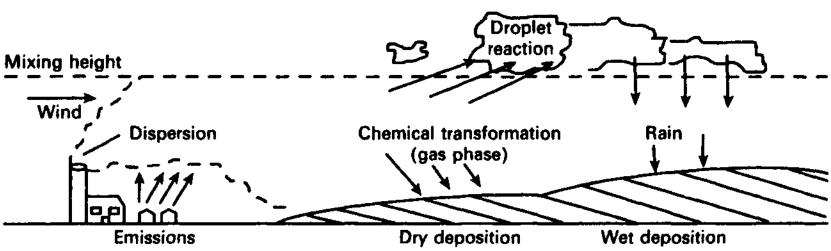


Fig. 7.1 Process involved between the emission of air pollutants and their being deposited on the ground

Chemical pollution is the introduction of substances into the environment (by man) that are liable to harm human health, living resources and ecological systems, damage structures or generally interfere with the legitimate use of the environment.

Sources of natural pollutants include:

- sulphur – emitted by volcanoes and from biological processes;
- nitrogen – from biological processes in the soil, lightning and biomass burning;
- hydrocarbons – methane from the fermentation of rice paddies, or from fermentation of the digestive tract of ruminants (e.g. cows). Hydrocarbons are also released by insects, coal mining and gas extraction.

Sources of man-made pollutants include:

- carbon dioxide and carbon monoxide produced during the burning of fossil fuels;
- soot formation accompanied by carbon monoxide, which is generally due to inadequate or poor air supply;
- hydrocarbons. Most boilers and central heating units burning fossil fuels result in very low emissions of gaseous hydrocarbons or oxygenated hydrocarbons such as aldehydes.

7.1.2 Introduction

Satisfactory performance during the desired lifetime of equipment depends on many parameters: some are determined by their design, others by the environment in which they have to function. Whilst the design of the equipment can be moderated and/or controlled, special attention has to be paid to polluting and contaminating substances within the atmosphere.

7.1.2.1 Pollutants

Although pollutant gases are normally only present in low concentrations, they can cause significant corrosion and a marked deterioration in performance of contacts and connectors. The gases in operating environments which cause corrosion are oxygen, water vapour and the so-called pollutant gases which include sulphur dioxide, hydrogen sulphide, nitrogen oxides and chlorine compounds.

Silver and some of its alloys are particularly susceptible to tarnishing by the minute quantities of hydrogen sulphide that occur in many environments. The tarnished product is dark in colour and consists largely of b-silver sulphide. Separable electrical connections employing these materials may, therefore, suffer from increased resistance and contact noise as a result.

The amount of tarnishing (of a metal) is dependent upon the amount of humidity present. Less corrosion occurs below 70% relative humidity (RH) but above 80% RH the rate of tarnishing increases rapidly. Temperature also has an effect on the amount of tarnishing as the nature of the corrosion mechanism has a tendency to change at temperatures above 30°C.

7.1.2.1.1 Hydrogen sulphide

Hydrogen sulphide is caused by the bacterial reduction of sulphates in vegetation, soil, stagnant water and animal waste on a worldwide basis. In the atmosphere, hydrogen sulphide is oxidised to sulphur dioxide which, in turn, is brought to the ground by rain. In an aerobic soil, bacteria turns the sulphur dioxide to sulphates. Sulphate reducing bacteria complete the cycle and turn the sulphates to hydrogen sulphide which is the principal natural sulphur input in the atmosphere and is, therefore, a widespread pollutant of air.

7.1.2.1.2 Sulphur dioxide

Sulphur dioxide is the pollutant gas most commonly found in the atmosphere and is usually present in high concentrations in urban and industrial locations. In combination with other pollutants and moisture (e.g. humidity) sulphur dioxide is responsible for the formation of high resistance, visible corrosion layers on all but the most noble metals (e.g. silver and gold) and alloys.

Note: Sulphur dioxide has little effect on silver unless both the concentration of the gas and humidity are high.

Whilst sulphur dioxide also occurs in volcanic emissions, it originates from both natural and man-made sources. Worldwide, natural sources predominate, but in urban and industrial areas the man-made sources prevail. The principal man-made source of sulphur dioxide is the combustion of fossil fuels which also releases other gases such as sulphur trioxide, nitrogen oxides and chlorine compounds. These other combustion products, although usually only present in low concentrations, will corrode most metals and alloys.

In urban areas, burning fossil fuels emits sulphur dioxide into the atmosphere where, unless it is rinsed with rain, it will accumulate. The content can be 10 times to 1000 times that of hydrogen sulphide and will become the dominant cause of corrosion. It should be noted, however, that in equal concentrations, hydrogen sulphide is far more corrosive than sulphur dioxide particularly on silver and copper.

Although the major input of the sulphur cycle is by hydrogen sulphide through natural processes, industrial processes also play a significant part – particularly oil refineries, chemical plants and gas works.

Table 7.1 lists representative concentrations of sulphur dioxide at a range of locations. These levels are sufficient to account for the natural tarnishing of silver. Other sulphurous pollutants are less important.

Table 7.1 Representative concentrations of sulphur dioxide at a range of locations (extracted from a paper (Ref. 1) by kind permission of Herne Consultancy Group)

Location	Average mg/m^3	Peak mg/m^3
Rural area (near sea)	0.1–0.3	
Quiet residential area	0.2–0.4	
Trunk road in a congested area	0.3–0.8	
Congested city centre	0.5–1.4	
Heavy industry	1–60	
London (summer)	0.1–0.5	
London (winter)	0.5–1	
London (fog December 1962)	5–10	
New York (offices)	9	33
New Jersey (chemical plant)	25	28
New Jersey (oil refinery)	194	102
Rotorura (New Zealand)	4–180	1600
Kitajimu Shikoku Island	100	5500
Netherlands (four sites)	85	724

Some organic sulphur derivatives do tarnish silver, as does elemental sulphur vapour, but these materials probably occur only in small amounts in the atmosphere. The two most common organic sulphurous pollutants are methyl mercaptan and carbon disulphide but these do not tarnish silver.

Although sulphur dioxide alone is less corrosive than other gases (such as sulphur trioxide, nitrogen oxides and chlorine compounds), the most extensive corrosion occurs when combustion products are present *together with* sulphur dioxide.

7.1.2.1.3 Nitrogen oxides

The production of nitrogen oxides is particularly significant because the rate of corrosion by sulphur dioxide is greatly accelerated in the presence of nitrogen dioxide. However, the corrosion products of both nitrogen oxide and sulphur dioxide have similar compositions.

7.1.2.2 Contaminants

Contaminants are composed of dust, sand, smoke and other particles that are contained within the air.

Dust, sand and smoke can have an effect on products in various ways, especially:

- ingress of dust into enclosures and encapsulations;
- deterioration of electrical characteristics (e.g. faulty contact, change of contact resistance);
- seizure or disturbance in motion bearings, axles, shafts and other moving parts;
- surface abrasion (erosion and corrosion);

- reduction in thermal conductivity;
- clogging of ventilating openings, bushes, pipes, filters and apertures that are necessary for operation, etc.

The presence of dust and sand in combination with other environmental factors such as water vapour can also cause corrosion and promote mould growth. Damp heat atmospheres cause corrosion in connection with chemically aggressive dust, and similar effects are caused by salt mist. The effects of ion conducting and corrosive dusts (e.g. de-icing salts) also need to be considered.

7.1.2.2.1 Dust and sand

The concentration of dust and sand in the atmosphere varies widely with geographical locality, local climatic conditions and the type and degree of activity taking place. The amount of dust and sand found in the air is dependent on terrain, wind, temperature, humidity and precipitation. Under certain conditions enormous amounts of dust and sand may be temporarily released and this suspended dust will drift away with the wind (see Table 7.2) depending on the concentration and the size of the particles.

Particles larger than 150 μm are generally confined to the air layer within the first metre above ground. Within this layer about half of the sand grains move within the first 10 mm above the surface and the remainder within the first 100 mm.

The dust and sand appearing in enclosed and sheltered locations is generated by several sources (e.g. quartz, de-icing salts, fertilisers, etc.) and penetrates into locations via ventilating ducts or badly fitting windows. The dust may also come from cloth or carpets in normal use in the working environment.

7.1.2.2.1.1 Dust

The dust found in and around electrotechnical products may be generated by several different sources. The dust may be quartz, coal, de-icing salts, fertilisers, small fibres from cotton or wool (real or artificial) that has been generated from cloth or carpets by normal use in living rooms and offices.

Table 7.2 Concentration of dust and sand (extracted with permission from a paper (Ref. 1) by Herne Consultancy Group)

Region	Dust and sand concentration μg/m^3
Rural and suburban	40–110
Urban	100–450
Industrial	500–2000

Actions and effects of dust
Penetration of dust into a piece of equipment can be:

- carried in by forced air circulation, for example for cooling purposes;
- carried in by the thermal motion of the air;
- pumped in by variations in the atmospheric pressure caused by temperature changes;
- blown in by wind.

Primary effects
The dust itself can have one or more of the following harmful effects:

- siezure of moving parts;
- abrasion of moving parts;
- adding mass to moving parts thereby causing unbalance;
- deterioration of electric insulation;
- deterioration of dielectric properties;
- clogging of air filters;
- reduction of thermal conductivity;
- interference with optical characteristics.

Secondary and combined effects

- corrosion and mould growth;
- overheating and fire hazard.

Dust may be defined as 'particulate matter of unspecified origin, composition and size ranging from 1 µm to 150 µm originating from quartz, flour, organic fibres, etc.'. Particles of less than 75 µm, because of their low terminal velocity, can remain suspended in the atmosphere for very long periods through the natural turbulence of the air. In sheltered and enclosed locations, the maximum grain size tends to be smaller (e.g. less than 100 µm) than non-weather protected locations due to the filtering effect of the shelter.

Dust and sand can act either as a physical agent, chemical component, or both, in causing the deterioration of materials or functions of equipment. Dust can also act as an unwanted abrasive on moving components of machinery which may accelerate corrosive action as well as affecting electrical property.

Whilst dust and sand can accelerate the corrosion of metallic surfaces by removing protective coatings or by disturbing semi-protective films of corrosion products, the degree of surface abrasion will depend on the velocity of the particles hitting the surface.

Note: A marked deterioration in the optical quality of aircraft windscreens has been reported after test flights at heights of 60 m and speeds of between 290 m/s and 320 m/s over the North African deserts.

Sand and the majority of dusts which are deposited on insulated surfaces are poor conductors in the absence of moisture. The presence of moisture, however, will result in the dissolving of the soluble particles and the formation of conducting electrolytes. For example, the leakage currents flowing over contaminated power line insulators can be of the order of one million times greater than those which flow through clean, dry insulators.

Dust adhering to the surface of materials may contain organic substances that provide a source of food for micro-organisms.

A reduction in heat transfer rates can be caused by the formation of insulating layers and can lower the efficiency of cooling systems.

7.1.2.2.1.2 Sand

Sand is the term applied to 'segregated unconsolidated accumulation of detrital sediment, consisting mainly of tiny broken chips of crystalline quartz or other mineral, between 100 µm and 1000 µm in size'. Particles greater than 150 µm are unable to remain airborne unless continually subjected to strong winds, induced air flows or turbulence. Sand is generally harder than most fused silica glass compositions and can, consequently, scratch the surface of most glass optical devices. Pressure applied over trapped grains of sand can cause fractures to occur in equipment.

The electrostatic charges produced by friction of the particles in sand storms can interfere with the operation of equipment and sometimes be dangerous to personnel. The breakdown of insulators, transformers and lightning arresters, and the failure of car ignition systems has been known to occur as a result of such charges. The electrostatic voltages produced can be large. Voltages as high as 150 kV have made telephone and telegraph communications inoperable during sand storms.

Quartz, because of its hardness, can result in rapid wear or damage to products, particularly moving parts. However, erosion of material requires that the presence of dust and sand is combined with a high velocity air stream over an extensive period of time.

7.1.2.2.1.3 Smoke or fumes

Smoke or fumes are dispersive systems in the air consisting of particles below 1 µm. As the particles are so small they do not usually affect equipment, provided that the equipment is properly designed.

7.1.2.3 Fauna and flora

With a few exceptions, fauna (rodents, insects, termites, birds, etc.) and flora (plants, trees, seeds, fruit, blossom, mould, bacteria and fungi, etc.) may be present at all locations where equipment is stored, transported or used. Whilst fauna may be the cause of damage inside buildings as well as open-air locations, damage by flora will predominantly occur in open-air conditions. Moulds and bacteria can, however, be present both inside buildings and in open-air conditions.

The concentration of this flora and fauna depends on temperature and humidity. In warm, damp climates, fauna and flora, especially insects and micro-organisms such as mould and bacteria, will find favourable conditions for life. Humid or wet rooms in buildings, or rooms in which processes produce humidity, are suitable living spaces for rodents, insects and micro-organisms. The range of temperature in which moulds may grow is from 0°C to 40°C, and the most favourable temperatures for many cultures is between 20°C and 30°C.

If surfaces of the products carry layers of organic substances (e.g. grease, oil, dust), or deposits of animal or vegetable origin, such surfaces are ideal locations for the growth of moulds and bacteria.

7.1.2.3.1 Effects of flora and fauna

Fauna and flora can affect equipment (during storage, transportation and/or use) in various ways, the most important being deterioration by mechanical forces and deterioration by deposits.

7.1.2.3.1.1 Deterioration by mechanical forces

The functioning of equipment and materials can be affected by physical attacks of fauna. Small animals and insects that feed from, gnaw at, eat into and chew at materials are particular problems as are termites cutting holes into material.

Materials such as wood, paper, leather, textiles, plastics (including elastomers) and even some metals such as tin and lead are all susceptible to attack.

Larger animals can also cause damage by stroke, impact or thrust. These attacks can cause:

- physical breakdown of material, parts, units, devices;
- mechanical deformation or compression;
- surface deterioration;
- electrical failure caused by mechanical deterioration.

7.1.2.3.2 Deterioration by deposits

Deposits from fauna (especially insects, rodents, birds, etc.) can be caused by the presence of the animal itself, nest building, deposited feed stocks and metabolic products such as excrement and enzymes, etc.

Deposits from flora may consist of detached parts of plants (leaves, blossom, seeds, fruits, etc.) and the growth layers of cultures of moulds or bacteria. These attacks can lead to:

- deterioration of material;
- metallic corrosion;
- mechanical failure of moving parts;
- electrical failure due to:
  - increased conductivity of insulators;
  - failure of insulation;

  - increased contact resistance;
  - electrolytic and ageing effects in the presence of humidity or chemical substances;
  - moisture absorption and adsorption;
- decreased heat dissipation.

These in turn can cause an interruption of electrical circuits, malfunctioning of mechanical parts and clouding of optical surfaces (including glass).

7.1.2.4 Mould

Mould can cause unforeseen deterioration of assembled specimens, whether constructed from mould resistant materials or not.

Fungi grows in soil and in, or on, many types of common material. It propagates by producing spores which become detached from the main growth and later germinate to produce further growth.

The spores are very small and easily carried by the wind (or moving air). They also adhere to dust particles carried in the air.

Contamination can also occur due to handling. Spores may be deposited by the hands or in the film of moisture left by the hands.

7.1.2.4.1 Germination and growth

Moisture is essential in allowing the spores to germinate and when a layer of dust or other hydrophilic material (i.e. moisture retaining) is present on the surface, sufficient moisture may be abstracted by it from the atmosphere.

In addition to high humidity, spores require (on the surface of the specimen) a layer of material that will absorb the moisture. Mould growth is also encouraged by stagnant air spaces and lack of ventilation.

When the relative humidity is below 65%, no germination or growth will occur. The higher the relative humidity above this value, the more rapid the growth will be. Spores can survive long periods of very low humidity and even though the main growth may have died, they will germinate and start a new growth as soon as the relative humidity becomes favourable again (i.e. in excess of 65%). The optimum temperature of germination for the majority of moulds is between 20°C and 30°C

7.1.2.4.2 Effects of mould growth

7.1.2.4.2.1 Primary effects

Moulds can live on most organic materials, but some of these materials are much more susceptible to attack than others. Mould growth normally occurs only on surfaces exposed to the air, and those which absorb or adsorb moisture will generally be more prone to attack.

Even where only a slightly harmful attack on a material occurs, the formation of an electrically conducting path across the surface due to a layer of wet mycelium (i.e. the vegetative part of fungus) can drastically lower the insulation resistance between electrical conductors supported by an insulation material. When the wet mycelium grows in a position where it is within the electromagnetic field of a critically adjusted electronic circuit, it can cause a serious variation in the frequency/impedance characteristics of the circuit.

Among the materials very susceptible to attack are leather, wood, textiles, cellulose, silk and other natural materials. Most plastic materials are less susceptible, but are also attacked. Plastic materials may contain non-polymerised monomers, oligomers and/or additives which may exude to the surface and be a nutrient for fungi. A copious growth may occur on the surface where these secondary materials are exposed. Some plastic materials depend, for a satisfactory life span, on the presence of a plasticiser which, if it is readily digested by fungi, will eventually give rise to failure of the main material.

Mould attack on materials usually results in a decrease of mechanical strength and/or changes in other physical properties.

7.1.2.4.2.2 Secondary effects

The growing mould on the surface of a material can yield acid products and other electrolytes which will cause a secondary attack on the material. This attack can lead to electrolytic or ageing effects, and even glass can lose its transparency due to this process. Oxidation or decomposition may be facilitated by the presence of catalysts secreted by the mould.

7.1.2.4.3 Prevention of mould growth

All insulating materials used should be chosen to give as great a resistance to mould growth as possible, thus maximising the time taken for mycelium to grow and minimising any damage to the material consequent upon such growth.

The use of lubricants during assembly (e.g. varnishes, finishes, etc.) is frequently necessary in order to obtain the required performance or durability of a product. Such materials should be chosen with regard to their ability to resist mould growth, for even though it can be shown that the lubricants do not support mould growth, they may collect dust which in turn will support mould growth.

Moisture traps which might possibly be formed during the assembly of equipment and in which mould can grow should be avoided. Examples of such less obvious traps are between unsealed mating plugs and sockets, or between printed circuit cards and edge connectors in particular attitudes. Other preventives of mould growth include:

- complete sealing of the equipment in (and with) a dry, clean atmosphere;
- continuous heating within an enclosure can ensure a sufficiently low humidity;

- operation of equipment within a suitable controlled environment;
- regularly replaced desiccants (e.g. silica beads);
- periodic and careful cleaning of enclosed equipment.

Where the material and functioning of the equipment allows such treatment, ultraviolet radiation or ozone may be used for sterilisation. Air currents of adequate velocity flowing over the parts can retard the development of mould growth and acaricides (i.e. mites and ticks) can be used to control the action of mites.

7.1.3 Test standards

All proposed equipment, components or other articles should be tested in their production configuration without the use of any additional external devices that have been added expressly for the purpose of passing these tests.

When tested, the sample (components, equipment or other article) shall perform as stipulated in the procuring specification and over the designated temperature range.

The following are the most common tests used for checking the effect of pollutants and contaminants:

IEC 68.2.10	Basic environmental testing procedures – Test J and guidance – Mould growth
IEC 68.2.42	Basic environmental testing procedures – Test Kc: Sulphur dioxide test for contacts and connections
IEC 68.2.43	Basic environmental testing procedures – Test Kd: Hydrogen sulphide test for contacts and connections
IEC 68.2.45	Basic environmental testing procedures – Test Xa and guidance – Immersion in cleaning solvents
IEC 68.2.68	Basic environmental testing procedures – Dust and sand
ISO 9225	Corrosion of metals and alloys – Corrosivity of atmospheres – Measurement of pollution

7.1.4 Other related standards and specifications

IEC 34.5	Rotating electrical machines – Classification of degrees of protection provided by enclosures for rotating machines
IEC 68.2.11	Basic environmental testing procedures – Test Ka: Salt mist
IEC 68.2.17	Basic environmental testing procedures – Test Q: Sealing
IEC 68.2.18	Environmental testing – Test R and guidance: Water
IEC 68.2.3	Basic environmental testing procedures – Test Ca: Damp heat, steady state
IEC 68.2.52	Basic environmental testing procedures – Test Kb: Salt mist, cyclic (sodium chloride solution)

IEC 144	Degrees of protection of enclosures for low voltage switchgear and controlgear
IEC 529	Classification of degrees of protection provided by enclosures
IEC 721.1	Classification of environmental conditions – Environmental parameters and their severities
IEC 721.2.3	Classification of environmental conditions – Environmental conditions appearing in nature – Air pressure
IEC 721.2.5	Classification of environmental conditions – Environmental conditions appearing in nature – Dust, sand, salt mist
IEC 721.2.7	Classification of environmental conditions – Environmental conditions appearing in nature – Fauna and flora
IEC 721.3.4	Classification of environmental conditions – Classification of groups of environmental parameters and their severities – Stationary use at non-weather protected locations
ISO 14001	Environmental management systems – Specification with guidance for use

7.2 Typical examples of contract requirements – pollutants and contaminants

The requirement for equipment to conform to various environmental specifications is becoming commonplace in today's contracts. More and more specifications are being used to describe the various conditions that equipment is likely to experience when being used, stored or whilst in transit.

The following are the most common environmental requirements found in modern contracts concerning pollutants and contaminants.

7.2.1 Pollutants

- Although the severity of pollution will depend upon the location of the equipment, the effects of pollution have to be considered in the design of equipment and components.
- Facilities need to be provided to reduce pollution by the effective use of protective devices. In most cases the protection against water and solid objects is normally specified using the protection degree as defined in IEC 529.
- In all cases the requirements of ISO 14001 regarding environmental protection and the prevention of pollution have to be met.

7.2.2 Contaminants

Regarding contaminants, most contracts will require consideration of the following:

- chemically active substances as specified in IEC 721.3.1 to IEC 721.3.7 inclusive to include:
  (a) other chemical substances
  (b) hydrogen sulphide
  (c) weedkiller
  (d) organic elements, etc.
  (e) salinity
- biologically active substances as specified in IEC 721.3.1 to IEC 721.3.7 inclusive;
- flora and fauna as defined in IEC 721.2.7;
- dust as defined in IEC 721.2.5;
- sand if specified for the application with ranges and values taken from IEC 721.3.1 to IEC 731.3.7 inclusive.

7.2.3 Mould

- In an assembled state, equipment needs to operate when exposed to airborne mould spores and within climates that will be conducive to the growth of moulds.
- Insulating materials have to be chosen to provide as much resistance to mould growth as possible and all materials used shall be chosen with regard to their ability to resist mould growth.

7.2.4 Tests

7.2.4.1 Test methods

Test methods for determining the suitability of a specimen shall include:

IEC 68.2.10	Environmental testing procedures – Test J and guidance: Mould growth
IEC 68.2.42	Environmental testing procedures – Test Kc: Sulphur dioxide test for contacts and connections
IEC 68.2.43	Environmental testing procedures – Test Kd: Hydrogen sulphide test for contacts and connections
IEC 68.2.45	Environmental testing procedures – Test Xa and guidance: Immersion in cleaning solvents
IEC 68.2.68	Environmental testing procedures – Dust and sand
ISO 9225	Corrosion of metals and alloys – Corrosivity of atmospheres – Measurement of pollution

7.3 Values and ranges

Table 7.3 Storage – flora and fauna

Installation location	Class	Flora	Fauna
Unit		None	None
Locations without particular risk of biological attack	1 B1	Negligible	Negligible
Locations where mould growth, where attacks by animals (less termites), may occur	1 B2	Presence of mould and fungus, etc.	Presence of rodents and other animals (less termites) harmful to products
Locations where attacks by termites may occur	1 B3	Presence of mould and fungus, etc.	Presence of rodents and other animals (including termites) harmful to products

Table 7.4 Storage – mechanically active substances

Installation location	Class	Sand mg/m^3	Dust (suspension) mg/m^3	Dust (sedimentation) mg/(m^2–h)
Precautions taken to minimise presence of dust and ingress of sand prevented	1S1	None	0.01	0.40
Locations without special precautions to minimise presence or effects of dust and sand, but not situated near a dust or sand source	1S2	30	0.20	1.50
Locations without special precautions to minimise the presence or effects of dust and sand, but in close proximity to dust and sand sources	1S3	300	5.00	20.00
Locations without special precautions to minimise presence or effect of dust and sand, but in areas with high proportion of wind driven dust and sand or locations producing dust and sand	1S4	1000	15.00	40.00

Table 7.5 Storage – Chemically active substances

Installation location	Class	Sea and road salts	Sulphur dioxide		Hydrogen sulphide		Chlorine		Hydrogen chloride	
		None	mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3
Rural and some suburban areas with low industrial activity and moderate traffic	1C1	No	0.1000	0.370	0.0100	0.0071	0.1000	0.0340	0.1000	0.0660
Locations with a continuously controlled atmosphere	1C1L	No	0.1000	0.0370	0.0100	0.0071	0.0100	0.0034	0.0100	0.0066
Urban areas with industrial activity scattered over the whole area or with heavy traffic	1C2	Salt mist	mean 0.3000	0.1100	mean 0.1000	0.0710	mean 0.1000	0.0340	mean 0.1000	0.0660
			max. 1.0000	0.3700	max. 0.5000	0.3600	max. 0.3000	0.1000	max. 0.5000	0.3300
Locations in the immediate neighbourhood of industrial sources with chemical emissions	1C3	Salt mist	mean 5.000	1.8500	mean 3.0000	2.1000	mean 0.3000	0.1000	mean 1.0000	0.6600
			max. 10.0000	3.7000	max. 10.0000	7.1000	max. 1.0000	0.3400	max. 5.0000	3.3000

continued

Table 7.5 (*cont.*)

Installation location	Class	Hydrogen fluoride		Ammonia		Ozone		Nitrogen oxide	
		mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3
Rural and some suburban areas with low industrial activity and moderate traffic	1C1	0.0030	0.0036	0.3000	0.4200	0.010	0.0050	0.1000	0.0520
Locations with a continuously controlled atmosphere	1C1L	0.0030	0.0036	0.3000	0.4200	0.0100	0.0050	0.1000	0.0520
Urban areas with industrial activity scattered over the whole area or with heavy traffic	1C2	mean 0.0100	0.0120	mean 1.0000	1.4000	mean 0.0500	0.0250	mean 0.5000	0.2600
		max. 0.0300	0.0360	max. 3.0000	4.2000	max. 0.1000	0.0500	max. 1.0000	0.5200
Locations in the immediate neighbourhood of industrial sources with chemical emissions	1C3	mean 0.1000	0.1200	mean 10.0000	14.0000	mean 0.1000	0.0500	mean 3.0000	1.5600
		max. 2.000	2.4000	max. 35.0000	49.0000	max. 0.3000	0.1500	max. 9.0000	4.6800

Table 7.6 Transportation – flora and fauna

Installation location	Class	Flora None	Fauna None
Transportation via means with very little likelihood of biological attack	2B1	No	No
Transportation where mould growth and attacks by animals (less termites) are likely	2B2	Presence of mould and fungus	Presence of rodents and other animals (excluding termites)
Transportation where attacks by termites are likely	2B4	Presence of mould and fungus	Presence of rodents and other animals including termites

Table 7.7 Transportation – mechanically active substances

Installation location	Class	Sand in air mg/m^2	Dust sediments mg/(m^2-h)
Enclosed and protected from sand and dust	2S1	No	No
Enclosed (or unenclosed) transportation where sweeping of dusty floors can take place	2S2	0.1	3.0
Outdoor transportation in sand desert areas	2S3	10.0	3.0

Table 7.8 Transportation – chemically active substances

Installation location	Class	Sea and road salts	Sulphur dioxide		Hydrogen sulphide		Chlorine		Hydrogen chloride	
		None	mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³
Enclosed (protected from salt mist) in areas with moderate industrial activity and traffic	2C1	No	0.1000	0.0370	0.0100	0.0071	N/A		0.1000	0.0660
Open, unprotected (except on open decks of ships) in areas with normal industrial activity, but excluding areas emitting large quantities of chemical pollutants	2C2	Conditions of salt mist	mean 0.3000 max. 1.0000	 0.1100 0.3700	mean 0.1000 max. 0.5000	 0.0710 0.3600	N/A		mean 0.1000 max. 0.5000	 0.0660 0.3300
All types of unprotected, open transportation in areas with a very high level of chemical pollutants	2C3	Conditions of salt mist	mean 5.0000 max. 10.0000	 1.8500 3.7000	mean 3.0000 max. 10.0000	 2.1000 7.1000	N/A		mean 1.0000 max. 5.0000	 0.6600 3.3000

Installation location	Class	Hydrogen fluoride		Ammonia		Ozone		Nitrogen oxides	
		mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³
Enclosed (protected from salt mist) in areas with moderate industrial activity and traffic	2C1	0.0030	0.0036	0.3000	0.4200	0.010	0.0050	0.1000	0.0520
Open, unprotected (excepted on open decks of ships) in areas with normal industrial activity, but excluding areas emitting large quantities of chemical pollutants	2C2	mean 0.0100 max. 0.0300	 0.0120 0.0360	mean 1.0000 max. 3.0000	 1.4000 4.2000	mean 0.0500 max. 0.1000	 0.0250 0.0500	mean 0.5000 max. 1.0000	 0.2600 0.5200
All types of unprotected, open transportation in areas with a very high level of chemical pollutants	2C3	mean 0.1000 max. 2.0000	 0.1200 2.4000	mean 10.0000 max. 35.0000	 14.0000 49.0000	mean 0.1000 max. 0.3000	 0.0500 0.1500	mean 3.0000 max. 10.0000	 1.5600 5.2000

Table 7.9 Operational – flora and fauna

Installation location Unit	Class	Flora None	Fauna None
Stationary use at weather protected locations where attacks from flora and fauna are unlikely	3B1	No	No
Stationary use at weather protected locations where flora and fauna attacks may occur, except termites	3B2	Presence of mould and fungus, etc.	Presence of rodents and other animals harmful to products, excluding termites
Stationary use at weather protected locations where flora and fauna attacks may occur, including termites	3B3	Presence of mould and fungus, etc.	Presence of rodents and other animals harmful to products, including termites
Stationary use at non-weather protected locations where attacks from flora and fauna may occur, except termites	4B1	Presence of mould and fungus, etc.	Presence of rodents and other animals harmful to products, excluding termites
Stationary use at non-weather protected locations where attacks from flora and fauna may occur, including termites	4B2	Presence of mould and fungus, etc.	Presence of rodents and other animals harmful to products, including termites
Ground vehicle installations where attacks from flora and fauna are unlikely	5B1	No	No
Ground vehicle installations where attacks from flora and fauna may occur, except termites	5B2	Presence of mould and fungus, etc.	Presence of rodents or other animals harmful to products, excluding termites
Ground vehicle installations where attacks from flora and fauna may occur, including termites	5B3	Presence of mould and fungus, etc.	Presence of rodents or other animals harmful to products, including termites
Shipborne environment where attacks from flora and fauna are unlikely	6B1	No	No
Shipborne equipment where attacks from flora and fauna may occur	6B2	Presence of mould and fungus, etc.	Presence of rodents or other animals harmful to products
Portable and non-stationary use, where particular attacks from flora and fauna are unlikely	7B1	No	No
Portable and non-stationary use where attacks from flora and fauna may occur	7B2	Presence of mould and fungus, etc.	Presence of rodents or other animals harmful to products, excluding termites
Portable and non-stationary use where attacks from flora and fauna may occur, including termites	7B3	Presence of mould and fungus, etc.	Presence of rodents or other animals harmful to products, including termites

Table 7.10 Operational – mechanically active substances

Location installation	Class	Sand mg/m^3	Dust (sedimentation) $mg/(m^2-h)$	Dust (suspension) mg/m^3
Stationary use at weather protected locations, protected from sand and dust	3S1	None	0.40	0.01
Stationary use at weather protected locations without special precautions to minimise the presence of sand and dust	3S2	30.00	1.50	0.20
Stationary use at weather protected locations in close proximity to sand and dust sources	3S3	300.00	15.00	0.40
Stationary use at weather protected locations in close proximity to sand or dust sources, in geographical areas with high wind	3S4	3000.00	40.00	4.00
Stationary use at non-weather protected locations in rural areas not expected to be close to sand sources	4S1	30.00	15.00	0.50
Stationary use at non-weather protected locations in urban areas with dust and sand sources	4S2	300.00	20.00	5.00
Stationary use at non-weather protected locations close to processes producing high dust and sand	4S3	1000.00	40.00	15.00
Stationary use at non-weather protected locations permanently exposed to high concentrations of dust and sand	4S4	4000.00	80.00	20.00
Internally mounted components not protected from dust but mainly protected from sand	5S1	No	1.00	N/A
Internally and externally mounted products not protected from sand and dust	5S2	100.00	3.00	N/A
Internally and externally mounted components not protected from dust and sand, including desert areas	5S3	10 000.00	3.00	N/A
Shipborne environment installations protected from sand, dust and soot	6S1	None	None	None
Shipborne environment installations, weather and non-weather protected, subject to dust and soot	6S2	100.00	3.00	Presence of soot

continued

Table 7.10 (*cont.*)

Location installation	Class	Sand mg/m^3	Dust (sedimentation) mg/(m^2–h)	Dust (suspension) mg/m^3
Shipborne environment non-weather protected installations subject to sand	6S3	10 000.00	3.00	Presence of soot
Portable equipment directly transferred between locations without any precautions	7S1	30.00	1.50	0.20
Portable equipment directly transferred between locations close to sand and dust sources	7S2	300.00	20.00	5.00
Portable equipment directly transferred between locations in geographical areas with high sand and dust sources	7S3	10 000.00	80.00	20.00

Table 7.11 Operational – chemically active substances

Installation location	Class	Sea salts	Sulphur dioxide		Hydrogen sulphide		Chlorine		Hydrogen chloride	
		None	mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³
Stationary use in weather protected locations in areas with low industrial activity and moderate traffic	3C1	No	0.1000	0.0370			0.1000	0.0340	0.1000	0.0660
Stationary use at weather protected locations with a stringently monitored and controlled atmosphere	3C1R	No	0.0100	0.0037	0.0015	0.0010	0.0010	0.00034	0.0010	0.00066
Stationary use at weather protected locations with a continuously controlled atmosphere	3C1L	No	0.1000	0.0370	0.0100	0.0071	0.0010	0.00034	0.0100	0.0066
Stationary use in weather protected urban locations with scattered industrial activity or heavy traffic	3C2	Salt mist	mean 0.3000 max. 1.0000	 0.1100 0.3700	mean 0.1000 max. 0.5000	 0.0710 0.3600	mean 0.1000 max. 0.3000	 0.0340 0.1000	mean 0.1000 max. 0.5000	 0.0660 0.3300
Stationary use in weather protected locations in the immediate vicinity of industrial sources with chemical emissions	3C3	Salt mist	mean 5.0000 max. 10.0000	 1.8500 3.7000	mean 3.0000 max. 10.0000	 2.1000 7.1000	mean 0.3000 max. 1.0000	 0.1000 0.3400	mean 1.0000 max. 5.0000	 0.6600 3.3000
Stationary use in weather protected locations in the immediate vicinity of industrial sources with high chemical emissions	3C4	Salt mist	mean 13.0000 max. 40.0000	 4.8000 14.8000	mean 14.0000 max. 70.0000	 9.9000 49.7000	mean 0.6000 max. 3.0000	 0.2000 1.0000	mean 0.6600 max. 5.0000	 3.3000
Stationary use at non-weather protected locations with low industrial activity and moderate traffic, except coastal areas	4C1	No	0.1000	0.0370	0.01000	0.0071	0.1000	0.0340	0.1000	0.0660

continued

Table 7.11 (*cont.*)

Installation location	Class	Sea salts	Sulphur dioxide		Hydrogen sulphide		Chlorine		Hydrogen chloride	
		None	mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³
Stationary use at non-weather protected locations in urban areas with scattered industrial activity or heavy traffic, including coastal traffic	4C2	Conditions of salt mist	mean 0.3000 max. 1.0000	 0.1100 0.3700	mean 0.1000 max. 0.5000	 0.0710 0.3600	mean 0.1000 max. 0.3000	 0.0340 0.1000	mean 0.0660 max. 0.5000	 0.3300
Stationary use at non-weather protected locations in the immediate vicinity of industrial sources of chemical emissions	4C3	Conditions of salt mist	mean 5.0000 max. 10.0000	 1.8500 3.7000	mean 3.0000 max. 10.0000	 2.1000 7.1000	mean 0.3000 max. 1.0000	 0.1000 0.3400	mean 1.0000 max. 5.0000	 0.6600 3.3000
Locations in the immediate vicinity of industrial sources with high chemical emissions (also applies to portable and non-stationary equipment)	4C4	Conditions of salt mist	mean 13.0000 max. 40.0000	 4.8000 14.8000	mean 14.0000 max. 70.000	 9.9000 49.7000	mean 0.6000 max. 3.0000	 0.2000 1.0000	mean 1.0000 max. 5.0000	 0.6600 3.3000
Ground vehicle installations used indoors or with closed compartments	5C1	No (also applies to road salts)	0.1000		0.01000		N/A		0.1000	
Ground vehicle installations subject to ingress of road salts and/or splashing	5C2	Conditions of salt mist Road salts – conditions of solid salt and salt water	mean 0.3000 max. 1.0000		mean 0.1000 max. 0.5000		N/A		0.1000	0.5000
Ground vehicle installations used in areas with industrial sources emitting high quantities of chemical pollution	5C3	Conditions of salt mist Road salts – conditions of solid salt and salt water	mean 5.0000 max. 10.0000		mean 3.0000 max. 10.0000		N/A		1.0000	5.0000
Shipborne environment, totally weather protected, not subjected to salt mist or engine exhausts	6C1	No	0.1000	0.0370	0.0100	0.0071	N/A		0.1000	0.0660

continued

Table 7.11 (*cont.*)

Shipborne environment, totally weather protected, subject to salt mist or engine exhausts	6C2	Yes	1.0000	0.3700	0.5000	0.3600	N/A		0.1000	0.0660
Shipborne environment, non-weather protected, subject to salt mist, engine exhausts and air pollutant emissions	6C3	Yes	1.0000	0.3700	0.5000	0.3600	N/A		0.5000	0.3300
Portable and non-stationary use at and transfer between locations with stringently monitored and controlled atmospheres	7C1R	Negligible	0.0100	0.0037	0.0015	0.0010	0.0010	0.00034	0.0010	0.00066
Portable and non-stationary use at and transfer between locations with a continuously controlled atmosphere	7C1L	Negligible	0.1000	0.0370	0.0100	0.0071	0.0100	0.0034	0.0100	0.0066
Portable and non-stationary use at and transfer between locations with low industrial activity and moderate traffic	7C1	Negligible	0.1000	0.0370	0.0100	0.0071	0.0100	0.0340	0.1000	0.0660
Portable and non-stationary use at and	7C2	Salt mist	mean		mean		mean		mean	
transfer between locations in urban			0.3000	0.1100	0.1000	0.0710	0.1000	0.0340	0.0660	
areas with scattered industrial activity			max.		max.		max.		max.	
or heavy traffic, including coastal areas			1.0000	0.3700	0.5000	0.3600	0.3000	0.1000	0.5000	0.3300
Portable and non-stationary use at and	7C3	Salt mist	mean		mean		mean		mean	
transfer between locations in the			5.0	1.8500	3.0	2.1000	0.3000	0.1000	1.0000	0.6600
immediate vicinity of industrial			max.		max.		max.		max.	
sources of chemical emissions			10.0000	3.7000	10.0000	7.1000	1.0000	0.3400	5.0000	3.3000
Portable and non-stationary use at and	7C4	Salt mist	mean		mean		mean		mean	
transfer between locations in the			13.0	4.8000	14.0	9.9000	0.6000	0.2000	1.0000	0.6600
immediate vicinity of industrial			max.		max.		max.		max.	
plants with high chemical emissions			40.0000	14.8000	70.0000	49.7000	3.0000	1.0000	5.0000	3.3000

continued

Table 7.11 *(cont.)*

Installation location	Class	Hydrogen fluoride		Ammonia		Ozone		Nitrogen oxides	
		mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³	mg/m³	cm³/m³
Stationary use in weather protected locations in areas with low industrial activity and moderate traffic	3C1	0.0030	0.0036	0.3000	0.4200	0.0100	0.0050	0.1000	0.0520
Stationary use at weather protected locations with a stringently monitored and controlled atmosphere	3C1R	0.0010	0.0012	0.0300	0.0420	0.0040	0.0020	0.0100	0.0050
Stationary use at weather protected locations with a continuously controlled atmosphere	3C1L	0.0030	0.0036	0.3000	0.4200	0.0100	0.0050	0.1000	0.0520
Stationary use in weather protected locations with scattered industrial activity or heavy traffic	3C2	mean		mean		mean		mean	
		0.0100	0.0120	1.0000	0.4000	0.0500	0.0250	0.5000	0.2600
		max.		max.		max.		max.	
		0.0300	0.0360	3.0000	4.2000	0.1000	0.0500	1.0000	0.5200
Stationary use in weather protected locations in the immediate vicinity of industrial sources with high chemical emissions	3C3	mean		mean		mean		mean	
		0.1000	0.1200	10.0000	14.0000	0.1000	0.0500	3.0000	1.5600
		max.		max.		max.		max.	
		2.0000	2.4000	35.0000	49.0000	0.3000	0.1500	9.0000	4.6800
Stationary use in weather protected locations in the immediate vicinity of industrial sources with high chemical emissions	3C4	mean		mean		mean		mean	
		0.1200		35.0000	49.0000	0.1000		5.2000	
		max.		max.		max.		max.	
		2.0000	2.4000	175.0000	247.0000	2.0000	1.0000	20.0000	10.4000
Stationary use at non-weather protected locations with low industrial activity and moderate traffic, except coastal areas	4C1	0.0030	0.0036	0.3000	0.4200	0.010	0.0050	0.1000	0.0520
Stationary use at non-weather protected locations in urban areas with scattered industrial activity or heavy traffic, including coastal areas	4C2	mean		mean		mean		mean	
		0.0120		1.4000		0.0250		0.5000	0.2600
		max.		max.		max.		max.	
		0.0300	0.0360	3.0000	4.2000	0.1000	0.0500	1.0000	0.5200

continued

Table 7.11 (*cont.*)

Stationary use at non-weather protected	4C3	mean		mean				mean	
	mean								
locations in the immediate vicinity of		0.1000	0.0120	10.000	14.000	0.1000	0.0500	3.0000	1.5600
industrial sources of chemical emissions		max.		max.		max.		max.	
		2.0000	2.4000	35.0000	49.0000	0.3000	0.1500	9.0000	4.6800
Locations in the immediate vicinity of	4C4	mean		mean		mean		mean	
industrial sources with high chemical		0.1000	0.1200	35.000	49.0000	0.2000	0.1000	10.000	5.2000
emissions (also applies to portable and non-		max.		max.		max.		max.	
stationary equipment)		2.0000	2.4000	175.0000	247.0000	2.0000	1.0000	20.0000	10.4000
Ground vehicle installations used indoors or with closed compartments	5C1	0.0030		0.3000		0.0100		0.1000	
Ground vehicle installations subject to ingress of road salts and/or splashing	5C2	0.0100	0.0300	1.0000	3.0000	0.0500	0.1000	0.5000	1.0000
Ground vehicle installations used in areas with industrial sources emitting high quantities of chemical pollution	5C3	0.1000	2.0000	10.000	35.0000	0.1000	0.3000	3.0000	10.000
Shipborne environment, totally weather protected, not subjected to salt mist or engine exhausts	6C1	0.0030	0.0036	0.3000	0.4200	0.0100	0.0050	0.1000	0.0520
Shipborne environment, totally weather protected subject to salt mist or engine exhausts	6C2	0.0030	0.0036	0.3000	0.4200	0.0100	0.0050	1.0000	0.5200
Shipborne environment, non-weather protected, subject to salt mist, engine exhausts and air pollutant emissions	6C3	0.0300	0.0360	3.0000	4.2000	0.1000	0.0500	1.0000	0.5200
Portable and non-stationary use at and transfer between locations with stringently monitored and controlled atmospheres	7C1R	0.0010	0.0012	0.0300	0.0420	0.0040	0.0020	0.0100	0.0050

continued

Table 7.11 (*cont.*)

Installation location	Class	Hydrogen fluoride		Ammonia		Ozone		Nitrogen oxides	
		mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3	mg/m^3	cm^3/m^3
Portable and non-stationary use at and transfer between locations with a continuously controlled atmosphere	7C1L	0.0030	0.0036	0.3000	0.4200	0.0100	0.0050	0.1000	0.0520
Portable and non-stationary use at and transfer between locations with low industrial activity and moderate traffic	7C1	0.0030	0.0036	0.3000	0.4200	0.0100	0.0050	0.1000	0.0520
Portable and non-stationary use at and transfer between locations in urban areas with scattered industrial activity or heavy traffic, including coastal areas	7C2	mean 0.0100 max. 0.0300	 0.0120 0.0360	mean 1.0000 max. 3.0000	 1.4000 4.2000	mean 0.0500 max. 0.1000	 0.0250 0.0500	mean 0.5000 max 1.0000	 0.2600 0.5200
Portable and non-stationary use at and transfer between locations in the immediate vicinity of industrial sources of chemical emissions	7C3	mean 0.1000 max. 2.0000	 0.1200 2.4000	mean 10.0000 max. 35.0000	 14.0000 49.0000	mean 0.1000 max. 0.3000	 0.0500 0.1500	mean 3.0000 max 9.0000	 1.5600 4.6800
Portable and non-stationary use at and transfer between locations in the immediate vicinity of industrial plants with high chemical emissions	7C4	mean 0.1200 max. 2.0000	 2.4000	mean 35.0000 max. 175.0000	 49.0000 247.0000	mean 0.1000 max. 2.0000	 1.0000	mean 10.0000 max. 20.0000	 5.2000 10.4000

7.4 Tests

This section details some of the test standards which may be applied to equipment and contains:

- a list of the most used environmental tests that a purchaser will normally require a manufacturer to adhere to;
- a list of other related standards and specifications;
- a brief description of the mandatory tests.

Note: Full details of each of these recommended (sometimes mandatory) tests are contained in the relevant ISO, IEC or other standard. A full list of these standards is supplied in the reference section of this book. Copies of all these standards may be obtained from any National Standards Organisation.

7.4.1 Mould growth (IEC 68.2.10 Test J)

Standard No.	IEC 68.2.10
Title	Environmental testing procedures – Test J: Mould growth
Equiv. Std	Technically equivalent to AS 1099:PT2.10 Identical to BS 2011:PT2.1J(1985) Identical to BS 2011:PT2.1J(1989) Identical to DIN IEC 68 PT2-10 Identical to HD 323.2.10 Identical to NEN 10068-2-10 Identical to NFC 20-710 Identical to UTEC 20-410 Identical to UTEC 20-410

7.4.1.1 Introduction

Surface contamination in the form of dust, splashes, condensed volatile nutrients or grease may be deposited on equipment. When that equipment is exposed (in use, storage or transportation) to the atmosphere, and without proper protective covering, mould growth will occur.

7.4.1.2 Purpose of this test

The purpose of this test is to investigate unforeseen causes of deterioration in assembled specimens, whether constructed from mould resistant materials or not.

7.4.1.3 General conditions

The following is a list of the cultures (or spores) most commonly found:

- *Aspergillus niger* – grows profusely on many materials and is resistant to copper salts;
- *Aspergillus terreus* – attacks plastic materials;

- *Aureobasidium pullulans* – attacks paints and lacquers;
- *Poecilomyces variotii* – attacks plastics and leather;
- *Penicillium funiculosum* – attacks many materials especially textiles;
- *Penicillium ochrochloron* – resistant to copper salts and attacks plastics and textiles;
- *Scopulariopsis brevicaulis* – attacks rubber;
- *Trichoderma viride* – attacks cellulose textiles and plastics.

Caution

It is the opinion of mycologists and pathologists that conducting a mould growth test can constitute a health hazard. Inhalation of mould spores and the possibility of them coming in contact with the skin (e.g. around the finger nails) is a potential hazard unless special precautions are taken. Details of these precautions are contained in Appendices attached to the IEC 68.2.10 standard.

7.4.1.4 Test conditions

IEC 68.2.10 describes a method for investigating unforeseen causes of deterioration in assembled specimens, whether constructed from mould resistant materials or not. It may be used to assess the extent to which mould will grow and/or the operational deterioration which may be expected from this source.

There are two basic types of test:

7.4.1.4.1 Variant 1

Variant 1 specifies direct inoculation of the specimen with the mould spores. The extent of mould growth is assessed after 28 days' incubation (or in some cases 84 days') and this is probably the most frequently used form of test.

7.4.1.4.2 Variant 2

Variant 2 specifies the pre-conditioning of the test specimen with nutrients which support mould growth. This variant is employed in order to assess the secondary effects of mould growth on materials but can also be used to assess the effectiveness of fungicide treatment on equipment. This test is not suitable for simulating the conditions of a very intensive surface contamination (e.g. due to large quantities of organic dust or dead insects).

Details of possible health hazards (when conducting these tests), safety precautions, decontamination procedures together with a flow chart depicting the various test stages are contained in Appendices to IEC 68.2.10.

7.4.1.5 Other standards

IEC 721.2.7	Classification of environmental conditions – Environmental conditions appearing in nature – Fauna and flora

7.4.2 General corrosion tests (IEC 68.2.42 and IEC 68.2.43 Tests Kc and Kd)

Standard No.	IEC 68.2.42
Title	Environmental testing procedures – Test Kc: Sulphur dioxide test for electrical contacts and connections
Summary	Test Kc provides accelerated means to assess the corrosive effects of atmospheres polluted with sulphur dioxide on contacts and connections.
Equiv. Std	Similar to BS 2011:PT2.1Kc(1991) Identical to DIN IEC 68 PT2-42 Identical to NEN 10068-2-42

Standard No.	IEC 68.2.43
Title	Environmental testing procedures – Kd: Hydrogen sulphide test for electrical contacts and connections
Summary	Test Kd is intended to provide accelerated means to assess the effects of the tarnishing of silver and silver alloys used for contacts and connections. It is particularly suitable for giving information on a comparative basis, but not as a general corrosion test, i.e. it may not predict the behaviour of contacts and connections in industrial atmospheres. The objects of the test are: (a) to determine the influence of atmospheres containing hydrogen sulphide on the contact properties of contacts made of silver or silver alloy, silver protected with another layer, other metals covered with silver or silver alloy; (b) to check wrapped or crimped connections made of the same materials as mentioned under (a) with regard to their tightness or effectiveness.
Equiv. Std	Technically equivalent to AS 1099:PT2Kd Identical to BS 2011:PT2.1Kd(1977) Identical to DIN IEC 68 PT2-43 Identical to NEN 10068-2-43

7.4.2.1 Introduction

These general corrosion tests are particularly suitable for providing information on a comparative basis for atmospheres polluted with sulphur dioxide and/or atmospheres containing hydrogen sulphide.

7.4.2.2 Purpose of these tests

7.4.2.2.1 IEC 68.2.42 (Kc)

The purpose of this test is to assess the corrosive effects of atmospheres containing sulphur dioxide on the contact properties of precious metal, or precious metal covered contacts, excluding contacts consisting of silver and some of its alloys.

7.4.2.2.2 IEC 68.2.43 (Kd)

The purpose of this test is to:

- provide a method for assessing the effects of atmospheres containing hydrogen sulphide on the contact properties of contacts made of silver, silver alloy, silver protected with another layer and other metals covered with silver or silver alloy;
- check wrapped or crimped connections made of the same materials as mentioned above with particular reference to their tightness or effectiveness.

7.4.2.3 General conditions

These tests are not suitable as general corrosion tests as they may not necessarily predict the behaviour of contacts and connections in industrial atmospheres. They are particularly suitable for providing information on a comparative basis and are intended to provide an accelerated means to assess the effects of tarnishing of silver and silver alloys used for contacts and crimped connections.

7.4.2.4 Test conditions

7.4.2.4.1 IEC 68.2.42 (Kc)

Test Kc (Sulphur dioxide test for contacts and connections) provides an accelerated means to assess the corrosive effects on contacts and connections of atmospheres polluted with combustion products. It is particularly suitable for giving information of a comparative basis but it is *not* suitable as a general purpose corrosion test. The standard provides the reader with detailed instructions on the composition of the atmosphere within the test chamber, schematic drawings of the apparatus required to generate the test conditioning atmosphere (see Figure 7.2) and a schematic flow diagram.

Temperature does not affect the rate or degree of corrosion occurring in the test to any marked degree. However, as temperature and relative humidity are intimately related and as the latter exerts a marked influence on the degree and nature of corrosion of the test, it is essential that the test temperature is closely controlled to enable the relative humidity to be held within the specified limits and produce the required test severity.

Relative humidity has a greater effect on the test severity than the difference in concentration of sulphur dioxide and temperature. The corrosion rate is relatively low at relative humidities below 70%. Corrosion is markedly accelerated, and the nature and properties of the corrosion products change considerably, at relative humidities above 85% (see Figure 7.2).

7.4.2.4.2 IEC 68.2.43 (Kd)

Test Kd (Hydrogen sulphide test for contacts and connections) provides details of tests aimed at assessing the effects of atmospheres containing

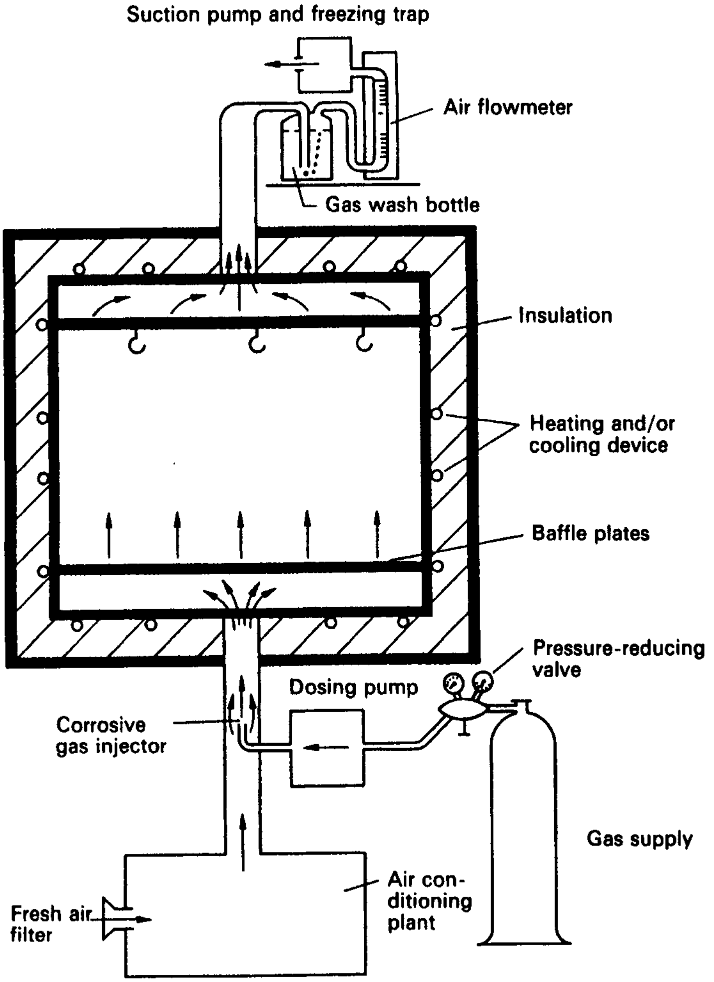


Fig. 7.2 Schematic drawing of apparatus for the generation of a conditioning atmosphere (reproduced from the equivalent standard BS 2011:PT2.1Kc (1991) by kind permission of the BSI)

hydrogen sulphide on the contact properties of contacts (and wrapped or crimped connections) made of silver, silver alloy, silver protected with another layer and other metals covered with silver or silver alloy. The major criteria of this test is to determine the change in contact resistance caused by exposure to the hydrogen sulphide containing atmosphere. The tests have been devised to assess the consequence of tarnishing silver and some of its alloys.

The tests have been validated by laboratory and field tests on silver, though limited tests have also been carried out on components with contacts made of some silver alloys. Gold contacts are largely unaffected by the test.

The standard provides the reader with detailed instructions on how to construct a test chamber and the composition of the atmosphere within the test chamber.

7.4.2.5 Other standards

IEC 144	Degrees of protection of enclosures for low voltage switchgear and controlgear
IEC 529	Classification of degrees of protection provided by enclosures

7.4.3 Immersion in cleaning solvents (IEC 68.2.45 Test Xa)

Standard No.	IEC 68.2.45
Title	Environmental testing procedures – Tests, Test Xa and guidance: Immersion in cleaning solvents
Summary	This test applies to electronic components and other parts mounted on printed circuit boards which may be subjected to cleaning operations. This publication gives information on the types of test solvents used and the test temperatures. It describes two different methods and contains a guide to the test.
Equiv. Std	Identical to BS EN 60068 PT2-45 Identical to DIN EN 60068 PT2-45 Identical to DIN IEC 68 PT2-45 Identical to EN 60068 PT2-45 Identical to HD 323.2.45 NEN 10068-2-45 Identical to NFC 20-745 Identical to NF EN 60068-2-45

7.4.3.1 Introduction

Many components or parts that are going to be mounted on printed circuit boards will be subjected to a solvent cleaning process. This process can affect the marking, encapsulation and coating of parts as well as influencing component characteristics.

7.4.3.2 Purpose of this test

The purpose of this test is to:

- simulate effects of cleaning operations and to verify the resistance of components or parts to solvents;
- determine the effects of cleaning solvents on electronic components and other parts (suitable for mounting on printed circuit boards) when subjected to immersion in these cleaning solvents.

7.4.3.3 General conditions

In many cases, total immersion of printed circuits in the cleaning solvent is required in order to remove fluxes and flux residue. In those cases, components on boards have to withstand a short-term immersion in the relevant cleaning solvent.

7.4.3.4 Test conditions

IEC 68.2.45 is a test procedure whereby specimens to be tested are immersed in a certain solvent at a specified temperature and for a specified time.

Generally speaking the cleaning solvent used depends upon the soldering flux chosen. The three most common solvents used are specified for the purpose of this test and consist of:

- demineralised or distilled water;
- 2-propanol (isopropyl alcohol);
- a mixture of trichlorotrifluorethane and 2-propanol (isopropyl alcohol).

Note: As trichlorotrifluorethane is a potential environmental hazard, it should only be used in exceptional circumstances.

7.4.3.5 Other standards

IEC 68.2.42	Environmental testing procedures – Test Kc: Sulphur dioxide test for electrical contacts and connections
IEC 68.2.43	Environmental testing procedures – Test Kd: Hydrogen sulphide test for electrical contacts and connections
ISO 9225	Corrosion of metals and alloys – Corrosivity of atmospheres – Measurement of pollution

7.4.4 Dust and sand (IEC 68.2.68 Test L)

Standard No.	IEC 68.2.68
Title	Environmental testing procedures – Dust and sand
Summary	Specifies test methods to determine the effects of dust and sand suspended in air, on electrotechnical products
Equiv. Std	Identical to BS EN 60068 PT2-68 Identical to DIN EN 60068 PT2-68 Identical to EN 60068 PT2-68

7.4.4.1 Introduction

This standard specifies test methods to determine the effects of dust and sand suspended in air, on electrotechnical products.

7.4.4.2 Purpose of this test

The test is structured into three groups:

- non-abrasive dust, primarily oriented towards investigation of the seals of the test specimen (Test La);

- free settling dust, oriented towards investigation of the effects which simulate conditions at sheltered locations (Test Lb);
- blown dust and sand, oriented towards investigation of the seals and the effect of erosion when simulating outdoor and vehicle conditions (Test Lc).

The purpose of this test is to determine the effect of:

- ingress of dust into enclosures;
- change of electrical characteristics (for example, faulty contact, change of contact resistance, change of track resistance);
- seizure or disturbance in motion of bearings, axles, shafts and other moving parts;
- surface abrasion (erosion);
- contamination of optical surfaces; contamination of lubricants;
- clogging of ventilating openings, bushings, pipes, filters, apertures necessary for operation, etc.

7.4.4.3 General conditions

For non-operational tests the specimen is introduced into the chamber in an unpacked, switched off, 'ready to use' state in its normal position unless otherwise specified.

When operational tests are required, the specimen has to be switched on or be electrically loaded.

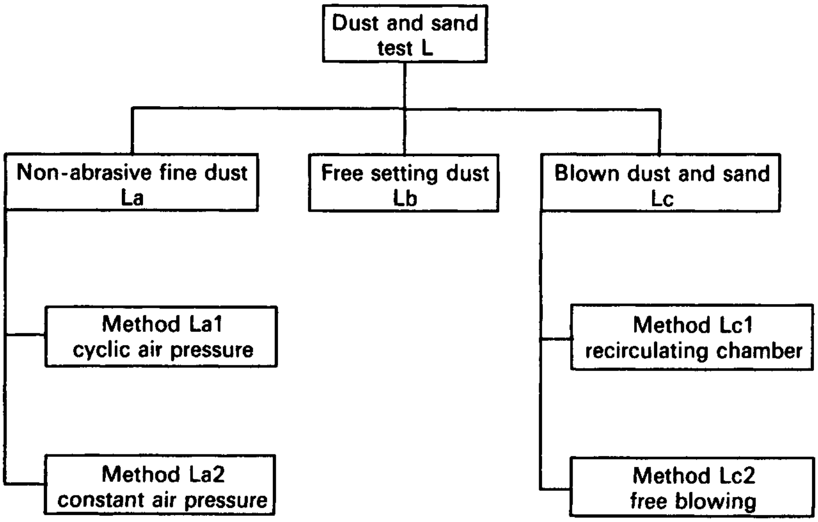


Fig. 7.3 Structuring of test methods (reproduced from the equivalent standard BS EN 60068.2.68 by kind permission of the BSI)

7.4.4.4 Test conditions

7.4.4.4.1 Test La: non-abrasive fine dust

The object of this test is to determine the degree of protection a piece of equipment has against the ingress of fine dust into electrotechnical products. Two methods are available:

- method La1 (cyclic air pressure) in which the specimen is exposed to dust laden air flow containing non-abrasive powder;
- method La2 (constant air pressure) in which the specimen is exposed to a heavily dust laden air flow containing non-abrasive powder.

7.4.4.5 Other standards

IEC 34.5	Rotating electrical machines – Classification of degrees of protection provided by enclosures for rotating machines
IEC 947.1	Low voltage switchgear and controlgear – General rules

7.4.5 Corrosivity of atmospheres (ISO 9225)

Standard No.	ISO 9225
Title	Corrosion of metals and alloys – Corrosivity of atmospheres – Measurement of pollution

7.4.5.1 Introduction

The ability of an atmosphere to cause corrosion of metals and alloys is controlled by the temperature-humidity complex and the amount of pollution.

When compiling a system specific specification it is useful to know the severity of the corrosive atmosphere into which it will be placed. This will assist in specifying suitable IEC 721 ranges.

This International Standard provides methods for the measurement of deposition rates of sulphur dioxide (SO_2) and airborne salinity.

7.4.5.2 Purpose of this test

The purpose of this test is to measure the deposition rates of sulphur dioxide and airborne salinity.

7.4.5.3 General conditions

The test uses three lead dioxide sulphation plates which are exposed to the prevailing atmosphere allowing them to react with airborne sulphur particles.

7.4.5.4 Test conditions

- Determination of sulphur dioxide deposition rate on lead dioxide sulphation plates. Atmospheric sulphur dioxide reacts with the lead dioxide to form lead sulphate. The plates are recovered and the sulphate analysis is performed on the contents to determine the extent of sulphur dioxide capture. The deposition rate of sulphur dioxide is expressed in milligrams per square metre day (mg/(m^2·d)). A 30 day $\pm$ 2 day exposure period is recommended.

- Determination of sulphur dioxide deposition rate on alkaline surfaces. Sulphur oxides and other sulphur compounds of an acid character are collected on the alkaline surface of porous filter plates saturated by a solution of sodium or potassium carbonate. The deposition rate of sulphur dioxide is expressed in milligrams per square metre day (mg/(m^2·d)). A 30 day $\pm$ 2 day exposure period is recommended.
- Determination of chloride deposition rate by the wet candle method. A rain protected wet textile surface, with a known area, is exposed to the atmosphere for a specified time. The amount of chloride deposited is determined by chemical analysis. For the results of this analysis the chloride deposition rate is calculated and expressed in milligrams per square metre day (mg/(m^2·d)).

7.4.5.5 Other standards

ISO 7539	Corrosion of metals and alloys – Stress corrosion testing – General guidance on testing procedures
ISO 9223	Corrosion of metals and alloys – Corrosivity of atmospheres – Classification
ISO 9224	Corrosion of metals and alloys – Corrosivity of atmospheres – Guiding values for the corrosivity categories
ISO 9226	Corrosion of metals and alloys – Corrosivity of atmospheres – Determination of corrosion rate of standard specimens for the evaluation of corrosivity
ISO 11845	Corrosion of metals and alloys – General principles for corrosion testing

Chapter 8

Mechanical

8.1 Guidance

8.1.1 What is mechanical?

Mechanics is the branch of physics concerned with the motions of objects and their response to forces. Modern descriptions of such behaviour begin with a careful definition of such quantities as displacement (distance moved), time, velocity, acceleration, mass and force.

8.1.2 Introduction

There is often a tendency to underestimate the effect that the mechanical environment can have on the reliability of equipment, especially the effects of vibration and shock.

8.1.2.1 Mechanical stresses (shocks and vibration)

Mechanical stresses are normally attributed to a moving mass and there is often a tendency to underestimate the effect of the mechanical environment on the reliability of static installations. Experience suggests, however, that vibrations and shocks are a significant Reliability, Availability and Maintainability (RAM) factor, not only from the point of view of vehicle mounted equipment, but also with respect to permanent installations.

If a 'white vibration' acts on a Printed Circuit Board (PCB), module or equipment, resonant oscillations will be induced in all components at their natural frequency. If, however, the spectrum has some more or less distinctive frequency bands, the elements will perform forced oscillations that will have the cyclic frequency of the interference and generally depend on both the characteristics of the oscillator (e.g. components) and on the interference.

8.1.2.2 Shocks

'Shock' may be generally defined as 'an impact shock characterised by a simple acceleration and free impact on a firm base'. The easiest way of defining 'shock' would be by referring to the maximum amplitude, form and duration of the phenomena.

Although the half sine pulse is normally used there are two other shock pulse shapes available:

- trapezoidal pulse – this produces a higher response over a wider frequency spectrum than the half-sine pulse and can be used when the purpose of the test is to reproduce the effects of shock environments such as the 'explosive bolt' phase of a space probe/satellite launch. It is not primarily intended for component type specimens;
- final-peak saw-tooth pulse – this has a more uniform response spectrum than the half-sine and trapesoidal pulse shapes and again is not aimed at component type specimens.

Stresses due to sudden variations (or movements) are conventionally presented as a shock response spectrum (Figure 8.1) produced from a half-sine pulse as shown in Figure 8.2.

8.1.2.3 Vibration

Components, equipment and other articles during transportation or in service may be subjected to conditions involving vibration of a harmonic pattern, generated primarily by rotating, pulsating or oscillating forces, such as occur in ships, aircraft, land vehicles, rotorcraft and space applications or are caused by machinery and seismic phenomena. Tests have been recommended for subjecting a specimen to sinusoidal vibration over a given frequency range or at discrete frequencies for a given period of time.

8.1.2.4 Acceleration

Equipment, components and electrotechnical products that are likely to be installed in moving bodies, e.g. flying vehicles and rotating machinery, will be subjected to forces caused by steady accelerations.

In general the accelerations encountered in service will have different values along each of the major axes of the moving body, and, in addition, usually have different values in the opposite senses of each axis.

8.1.2.5 Protection

As can be seen from Figure 8.1 the impact stresses produced in components are more or less damped natural oscillations (assuming pulse shaped impacts) and can, as a result of the returning accelerations, lead to fatigue fracture. Although these stresses mainly affect connecting wires (especially these which are bent to very sharp angles) other structural parts may be affected, provided that the stresses due to the initial impact have not already resulted in their destruction.

The resonant frequency of components is greatly influenced by the length of their connecting wires, and the actual length of the connecting

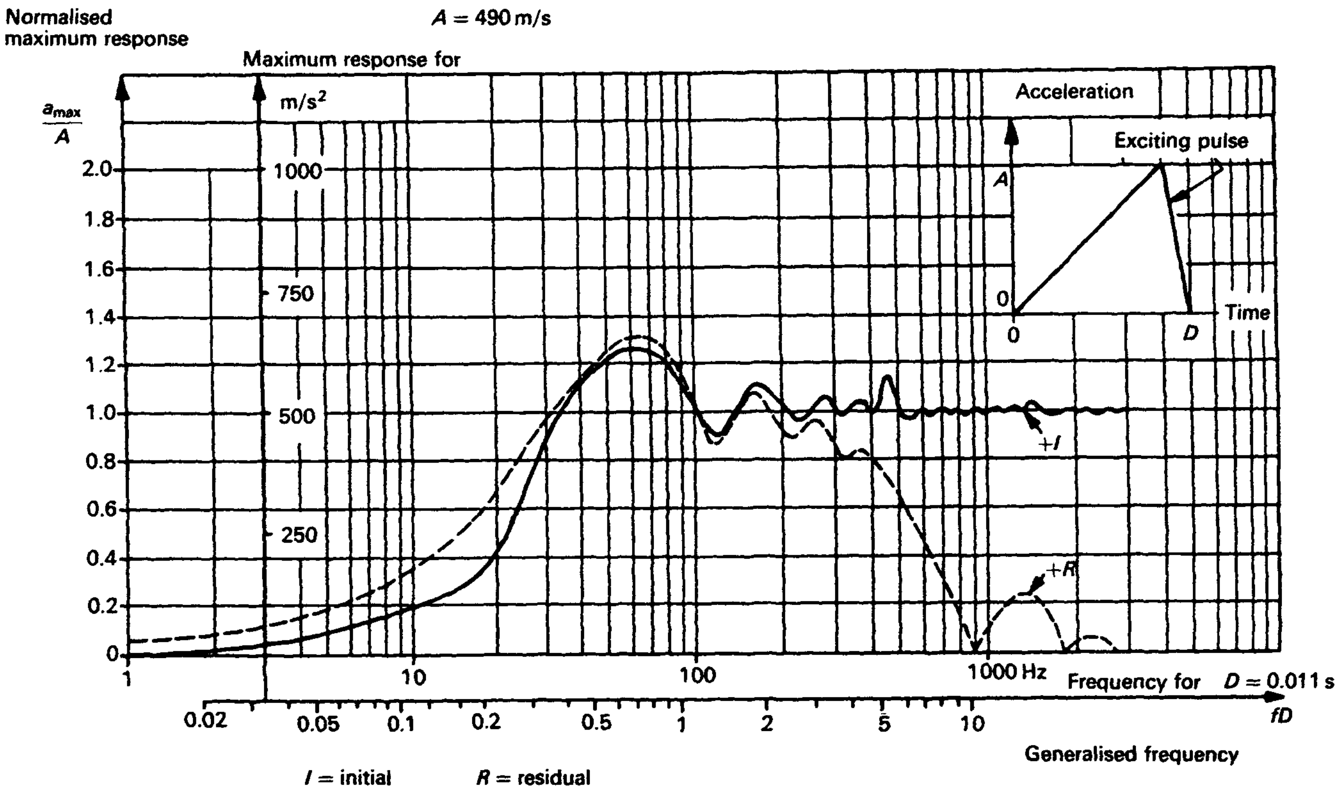
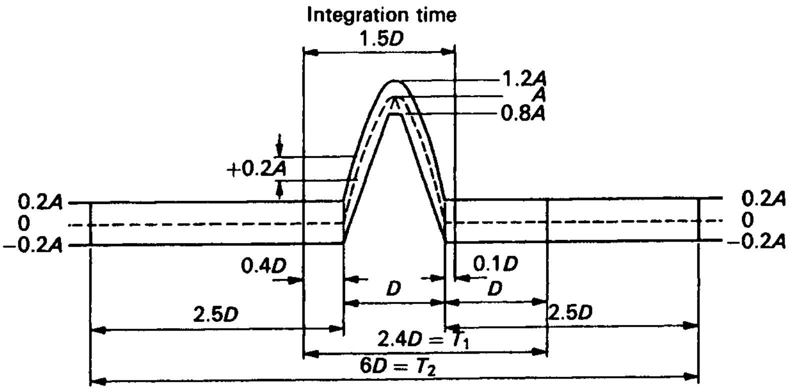


Fig. 8.1 Shock response spectrum



– – – nominal pulse
——— limits of tolerance
D = duration of nominal pulse
A = peak acceleration of nominal pulse
T_1 = minimum time during which the pulse shall be monitored for shocks produced using a conventional shock testing machine
T_2 = minimum time during which the pulse shall be monitored for shocks produced using a vibration generator

Fig. 8.2 Half-sine pulse (reproduced from BS 2011:Part 2.1Ea:1988 by kind permission of the BSI)

wires may well be the decisive factor as to whether a component fails or remains functioning under given vibration and impact conditions.

The amplitude of shocks on the equipment can be reduced by use of special mounting devices.

Shock absorption is based on storing the impact and releasing it at a retarded rate. The peak acceleration is reduced and the high frequencies damped, thus providing protection for the components with their relatively higher natural frequencies (of some hundred hertz).

Vibration dampers and shock absorbers are often used as a form of protection against mechanical stresses. The basic difference between vibration dampers and shock absorbers is that with the former the natural frequency lies below the interference frequency, whilst the latter is above.

Generally speaking vibration dampers provide no protection whatsoever against shocks and similarly shock absorbers offer no protection against vibrations. Only in exceptional cases can vibration dampers, for high frequencies, be used as shock absorbers.

Elastic suspension of equipment can cause a critical increase in amplitude at certain frequencies and, where translatory and rotary displacements greater than six degrees of freedom are possible, very complex motions may arise. Wherever possible, therefore, one should try to ensure that none of the (possible) resonant frequencies fall within the range of the induced displacements.

Sheathing circuits by means of cast resins can, in most cases, be a very effective means of counteracting mechanical stresses combined with temperature/humidity.

8.1.3 Test standards

All proposed candidate equipment, components or other articles will normally be expected to be tested in their production configuration without the use of any additional external devices that have been added expressly for the purpose of passing testing.

When tested, the sample (components, equipment or other article) shall be required to perform as stipulated in the procuring specification and over the designated temperature range.

The following are normally considered as mandatory mechanical tests for equipment.

IEC 68.2.27	Environmental testing procedures – Test Ea: Shock *Note:* IEC 68.2.27 is intended to reproduce the effects of non-repetitive shocks likely to be encountered by components and equipment in service and during transportation
IEC 68.2.29	Environmental testing procedures – Test Eb and guidance: Bump *Note:* IEC 68.2.29 is intended to reproduce the effects of repetitive shocks or jolts likely to be encountered by components and equipment during transportation or when installed in various classes of vehicles
IEC 68.2.31	Environmental testing procedures – Test Ec: Drop and topple (primarily for equipment type specimens) *Note:* IEC 68.2.31 is a simple test intended to assess the effects of knocks or jolts likely to be received (primarily) by equipment type specimens during repair work or rough handling on a table or bench
IEC 68.2.32	Environmental testing procedures – Test Ed: Freefall *Note:* IEC 68.2.32 Procedure 1 is a simple test intended to assess the effects of falls likely to be received during rough handling on a table or bench. It is also suitable for showing the degree of robustness IEC 68.2.32 Procedure 2 is intended to reproduce the effects of repetitive shocks likely to be received by certain component type specimens, for example connectors in service
IEC 68.2.35	Environmental testing procedures – Test Fda: Random vibration wide band – Reproducibility high
IEC 68.2.36	Environmental testing procedures – Test Fdb: Random vibration wide band – Reproducibility medium

IEC 68.2.37	Environmental testing procedures – Test Fdc: Random vibration wide band – Reproducibility low
IEC 68.2.50	Environmental testing procedures – Test Z/AFc: Combined cold/vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.2.51	Environmental testing procedures – Test Z/BFc: Combined dry heat/vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.2.53	Environmental testing procedures – Guidance to tests Z/AFc and Z/BFc: Combined temperature (cold and dry heat) and vibration (sinusoidal) tests
IEC 68.2.55	Environmental testing procedures – Test Ee and guidance: Bounce *Note:* IEC 68.2.55 is a simple test intended to reproduce the effects of the random shock conditions experienced by specimens which may be carried as loose cargo in vehicles travelling over rough surfaces
IEC 68.2.57	Environmental testing procedures – Test Ff: Vibration – Time history method
IEC 68.2.59	Environmental testing procedures – Test Fe: Vibration – Sine-beat method
IEC 68.2.6	Environmental testing procedures – Test Fc and guidance: Vibration (sinusoidal)
IEC 68.2.62	Environmental testing procedures – Test Ef: Impact, pendulum hammer
IEC 68.2.7	Environmental testing procedures – Test Ga and guidance: Acceleration, steady state

8.1.4 Other related standards and specifications

IEC 68.1	Environmental testing procedures – General and guidance
IEC 68.2.47	Environmental testing procedures – Mounting of components, equipment and other articles for dynamic tests including Shock (Ea), Bump (Eb), Vibration (Fc and Fd) and Steady state acceleration (Ga) and guidance
ISO 48	Rubber, vulcanised or thermoplastic – Determination of hardness

8.2 Typical contract requirements – mechanical

The requirement for equipment to conform to various environmental specifications is becoming commonplace in today's contracts. More and more specifications are being used to describe the various conditions that equipment is likely to experience when being used, stored or whilst in transit.

The following are the most common environmental requirements found in modern contracts concerning mechanical conditions.

8.2.1 Vibrations and shocks

Most contracts are very strict regarding the effects of vibrations and shocks and it should be noted that their effect can be reduced by the use of suitable dampers and equipment mountings. Any dampers or anti-vibration mountings should, however, be integral with the equipment to prevent the unit being accidentally installed without them.

8.2.1.1 Mechanical shock

Equipment should be capable of withstanding shock pulses of the shape and tolerance shown in Figure 8.3 and should be capable of withstanding a minimum of 20 000 shocks at a shock level of 20 g.

8.2.1.1.1 On or near the roadside

Equipment located on or near the roadside needs to be capable of withstanding vibrations and shocks as shown overleaf:

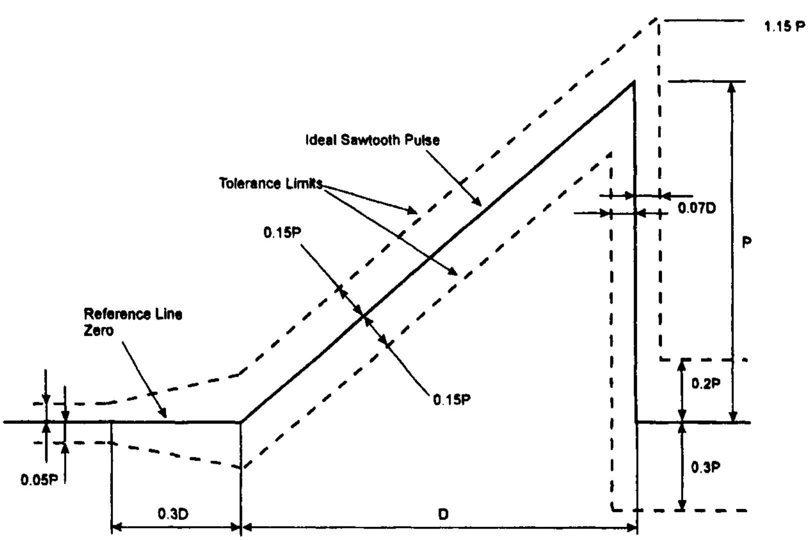


Fig. 8.3 Shock pulse configuration and its tolerance limits

Table 8.1 Minimum requirements (on or near the roadside)

	In a box, upon a post, in a sentry box, in a closet or in a technical area
Vibration	3–40 Hz/A^* = 0.2 mm 40–100 Hz/A^* = 0.03 mm
Shock	$\grave{a} = 2\,g$ $\mathring{a} = 2\,g$

* Where A^* = peak amplitude (elongation)
$\grave{a}$ = peak amplitude (elongation)
$\mathring{a}$ = peak acceleration value

As a minimum requirement equipment should be capable of withstanding shocks as shown below:

Table 8.2 Short-term exposure to shocks

Peak acceleration	$A = 100\,g$
Duration of shock	$D = 6$ ms
Form	Semi-sinusoidal
Permissible velocity	m/s

Note: Tests to determine equipment resistance to shocks are detailed in IEC 68.2.27.

Equipment should also be capable of withstanding long-term exposure to shocks as shown below:

Table 8.3 Long-term exposure to shocks

Peak acceleration	$A = 20\,g$
Number of shocks	Per direction specified
Duration of shock	$D = 6$ ms
Permissible velocity	m/s

Note: Tests to determine equipment resistance to long-term exposure to shock are detailed in IEC 68.2.29.

8.2.1.1.2 Encapsulated outdoor installations

Equipment contained in encapsulated outdoor installations should be capable of withstanding vibrations and shocks as shown below:

Table 8.4 Minimum requirements (encapsulated outdoor installations)

	Range
Vibration	3–40 Hz/A^* = 0.2 mm 40–100 Hz/A^* = 0.03 mm
Shock	2 g

Where A^* = peak amplitude (elongation)

8.2.1.1.3 Closed rooms

Equipment located in closed room installations should be capable of withstanding self-induced vibrations as shown below:

Table 8.5 Minimum requirements (closed rooms)

	Range
Vibration	Only self-induced vibration need be considered (for instance, by relay operation)
Shock	Not applicable

8.2.1.1.4 Trainborne equipment

The vibrations (accelerations and frequencies) to which trainborne equipment is exposed depend upon the equipment location within the vehicle. Pending the progress made by CENELEC Working Groups on an environmental definition based on random vibration, the variation is conventionally considered to be of sine wave form.

Table 8.6 (see next page) provides equivalent sinusoidal maximum conditions to be expected with equipment and should be taken into consideration.

8.2.1.1.5 Tractive units and other vehicles

Equipment installed in tractive units and other vehicles should be capable of withstanding vibrations and shocks as shown below:

Table 8.7 Minimum requirements (tractive units and other vehicles)

	Body	Bogie frame	Unsprung masses
Vibration	Up to 1200 Hz at the locomotive body		Up to 800 GHz on simply sprung and unsprung masses
Shock	1–5 g	3–5 g	30–50 g

Note: Accelerations in the longitudinal direction of the body are usually greater than those of the transverse direction of the body that may be assumed to have a value between 1 and 2 g.

8.2.1.1.6 Other locations

Equipment installed in all other locations should be capable of withstanding vibrations and shocks as shown in Tables 8.8 and 8.9.

8.2.1.1.7 Transportation

Whilst being transported, equipment will sustain, in its cabinet, mechanical shocks depending on transport conditions. The equipment, in its packaging, shall comply with the tests described in the IEC 68 series.

Table 8.6 Equivalent sinusoidal maximum conditions

Location of equipment	Equipment mass (kg)	Frequency range (Hz)	Cross-over frequency (Hz)	Displacement amplitude below cross-over frequency (mm)	Acceleration amplitude above cross-over frequency (m/s^2)
Equipment directly mounted on vehicle body or underframe	>2000	1–35	8.2	0.75	2
	<2000	5–100	7.1	1.5	3
Equipment and components in frames and boxes mounted on vehicle body or underframe	>30	5–150	8.2	1.5	4
	3–30	5–150	8.4	2.5	7
	0.3–3	5–150	8.7	5	15
	<0.3	5–150	22.5	1.5	30
Equipment mounted on sprung part of bogie	No limit	5–100*	8.3*	7.5*	20*
Equipment mounted on unsprung part of bogie (e.g. wheelset)	No limit	5–100	20.5	12	200

* Frequencies above 22 Hz use the following values:
22–33 Hz Displacement amplitude 1 mm
32–100 Hz Acceleration amplitude 40 m/s^2

Table 8.8 Minimum requirements (vehicles)

	Condition	Vehicle interior cab	Vehicle interior non-cab	Vehicle exterior body mounted	Vehicle exterior truck mounted – truck	Vehicle exterior truck mounted – axle
Vibration	5–10 Hz	7.5 mm peak–peak	7.5 mm peak–peak	5 mm peak–peak	5 mm peak–peak	6 m peak–peak
	10–50 Hz	1.5 g peak	1.5 g peak	2.5 g peak	10 g peak	42 g peak
	50–100 Hz	1.5 g peak	1.5 g peak	2.5 g peak	10 g peak	42 g peak
	100–200 Hz	1.5 g peak	1.5 g peak	2.5 g peak	10 g peak	42 g peak
	200–1000 Hz			2.5 g peak	10 g peak	42 g peak
Mechanical shock	Transported (1 msec pulse)	20 g peak	20 g peak	10 g peak	10 g peak	10 g peak
	Transported (11 misc pulse)	20 g peak	20 g peak	20 g peak	20 g peak	100 g peak

Table 8.9 Minimum requirements (other locations)

	Condition	Outdoors	Instrument cases	Control rooms	Central office computer room
Vibration	5–10 Hz	2 mm peak–peak	2 mm peak–peak	2 mm peak–peak	2 mm peak–peak
	10–50 Hz	2.8 g peak	1.5 g peak	1.5 g peak	1.5 g peak
	50–100 Hz	2.8 g peak	1.5 g peak	1.5 g peak	1.5 g peak
	100–200 Hz	2.8 g peak	1.5 g peak	1.5 g peak	1.5 g peak
	200–1000 Hz	–	–	–	–
	1000–3000 Hz	–	–	–	–
Mechanical shock	Transported (1 msec pulse)	10 g peak	10 g peak	10 g peak	10 g peak
	Transported (11 msec pulse)	10 g peak	10 g peak	10 g peak	10 g peak

In many contracts, the following requirements may be stipulated:

- equipment shall be capable of withstanding without deterioration or malfunction all mechanical stresses that occur in service;
- equipment shall be designed to withstand the following stationary/non-stationary vibration (sinusoidal and random) and shock stresses.

The specifier will then include suitable classifications from the IEC 721 series as appropriate to the device being specified, e.g. axle mounted sensor – 5M3.

8.2.1.1.8 Random vibration

Equipment should be capable of withstanding random vibration with a power spectral density as shown in Figure 8.4.

8.2.2 Tests

8.2.2.1 Production configuration

All proposed candidate equipment should be tested in their production configuration without the use of any additional external devices that have been added expressly for the purpose of passing mechanical testing, particularly shock and vibration.

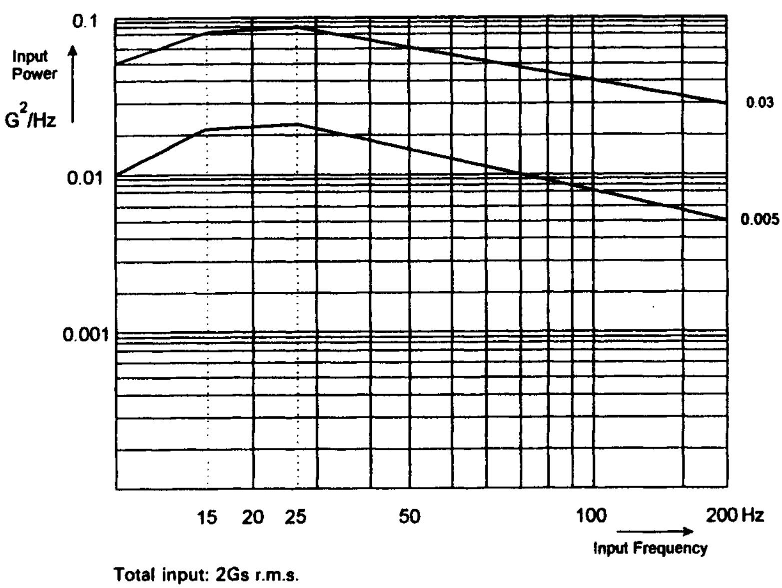


Fig. 8.4 Power spectral density graph for random vibration testing

Note: If the equipment has been specifically designed to be used with anti-vibration mounts, these mountings should be incorporated in the test.

8.2.2.2 Procuring specification

When tested, the sample shall perform as stipulated in the procuring specification and over the designated vibration, shock and acceleration ranges.

8.2.2.3 Test methods

Test methods for determining the suitability of a specimen shall include:

IEC 68.2.27	Environmental testing procedures – Test Ea and guidance: Shock
IEC 68.2.29	Environmental testing procedures – Test Eb and guidance: Bump
IEC 68.2.31	Environmental testing procedures – Test Ec: Drop and topple (primarily for equipment type specimens)
IEC 68.2.32	Environmental testing procedures – Test Ed: Freefall
IEC 68.2.35	Environmental testing procedures – Test Fda: Random vibration wide band – Reproducibility high
IEC 68.2.36	Environmental testing procedures – Test Fdb: Random vibration wide band – Reproducibility medium
IEC 68.2.37	Environmental testing procedures – Test Fdc: Random vibration wide band – Reproducibility low
IEC 68.2.50	Environmental testing procedures – Test Z/Afc: Combined cold vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.2.51	Environmental testing procedures – Test Z/BFc: Combined dry heat vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.2.55	Environmental testing procedures – Test Ee and guidance: Bounce
IEC 68.2.57	Environmental testing procedures – Test Ff: Vibration – Time-history method
IEC 68.2.59	Environmental testing procedures – Test Fe: Vibration – Sine-beat method
IEC 68.2.6	Environmental testing procedures – Test Fc and guidance: Vibration (sinusoidal)
IEC 68.2.7	Environmental testing procedures – Test Ga and guidance: Acceleration, steady state

8.3 Values and ranges

Table 8.10 Storage

Installation location	IEC 721 class	Stationary vibration sinusoidal		Non-stationary vibration including shock			Static load (kPa)
		Displacement amplitude (2–9 Hz) (mm)	Acceleration amplitude (9–200 Hz) (m/s^2)	Type L (m/s^2)	Type I (m/s^2)	Type II (m/s^2)	
Locations with insignificant vibration and shock	1M1	0.3	1	40	None	None	5
Locations with vibration of a low significance	1M2	1.5	5	40	None	None	5
Locations with significant vibration and shock[1]	1M3	3.0	10	None	100	None	5
Locations where the level of vibration and shock are high[2]	1M4	7.0	20	None	None	250	5

Notes:
1 Transmitted from machines or passing vehicles in the vicinity.
2 Close to heavy machines.

Table 8.11 Transportation

Installation location	IEC 721 class	Stationary vibration sinusoidal			Stationary vibration random		Non-stationary vibration including shock	
		Displacement amplitude (2–9 Hz) (mm)	Acceleration amplitude (9–200 Hz) (m/s^2)	Acceleration amplitude (200–500 Hz) (m/s^2)	Acceleration spectral density (10–200 Hz) (m^2/s^3)	Acceleration spectral density (200–2000 Hz) (m^2/s^3)	Type 1 (m/s^2)	Type 2 (m/s^2)
Transportation in aircraft, lorries and air-cushioned tracks and trailers	2M1	3.5	10	15	1	0.3	100	No
Transportation in all kinds of lorries and trailers and trains with specially designed shock reducing buffers	2M2	3.5	10	15	1	0.3	100	300
Transportation in all other kinds of transport	2M3	7.5	20	40	3	1	300	10 000

continued

Table 8.11 (*cont.*)

Installation location	IEC 721 class	Freefall			Toppling			Rolling and pitching		Steady state acceleration (m/s^2)	Static load (kPa)
		Mass less than 20 kg (m)	Mass 20 kg to 100 kg (m)	Mass more than 100 kg (m)	Mass less than 20 kg None	Mass 20 kg to 100 kg None	Mass more than 100 kg None	Angle (°)	Period (s)		
Transportation in aircraft, lorries and air-cushioned tracks and trailers	2M1	0.25	0.25	0.25	*	No	No	No	No	20	5
Transportation in all kinds of lorries and trailers and trains with specially designed shock reducing buffers	2M2	1.2	1.0	0.25	*	*	No	≥35	8	20	10
Transportation in all other kinds of transport	2M3	1.5	1.2	0.5	*	*	*	≥35	8	20	10

* Toppling around any of the edges.

Table 8.12 Operational

Installation location	IEC 721 class	Non-stationary vibration including shock			Stationary vibration sinusoidal	
		Type L (m/s^2)	Type I (m/s^2)	Type II (m/s^2)	Displacement amplitude (2–9 Hz) (mm)	Acceleration amplitude (9–200 Hz) (m/s^2)
Stationary use at weather protected locations with insignificant vibration and shock	3M1	40	None	None	0.3	1
Stationary use at weather protected locations with vibration of low significance	3M2	40	None	None	1.5	5
Stationary use at weather protected locations with vibration and shocks of low significance	3M3	70	None	None	1.5	5
Stationary use at weather protected locations with significant vibration and shock	3M4	None	100	None	3.0	10
Stationary use at weather protected locations where the level of shock is high	3M5	None	None	250	3.0	10
Stationary use at weather protected locations where the levels of shock and vibration are high	3M6	None	None	250	7.0	20
Stationary use at weather protected locations where the level of vibration is very high	3M7	None	None	250	10	30
Stationary use at weather protected locations where the level of vibration is extremely high	3M8	None	None	250	15	50
Stationary use at non-weather protected locations protected from significant vibration or shock	4M1	40	No	No	0.3	1
Stationary use at non-weather protected locations protected from significant vibration or shock	4M2	40	No	No	1.5	5

continued

Table 8.12 (*cont.*)

Installation location	IEC 721 class	Non-stationary vibration including shock			Stationary vibration sinusoidal	
		Type L (m/s^2)	Type I (m/s^2)	Type II (m/s^2)	Displacement amplitude (2–9 Hz) (mm)	Acceleration amplitude (9–200 Hz) (m/s^2)
Stationary use at non-weather protected locations protected from significant vibration but not shocks	4M3	70	No	No	1.5	5
Stationary use at non-weather protected locations not protected from transmitted vibrations or shock	4M4	No	100	No	3.0	10
Stationary use at non-weather protected locations not protected from transmitted vibrations or higher levels of shock	4M5	No	No	250	3.0	10
Stationary use at non-weather protected locations not protected from transmitted vibrations or higher levels of shock	4M6	No	No	250	7.0	20
Stationary use at non-weather protected locations not protected from high level vibrations and shock	4M7	No	No	250	10	30
Stationary use at non-weather protected locations not protected from high level vibrations and shock	4M8	No	No	250	15	50
Ground level installations in vehicles powered by electrical engines, used indoors on smooth surfaces	5M1	–	50	No	1.5	5
All road vehicles except tractors and motorbikes on well developed road systems	5M2	–	100	300	3.3	
All road vehicles on underdeveloped road systems	5M3	–	300	1000	7.5	
Installations in ships not powered by engines	6M1	–	50	100	None	10
Installations on powered ships larger than 1000 metric tons dead weight	6M2	–	100	300	1.5	10

continued

Table 8.12 (*cont.*)

Installations on powered ships smaller than 1000 metric tons dead weight	6M3	–	100	300	1.5	20
Ship mounted equipment directly connected to reciprocating types of machinery	6M4	–	100	300	1.5	50

Installation location	IEC 721 class	Non-stationary vibration including shock			Stationary vibration random		Stationary vibration sinusoidal		
		Type L (m/s^2)	Type I (m/s^2)	Type II (m/s^2)	Acceleration spectral density (m^2/s^3)	Frequency range (m^2/s^3)	Displacement amplitude (2–9 Hz) (mm)	Acceleration amplitude (9–200 Hz) (m/s^2)	Acceleration amplitude (200–500 Hz) (m/s^2)
Equipment being transferred between locations but experiencing only low level vibrations and with medium level shocks	7M1		100	None	100	None	3.5	10	15
Equipment being used at (or directly transferred between) locations with high level shocks	7M2		100	300	100	300	7.5	20	15
Equipment being used at (or directly transferred between) locations with significant vibrations or with high level shocks	7M3		300	1000	300	1000	7.5	20	40

continued

Table 8.12 (*cont.*)

Installation location	IEC 721 class	Free fall		
		Mass less than 20 kg (m)	Mass between 1 kg and 10 kg (m)	Mass between 10 kg and 50 kg (m)
Equipment being transferred between locations – but experiencing only low level vibrations and with medium level shocks	7M1	0.025	0.025	0.25
Equipment being used at or directly transferred between locations with high level shocks	7M2	0.25	0.1	0.05
Equipment being used at or directly transferred between locations with significant vibrations or with high level shocks	7M3	1.0	0.5	0.25

8.4 Tests

This section details some of the test standards which may be applied to equipment and contains:

- details of the most used environmental tests that a purchaser will normally require a manufacturer to adhere to;
- a list of other related standards and specifications;
- a brief description of the more common tests.

Note: Full details of each of these recommended tests are contained in the relevant ISO, IEC or other standard. A full list of these standards is supplied in the reference section of this book. Copies of all these standards may be obtained from any National Standards Organisation.

8.4.1 Shock test (IEC 68.2.27 Test Ea)

Standard No.	IEC 68.2.27
Title	Environmental testing procedures – Test Ea and guidance: Shock
Summary	Applicable to components, equipment and other electrotechnical products which, during transportation or in use, may be subjected to conditions involving relatively infrequent non-repetitive shocks. The object is to provide a standard procedure for determining the ability of a specimen to withstand specified severities of shock. Tests, shock, environmental testing.
Equiv. Std	Technically equivalent to AS 1099 PT2.27 Identical to BS EN 60068 PT2-27 Similar to DIN 40046(PT7) Identical to DIN EN 60068 PT2-27 Identical to DIN IEC 68 PT2-27 Corresponds to EN 60068 PT2-27 Identical to HD 323.2.27 Identical to NEN 10068-2-27 Identical to NFC 20-727 Identical to NF EN 60068-2-27 Similar to SEN 43 16 05

8.4.1.1 Introduction

Equipment and particularly components are quite likely to be subjected to shocks that will be at widely varying levels and are frequently complex in nature. The ability of a specimen to withstand infrequent non-repetitive shocks while being transported, used or handled needs therefore to be determined.

For packaged items, the shocks encountered during handling and transportation are often of a simple nature. IEC 68.2.27 has been designed as a check for unpackaged items and is intended to reproduce the effects of non-repetitive shocks likely to be encountered by components and equipment whilst in service and during transportation.

A test to determine the ability of components, equipment and other electrotechnical products to withstand repetitive shocks is provided in IEC 68.2.29 (see paragraph 8.4.2).

8.4.1.2 Purpose of this test

The purpose of this test is to:

- provide a standard procedure for determining the ability of a specimen to withstand specified severities of shock;
- reveal mechanical weakness and/or degradation in specified performance and to use this information to determine whether a specimen is acceptable or not. This test is particularly aimed at specimens which will be subjected to non-repetitive mechanical shock.

8.4.1.3 General conditions

Whereas this test is primarily intended for unpackaged specimens, it may also be used to test the suitability of packaging and to determine their structural integrity and for quality control.

Normally the transportation environment is far more severe than the operational environment and although a specimen has to survive the transportation environment it will also be required to function when it becomes part of the operational environment. Because of this it may be necessary to carry out shock tests under both conditions together with measurements of certain parameters after the 'transportation environment' test and functional checks during the 'operational environment'.

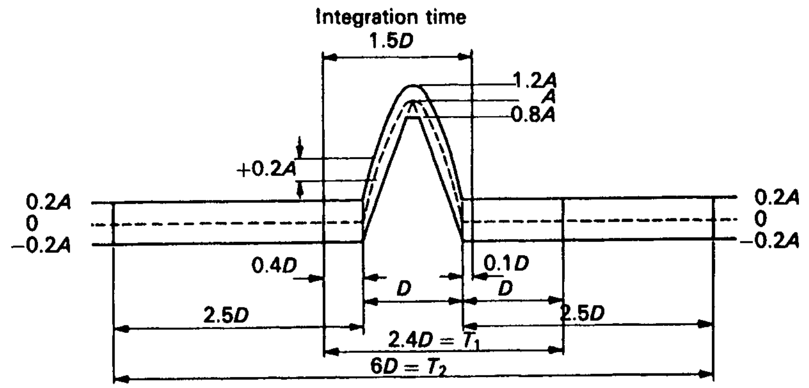
8.4.1.4 Test conditions

IEC 68.2.27 is intended to produce in a specimen the effects of relatively non-repetitive shocks that will probably be encountered by equipment and components in service or whilst being transported.

The standard is written in terms of pulse shapes. The specimen being subjected to a pulse (accelerated against time) whose shape can be either half-sine (which is normally the case), final-peak saw-tooth or trapezoidal (although this is not primarily intended for component type specimens).

The choice of pulse depends on a number of factors, but basically falls into one of the following categories:

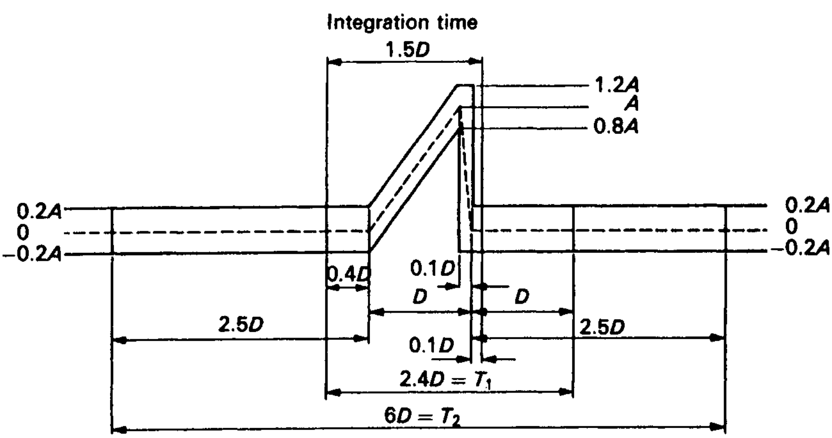
Half-sine pulse – most applicable when reproducing the effects of a shock resulting from impact with, or retardation by, a linear rate system (e.g. impact involving a resilient structure).



– – – nominal pulse
——— limits of tolerance
D = duration of nominal pulse
A = peak acceleration of nominal pulse
T_1 = minimum time during which the pulse shall be monitored for shocks produced using a conventional shock testing machine
T_2 = minimum time during which the pulse shall be monitored for shocks produced using a vibration generator

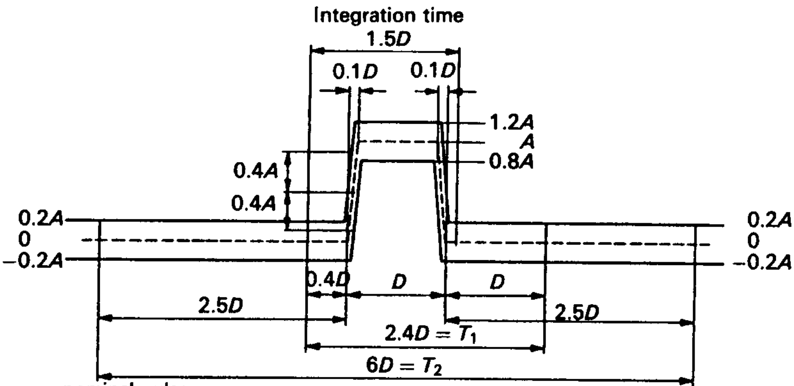
Fig. 8.5 Half-sine pulse

Final-peak saw-tooth pulse – an asymmetrical triangular pulse with short rise and fall times, which has a more uniform response spectrum than the half-sine or trapezoidal pulse shapes.



– – – nominal pulse
——— limits of tolerance
D = duration of nominal pulse
A = peak acceleration of nominal pulse
T_1 = minimum time during which the pulse shall be monitored for shocks produced using a conventional shock testing machine
T_2 = minimum time during which the pulse shall be monitored for shocks produced using a vibration generator

Fig. 8.6 Final-peak saw-tooth pulse (reproduced from BS 2011: Part 2.1 Ea:1988 by kind permission of the BSI)



– – – nominal pulse
——— limits of tolerance
D = duration of nominal pulse
A = peak acceleration of nominal pulse
T_1 = minimum time during which the pulse shall be monitored for shocks produced using a conventional shock testing machine
T_2 = minimum time during which the pulse shall be monitored for shocks produced using a vibration generator

Fig. 8.7 Trapezoidal pulse (reproduced from BS 2011:Part 2.1Ea:1988 by kind permission of the BSI)

Trapezoidal pulse – a symmetrical trapezoid with short rise and fall times. This pulse produces a higher response over a wider frequency spectrum than the half-sine pulse.

8.4.1.5 Other standards

IEC 68.1 Environmental testing procedures – General and guidance

8.4.2 Bump test (IEC 68.2.29 Test Eb)

Standard No.	IEC 68.2.29
Title	Environmental testing procedures – Test Eb and guidance: Bump
Summary	Provides a standard procedure for determining the ability of a specimen to withstand specified severities of bump. The standard is written in terms of a prescribed amount of repetitive half-sine pulses with given peak acceleration and duration. The test is primarily meant for unpackaged specimens and for items in their transport case when the latter may be thought of as part of the specimen.
Equiv. Std	Identical to AS 1099.2.29 Identical to BS 2011:PT2.1Eb(1987) Similar to DIN 40046(PT26) Identical to DIN EN 60068 PT2-29

Table 8.13 Examples of pulse shapes and test severities (reproduced from the equivalent standard BS2011.1.1: 1989 by kind permission of the BSI)

Peak acceleration			Corresponding velocity change			Equipment use
g_n	Equivalent (m/s^2)	Corresponding duration of the nominal pulse (ms)	Half-sine (m/s)	Final-peak saw-tooth (m/s)	Trapezoidal	
15	150	11	Yes	Yes	Yes	Land based equipment permanently installed or transported in shock resistant packages
30	300	18	Yes	Yes	Yes	Equipment installed or transported in a secured position
50	500	11	Yes	Yes	Yes	Equipment carried loose and components installed in heavy industrial equipment
100	1 000	6	Yes	Yes	Yes	Equipment subjected to high intensity shocks and components carried loose in road and rail vehicles
500	5 000	1	Yes	N/A	N/A	Blast excited shocks, land sea or air
1 500	15 000	0.5	Yes	N/A	N/A	

Notes

1 One of the basic requirements of the test is to apply three shocks in each of six directions.

2 In some components and for most equipment, the internal parts can form more complicated systems than undamped systems. In these cases, shock excited oscillations in one outer system may cause damage to an inner system by coupled resonant effects.

Identical to DIN IEC 68 PT2-29
Identical to EN 60068 PT2-29
Identical to HD 323.2.29
Identical to NEN 10068-2-29
Identical to NFC 20-729
Identical to NF EN 60068-2-29
Similar to SEN 43 16 05

8.4.2.1 Introduction

When being transported and whilst in use, equipment can be subjected to repeated bumps. This test is designed to provide a standard procedure for determining the ability of a specimen to withstand specified severities of bump.

8.4.2.2 Purpose of this test

The purpose of this test is:

- to reveal the accumulated damage or degradation caused by repetitive shocks and jolts that are likely to be encountered by components and equipment during transportation or when installed and whilst in use in road and/or rail vehicles as portable equipment, or whilst shipborne;
- primarily intended for unpackaged specimens and for items in their transport case. It may also be used to assess the structural integrity of specimens as a means of quality control.

8.4.2.3 General conditions

This test is basically a robustness test conducted to give a measure of confidence. It may also be used for establishing the satisfactory design of a specimen in as far as its structural integrity is concerned and as a means of quality control. It is not intended to simulate precisely the real environment.

Repetitive bumping during transportation is mainly due to the discontinuities of the medium (e.g. road) and is of moderate intensity. For impacts of a non-repetitive nature, the test described in IEC 68.2.27 (see Section 8.4.1) should be used.

8.4.2.4 Test conditions

IEC 68.2.29 describes a test that subjects a specimen to repetitive shocks (or jolts) of a standard pulse shape with a specified peak acceleration and duration. The severity of the test depends on the specimen under test and the designated number of bumps applied in each direction in three mutually perpendicular axes.

Table 8.14 lists severities which are not mandatory but which are typical of the various applications. As IEC point out, it should be remembered that there will be instances where the real severities differ from those shown in this table.

Table 8.14 Examples of severities typically employed for various applications (reproduced from the equivalent standard BS 2011.2.1:1987 by kind permission of the BSI)

Severity				
Peak acceleration g_n (equivalent m/s^2)	Duration (ms)	No. of bumps in each specified direction	Component use	Equipment use
10 (100)	16	1000	Transportation of fragile items by road, excluding cross-country	General robustness tests and for items installed or transported in a secured position in wheeled vehicles with no cross-country requirement
15 (150)	6	4000	Minimal robustness test and for items of general application with main mechanical load occurring during transportation	Items installed in control equipment of stationary or heavy mobile machinery, for example in the vicinity of power plants
25 (250)	6	1000		Items installed or transported in a secured position in full cross-country vehicles. Items installed in mechanical handling equipment, for example dock cranes, fork-lift trucks
40 (400)	6	1000	Transportation of items intended for use in equipment of a non-portable nature	Items which may be carried loose in wheeled vehicles (road or rail) for occasional journeys, for example delivery
40 (400)	6	4000	Items for use in transportable equipment	Transportable items which are repeatedly carried loose in any type of vehicle, rail, road or cross-country
100 (1000)	2	4000	Lamps and spring contacts, for example for keys, telephones or switchboards	

Note
It is recommended that the test severities of 250 and 400 m/s^2 should only be specified for specimens with a nominal mass of less than 100 kg. For heavier specimens the 100 m/s^2 severity is generally more appropriate.

8.4.2.5 Other standards

IEC 68.1	Environmental testing procedures – General and guidance

8.4.3 Drop and topple tests (IEC 68.2.31 Test Ec)

Standard No.	IEC 68.2.31
Title	Environmental testing procedures – Test Ec: Drop and topple (primarily for equipment type specimens)
Summary	The object of the test is to determine the effects upon a specimen of simple standard treatments intended to be representative of the knocks and jolts likely to occur during repair work or rough handling in use on a table or bench. Test Ec is intended to simulate the effects of knocks and jolts which may be received during rough handling of equipment.
Equiv. Std	Identical to AS 1099.2.31 Identical to BS EN 60068 PT2-31 Identical to DIN EN 60068 PT2-31 Identical to DIN IEC 68 PT2-31 Corresponds to EN 60068 PT2-31 Identical to HD 323 Identical to HD 323.2.31 Identical to NEN 10068-2-31 Identical to NFC 20-731 Identical to NF EN 60068-2-31 Similar to SEN 43 16 05

8.4.3.1 Introduction

During transportation and whilst in use, equipment is quite likely to be roughly handled or subjected to some hard knocks and jolts. This test provides a standard procedure for determining the ability of a specimen to withstand specified severities of drops, topples or pushovers.

8.4.3.2 Purpose of this test

The purpose of this test is to:

- assess the effects of bumps, knocks or jolts that are likely to be received by equipment whilst under repair or whilst being subjected to rough handling on a table or bench;
- demonstrate a minimum degree of robustness for assessing safety requirements.

8.4.3.3 General conditions

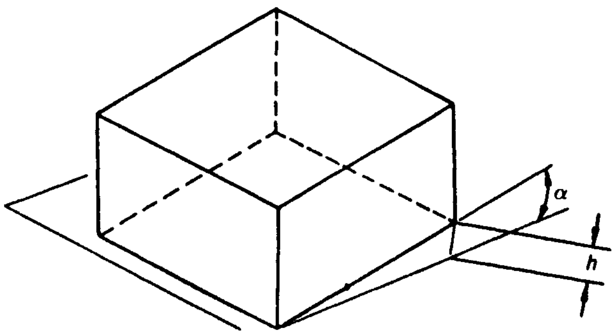
The test should only be specified for equipment that is likely to receive such rough handling (e.g. those that are small to medium in size and mass) and should be applied only to those faces and corners where there is a risk of such treatment being encountered.

This test is primarily intended for specimens out of their packing and is not applicable to equipment forming an integral part of a permanent installation or to specimens which are large enough to make them stable while being handled.

8.4.3.4 Test conditions

IEC 68.2.31 consists of three distinct procedures:

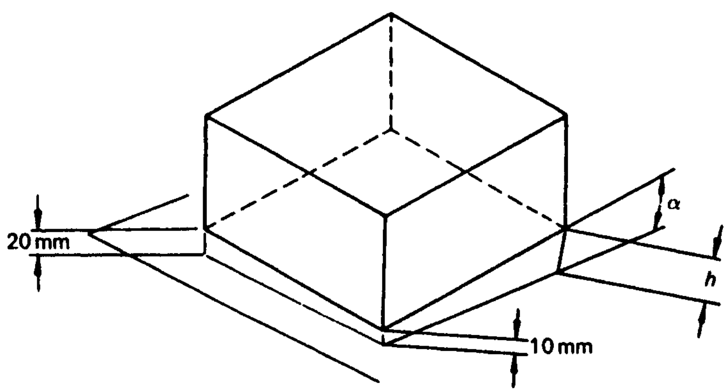
1 Dropping onto a face.



h = distance between edge of specimen and test surface
α = angle between bottom face of specimen and test surface

Fig. 8.8 Drop and topple tests – dropping onto a face (reproduced from the equivalent standard BS EN 60068.2.31 by kind permission of the BSI)

2 Dropping onto a corner.



h = distance between edge of specimen and test surface
α = angle between bottom face of specimen and test surface

Fig. 8.9 Drop and topple tests – dropping onto a corner (reproduced from the equivalent standard BS EN 60068.2.31 by kind permission of the BSI)

3 Toppling (or pushover).

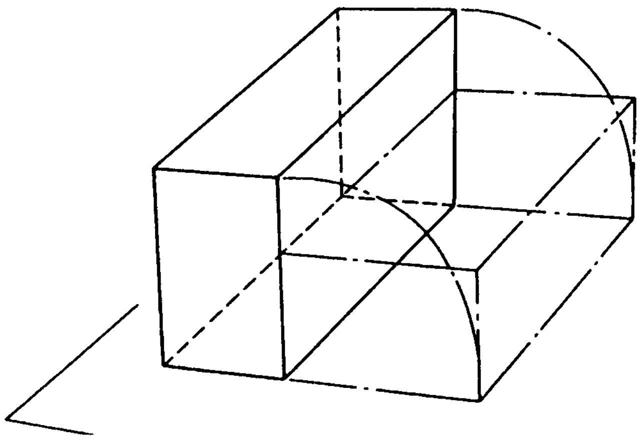


Fig. 8.10 Drop and topple tests – toppling (or pushover) (reproduced from the equivalent standard BS EN 60068.2.31 by kind permission of the BSI)

The purpose of each of these procedures is basically the same, but they cover different kinds of handling.

8.4.3.5 Other standards

IEC 68.1	Environmental testing procedures – General and guidance

8.4.4 Free fall test (IEC 68.2.32 Test Ed)

Standard No.	IEC 68.2.32
Title	Environmental testing procedures – Testing – Test Ed: Free fall
Summary	The object of the test is to determine the effects on a specimen of simple standard treatments intended to be representative of the falls likely to be experienced during rough handling, or to demonstrate a minimum degree of robustness, for the purpose of assessing compliance with safety requirements.
Equiv. Std	Technically equivalent to AS 1099:PT2Ed Identical to BS EN 60068 PT2-32 Identical to DIN EN 60068 PT2-32 Identical to DIN IEC 68 PT2-32 Corresponds to EN 60068 PT2-32 Identical to HD 323

Identical to HD 323.2.32
Identical to NEN 10068-2-32
Identical to NFC 20-732
Identical to NF EN 60068-2-32
Similar to SEN 43 16 05

8.4.4.1 Introduction

During operation and whilst being transported, handled or repaired, unpacked components and equipment are quite likely to be dropped from a work surface or dropped from a means of transport.

8.4.4.2 Purpose of this test

The purpose of this test is to assess the effects of falls that are likely to be received by equipment during rough handling, while being transported or used.

8.4.4.3 General conditions

The test is not suitable for heavy specimens or those with large dimensions (e.g. large power transformers). The test can also be used to demonstrate the minimum degree of robustness, for assessing safety requirements.

8.4.4.4 Test conditions

IEC 68.2.32 specifies two types of procedures:

Free fall –	this procedure is primarily intended for testing cable connected devices such as small remote control units, and simulates situations (i.e. falls) where apparatus has been dropped frequently onto hard surfaces. The test is normally restricted to two falls from a prescribed attitude onto a specified surface from a specified height.
Free fall – (repeated)	simulating repeated falls. Such repeated falls may occur to devices that are normally attached to cables during use. The test consists of a number of repeated falls onto a specified surface from a specified height using a suitable apparatus (e.g. a tumbling, rotating barrel).

The severity of these tests varies according to the specimen being tested and can be chosen from Table 8.15.

8.4.4.5 Other standards

IEC 68.1	Environmental testing procedures – General and guidance

Table 8.15 Examples of test severities typically employed

Height of fall (mm)	Specimen mass		Example of unpacked specimen	Type of handling
	Unpackaged (kg)	In integral transport cases (kg)		
25	$>100 \leq 250$	>500	Cubicles	Fork-lift trucks*
50	$>50 \leq 100$	≤ 500	Cabinets	Fork-lift trucks*
100	$>10 \leq 50$	≤ 200	Switchboards	Cranes*
250	$>5 \leq 10$	≤ 100	Portable cases	Storage, stacking
500	$>2 \leq 5$	≤ 50	Small items	Fall from conveyor belts
1000	≤ 2	≤ 20	Components, small assemblies	Fall from work benches or tail board of truck

Note
The total number of falls can be selected from 50, 100, 200, 500 or 1000.
* This is intended to simulate the impact when lowered to the loading level by a fork-lift truck or crane, not dropping from the platform of the truck or sling of the crane.

Table 8.16 Random vibration test standards

Standard No.	Title	Summary	Equivalent standards
IEC 68.2.34	Environmental testing procedures – Test Fd: Random vibration wide band – General requirements	The object of the test is to determine the ability of components and equipment to withstand specified severities of random vibration. Gives guidance for Test Fd: Random vibration wide band – General requirements	Technically equivalent to BS 2011:PT2.1Fd(1973) Similar to DIN 40046(PT22) Identical to HD 323.2.34 Identical to NEN 10068-2-34 Identical to NFC 20-734
IEC 68.2.35	Environmental testing procedures – Test Fda: Random vibration wide band – Reproducibility high	The object of the test is to determine the ability of components and equipment to withstand specified severities of random vibration	Technically equivalent to BS 2011:PT2.1Fda(1973) Technically equivalent to DIN 40046(PT23) Identical to HD 323.2.35 Identical to NEN 10068-2-35 Identical to NFC 20-735
IEC 68.2.36	Environmental testing procedures – Test Fdb: Random vibration wide band – Reproducibility medium	The object of the test is to determine the ability of components and equipment to withstand specified severities of random vibration	Technically equivalent to BS 2011:PT2.1Fdb(1973) Technically equivalent to DIN 40046(PT24) Identical to HD 323.2.36 Identical to NEN 10068-2-36 Identical to NFC 20-736
IEC 68.2.37	Environmental testing procedures – Test Fdc: Random vibration wide band – Reproducibility low	The object of the test is to determine the ability of components and equipment to withstand specified severities of random vibration	Technically equivalent to BS 2011:PT2.1Fdc(1973) Technically equivalent to DIN 40046(PT25) Identical to HD 323.2.37 Identical to NEN 10068-2-37 Identical to NFC 20-737

8.4.5 Random vibration tests (IEC 68.2.34/35/36/37 Tests Fd, Fda, Fdb and Fdc)

8.4.5.1 Introduction

These tests are applicable to components and equipment which may be subjected to conditions involving vibration of a stochastic (i.e. random) nature. The purpose of the tests is to determine the resulting degree of mechanical weakness and/or degradation in specified performance that result and to see if the specimen can continue to meet the required specification.

Three possible degrees of reproducibility are specified namely, high (IEC 68.2.35), medium (IEC 68.2.36) and low (IEC 68.2.37).

8.4.5.2 Purpose of these tests

The purpose of these tests is to augment the existing sinusoidal vibration test provided in IEC 68.2.6 (see paragraph 8.4.11) as a step nearer to the type of vibration likely to exist in the real environment and to produce effects in the specimen more closely related to those actually occurring in service.

8.4.5.3 General conditions

It is essential that if random vibration testing is to achieve the degree of realism that justifies its introduction, engineering judgement must be allowed in its application.

In these standards two terms are referred to frequently. For clarification:

- Acceleration Spectral Density (ASD) – is the spectral density of an acceleration variable and is given in units of acceleration squared per unit frequency.
- ASD Spectrum – defines the way that ASD varies within the frequency range.

8.4.5.4 Test conditions

There are three types of test (IEC 68.2.35/36/37, relating to 'high', 'medium' or 'low' reproducibility) which are designed to determine mechanical weakness, degradation and/or changes in performance of specimens when subjected to conditions involving vibration of a random (stochastic) nature. A fourth standard (IEC 68.2.34) provides guidance in the use and applicability of these tests.

The specimens are vibrated in three mutually perpendicular axes in turn, these axes being chosen to ensure that faults are most likely to be revealed. The severity of the test is defined by the combination of frequency range, Acceleration Spectral Density (ASD) level and duration of conditioning.

8.4.5.4.1 Resonance search procedure

When there is a requirement for resonance searches, the initial resonance search can, to some extent, be completed at the same time as the frequency response measurement.

During these searches the specimen shall be examined in order to determine:

- frequencies (dependent on vibration) at which specimens malfunction and/or a deterioration of performance are exhibited;
- frequencies at which mechanical resonances occur.

8.4.5.5 Other standards

IEC 68.1	Environmental testing procedures – General and guidance

8.4.6 Combined cold vibration (sinusoidal) test (IEC 68.2.50 Test Z/AFc)

Standard No.	IEC 68.2.50
Title	Environmental testing procedures – Test Z/AFc: Combined cold vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
Summary	This standard is basically a combination of Test Fc: Vibration (sinusoidal) and Test A: Cold.
Equiv. Std	Identical to BS 2011:PT2.1Z/AFc(1984) Identical to DIN IEC 68 PT2-50 Identical to HD 323.2.50 Identical to NEN 10068-2-50

8.4.6.1 Introduction

During the transportation or storage of heat dissipating and non-heat dissipating equipment they may occasionally be subjected to a combination of low temperature combined with (sinusoidal) vibration.

8.4.6.2 Purpose of this test

The purpose of this test is to determine the suitability of heat dissipating and non-heat dissipating components, equipment or other articles for use, storage and transportation under conditions of low temperature combined with (sinusoidal) vibration.

8.4.6.3 General conditions

The temperature conditions for testing heat dissipating specimens are intended to subject the specimen to thermal stresses in a manner equivalent to those found in free air conditions.

For packaged items, the shocks encountered during handling and transportation are often of a simple nature.

The procedures are limited to the case of specimens which reach temperature stability during exposure to low temperature conditions.

This standard calls for the use of procedures that may be injurious to health if adequate precautions are not taken.

8.4.6.4 Test conditions

IEC 68.2.50 is basically a combination of IEC 68.2.6 (Vibration) (see paragraph 8.4.11) and IEC 68.2.1 (Cold) (see paragraph 2.4.1). The procedure is limited to the case of specimens that reach temperature stability during exposure to low temperature conditions.

Unless these tests have been performed (and the results recorded) a vibration test under laboratory temperature conditions is first performed and the specimen is then subjected to the low temperature until temperature stability has been reached, after which it is subjected to the combination of vibration and low temperature.

Test profiles are shown in the specification and the vibration environment may be a combination of one or more of the following:

- endurance by sweeping;
- endurance at pre-determined frequencies.

8.4.6.5 Other standards

IEC 68.2.51	Environmental testing procedures – Test Z/BFc: Combined dry heat/vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
IEC 68.2.53	Environmental testing procedures – Guidance to Tests Z/AFc and Z/BFc: Combined temperature (cold and dry heat) and vibration (sinusoidal) tests

8.4.7 Combined dry heat vibration (sinusoidal) test (IEC 68.2.51 Test Z/BFc)

Standard No.	IEC 68.2.51
Title	Environmental testing procedures Test Z/BFc: Combined dry heat/vibration (sinusoidal) tests for both heat dissipating and non-heat dissipating specimens
Summary	This standard is basically a combination of Test Fc: Vibration (sinusoidal) and Test B: Dry heat.
Equiv. Std	Identical to BS 2011:PT2.1Z/BFc(1984) Identical to DIN IEC 68 PT2-51 Identical to HD 323.2.51 Identical to NEN 10068-2-51

8.4.7.1 Introduction

During the transportation or storage of heat dissipating and non-heat dissipating equipment they may occasionally be subjected to a combination of high temperature combined with (sinusoidal) vibration.

8.4.7.2 Purpose of this test

The purpose of this test is to determine the suitability of heat dissipating and non-heat dissipating equipment under conditions of high temperature combined with (sinusoidal) vibration.

8.4.7.3 General conditions

The temperature conditions for testing heat dissipating specimens are intended to subject the specimen to thermal stresses in a manner equivalent to that found in free air conditions.

IEC 68.2.53 provides guidance on the application of the combined tests.

8.4.7.4 Test conditions

IEC 68.2.51 (Combined dry heat vibration (sinusoidal) test) is basically a combination of IEC 68.2.6 (Vibration) (see paragraph 8.4.11) and IEC 68.2.2 (Dry heat) (see paragraph 2.4.2).

The procedure is limited to the case of specimens that reach temperature stability during exposure to high temperature conditions.

8.4.7.5 Other standards

IEC 68.2.53	Environmental testing procedures – Guidance to Tests Z/AFc and Z/BFc: Combined temperature (cold and dry heat) and vibration (sinusoidal) tests

8.4.8 Bounce test (IEC 68.2.55 Test Ee)

Standard No.	IEC 68.2.55
Title	Environmental testing procedures – Test Ee and guidance: Bounce
Summary	Provides a standard procedure for determining the ability of a specimen to withstand specified severities bounce. Coverage includes definitions, conditioning and severities. Includes detailed diagrams and appendices.
Equiv. Std	Identical to BS EN 60068 PT2-55 Identical to DIN EN 60068 PT2-55 Identical to DIN IEC 68 PT2-55 Identical to EN 60068 PT2-55 Identical to HD 323.2.55 Identical to NEN 10068-2-55 Identical to NFC 20-755 Identical to NF EN 60068-2-55

8.4.8.1 Introduction

When equipment is carried as loose cargo whilst being transported on load carrying vehicles it is often subjected to severe and repetitive shock from impacting, rebounding and scuffing on the floor of the transporting vehicle or from colliding with the walls of the vehicle or other cargo. Even when tied to the vehicle platform, equipment can be subject to shock if the constraint allows freedom of movement.

The bounce test fulfils a similar function to the bump test of IEC 68.2.29 (see paragraph 8.4.2) except that it more closely simulates the stress resulting from impact and shock to which the specimen would be subjected when carried loose in a vehicle.

8.4.8.2 Purpose of this test

The purpose of this test is to provide a standard procedure to determine the suitability of equipment that has to be transported on a load carrying vehicle when it is either not fastened down or when it has some degree of freedom, and can, therefore, be subjected to dynamic stresses resulting from random shock conditions.

8.4.8.3 General conditions

The shock test may also be used for assessing the satisfactory design of a specimen as far as its structural integrity is concerned.

The test is primarily intended for specimens prepared for transportation, including specimens in their transit case when the latter may be considered as part of the specimen itself.

When items are stacked in a vehicle, there can be significant differences between the environments experienced by the top and bottom layers. It is the transport case of a specimen that is most vulnerable when it is in the bottom layer; while in the top layer, it is its contents.

8.4.8.4 Test conditions

IEC 68.2.55 tests the ability of a specimen to withstand specific severities of bounce.

Whenever possible the test severity applied to the specimen should be related to the operational environment to which the specimen will be subjected during transportation.

Two methods of carrying out the bounce test are given in the standard:

- Method A – this provides a circular motion of amplitude and speed sufficient to produce an acceleration more than $1\,g_n$ in the vertical plane. The vertical motion induces bounce and the horizontal motion induces occasional impact with the platform rails.
- Method B – this is based on a non-synchronous platform motion in which two drive points are driven at different speeds which results in a motion that progressively changes from linear vertical to pitching. The vertical motion induces bouncing; the pitching motion impacts with the barrier rails.

Both methods are considered equally effective in simulating the transportation environment.

8.4.8.5 Other standards

IEC 68.1	Environmental testing procedures – General and guidance

8.4.9 Vibration test – time-history method (IEC 68.2.57 Tests Ff)

Standard No.	IEC 68.2.57
Title	Environmental testing procedures – Test Ff: Vibration – Time-history method
Summary	Details methods for testing components, equipment and other electrotechnical products which in service can be subjected to short-duration, random type, dynamic forces, typical examples of which are the stresses induced in equipment as a result of earthquakes, explosions and some phases of transportation.
Equiv. Std	Identical to BS EN 60068 PT2-57 Identical to DIN EN 60068 PT2-57 Identical to DIN IEC 68 PT2-57 Identical to EN 60068 PT2-57 Identical to HD 323.2.57 Identical to NEN 10068-2-57 Identical to NFC 20-757 Identical to NF EN 60068-2-57

8.4.9.1 Introduction

Equipment whilst being transported or whilst in service may be subjected to short-duration, random type, dynamic forces (e.g. stresses induced in equipment as a result of earthquakes, explosions and some phases of transportation). IEC 68.2.57 provides a standard procedure for determining by the time-history method the ability of a specimen to withstand specified severities of transient vibration.

8.4.9.2 Purpose of this test

The purpose of this test is:

- to determine mechanical weakness and/or degradation in specified performance and to use this information, in conjunction with the relevant specification, to decide whether a specimen is acceptable or not;
- to demonstrate the mechanical robustness of specimens and/or to study their dynamic behaviour.

8.4.9.3 General conditions

Many recognised testing procedures exist for demonstrating the ability of

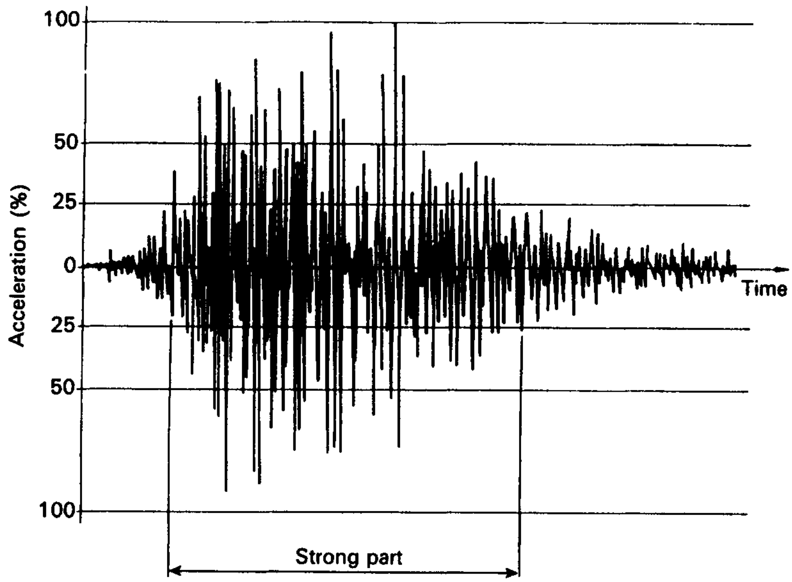


Fig. 8.11 Typical time-history (reproduced from the equivalent standard BS EN 60068.2.57 by kind permission of the BSI)

specimens to withstand various types of vibrational forces (see previous sections). These procedures range from the simple continuous sinusoid to complex highly specialised time-history methods, each being best suited for particular circumstances or requirements, or for representing a particular vibration environment.

The time-history method becomes important for:

- applications where the vibration environment is to be reproduced as closely as possible;
- applications where little is known about the spectrum, or there is great difficulty in determining critical aspects about the specimen (e.g. critical frequencies, etc.).

Compared with other methods, the time-history method avoids a tendency to overtest because it closely represents the real environment.

The use of a time-history allows a single test wave to envelope a broad response spectrum. A typical time-history is shown in Figure 8.11, whilst Figure 8.12 shows a typical logarithmic plot of a required response spectrum.

Natural time-history is the recording, as a function of time, of the acceleration, velocity or displacement resulting from a given event. It should be noted that time-history requires the test laboratory to utilise sophisticated and accurate instrumentation, as well as digital computer equipment for control and analysis.

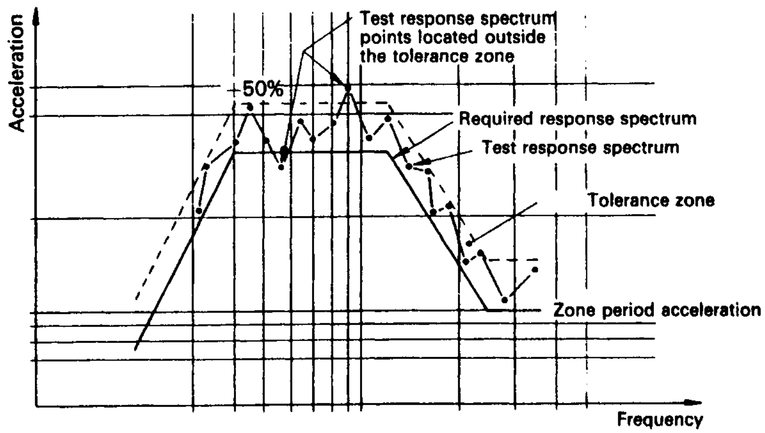


Fig. 8.12 Typical logarithmic plot of a required response spectrum (reproduced from the equivalent standard BS EN 60068.2.57 by kind permission of the BSI)

8.4.9.4 Test conditions

IEC 68.2.57 describes a method for determining the mechanical weakness and/or degradation in specified performance and to use this information, in conjunction with the relevant specification, to decide whether a specimen is acceptable or not. It may also be used, in some cases, to demonstrate the mechanical robustness of specimens and/or to study their dynamic behaviour.

During the test the specimen is subjected to either a natural time-history or a synthesised time-history generated from frequencies included within the specified range and with characteristics simulating the effects of the dynamic forces.

A time-history may be obtained from:

- a natural event (natural time-history);
- a random sample (artificial time-history);
- a synthesised signal (artificial time-history).

The test severity is defined by a combination of frequency range, required response spectrum, number and duration of time-histories and (where applicable) number of high stress response cycles.

Procedures are described for conducting the test, the choice of test severity, frequency range, required response spectrum, number and duration of time-histories, the number of high stress response cycles and for measurement of the vibration at given points.

8.4.9.5 Other standards

IEC 68.1 Environmental testing procedures – General and guidance

8.4.10 Vibration test – sine-beat method (IEC 68.2.59 Test Fe)

Standard No.	IEC 68.2.59
Title	Environmental testing procedures – Test Fe: Vibration – Sine-beat method
Summary	Details methods for testing components, equipment and other electrotechnical products which in service can be subjected to pulsating or oscillating forces of short duration caused, for example, by seismic or explosive phenomena or by vibration in machinery.
Equiv. Std	Identical to BS 2011:PT2.1Fe(1991) Identical to BS EN 60068 PT2-59 Identical to DIN EN 60068 PT2-59 Identical to DIN IEC 68 PT2-59 Corresponds to EN 60068 PT2-59 Identical to HD 323.2.59 Identical to NEN 10068-2-59 Identical to NFC 20-759 Identical to NF EN 60068-2-59

8.4.10.1 Introduction

Whilst in service, equipment can be subjected to pulsating or oscillating forces for short durations (e.g. caused by seismic explosive phenomena or by vibration in machinery). IEC 68.2.59 provides a standard procedure for determining the ability of components, equipment and other electrotechnical products to withstand specified severities of transient vibration.

8.4.10.2 Purpose of this test

The purpose of this test is to provide a standard procedure for determining, by the sine-beat method, the ability of a specimen to withstand specified severities of transient vibration.

8.4.10.3 General conditions

In vibration testing, the usual approach is to conduct a vibration response investigation to search for the critical frequencies of the specimen in the required frequency range. Some form of endurance test is then undertaken which often consists of vibrating a specimen for prescribed times at each of these critical frequencies.

The vibration response investigation is normally carried out using single-axis sinusoidal excitation with a single sweep cycle over the required frequency range. The amplitude of vibration during this investigation should not be so large as to produce effects comparable to those of the endurance test itself and should be at a sufficiently low sweep rate to determine the critical frequencies. A change in frequency may indicate that some fatigue has occurred and the specimen may therefore be unsuitable for the operational environment.

The sine-beat method is suitable for testing equipment that is subjected in service to pulsating or oscillating forces of short durations that are not accurately defined. It is particularly suitable for testing equipment that is to be mounted in structures that may then be subjected in service to random or multi-frequency excitations.

The reproduction of the effects of low cycle, high stress fatigue that could be produced by vibration (e.g. produced by earthquakes, explosions) requires that the specific environment be simulated as accurately as possible.

8.4.10.4 Test conditions

IEC 68.2.59 provides a standard procedure for determining the ability of equipment to withstand specified severities of transient vibration.

Procedures are described for conducting the test (e.g. exciting the specimen at fixed frequencies with a preset number of sine beats) and for the measurement of the vibration at given points.

The requirements for the vibration motion and for the choice of severities (including frequency range, test levels, sine-beat cycles and number of sine beats) are also detailed.

Pauses are deliberately inserted between the individual sine beats to allow decay of the free response of the specimen.

8.4.10.5 Other standards

IEC 68.1	Environmental testing procedures – General and guidance

8.4.11 Vibration (sinusoidal) tests (IEC 68.2.6 Test Fc)

Standard No.	IEC 68.2.6
Title	Environmental testing procedures – Test Fc and guidance: Vibration (sinusoidal)
Summary	The object of this test is to determine the ability of components and equipment to withstand a sinusoidal vibration over a given frequency or at discrete frequencies. The publication deals primarily with the methods of controlling the test at specified points, and gives, in details, the testing procedure, frequency ranges, amplitudes and endurance times.
Equiv. Std	Identical to BS EN 60068 PT2-6 Identical to DIN EN 60068 PT2-6 Identical to EN 60068 PT2-6 Identical to NEN 10068-2-6 Identical to NF EN 60068-2-6

8.4.11.1 Introduction

Equipment, during transportation or whilst in service, may be subjected to prolonged conditions involving vibration of a harmonic pattern, generated primarily by rotating, pulsating or oscillating forces, similar to those caused by machinery and seismic phenomena. IEC 68.2.6 provides a standard procedure for determining the ability of components, equipment and other articles to withstand specified severities of sinusoidal vibration.

8.4.11.2 Purpose of this test

The purpose of this test is to determine mechanical weakness and/or degradation in specified performance, and to use this information, together with the relevant specification, to decide whether or not an item of equipment or component is acceptable.

8.4.11.3 General conditions

In vibration testing the usual approach is to search for the resonances and then to undertake an endurance test in which a specimen is vibrated at resonant frequencies for a prescribed time.

The problem with this sort of test is that it is extremely difficult to differentiate between resonances which are liable to cause failure in service and those likely to cause trouble. Endurance by sweeping, which the test also includes, reduces these difficulties and avoids the necessity of defining significant and damaging resonances.

IEC 68.2.6 is also used to determine critical frequencies at which the specimen malfunctions (or its performance deteriorates) and can be used to determine when mechanical resonances and other response effects (e.g. chatter) occur. Sometimes this test may be used to detect the structural integrity of specimens and/or study their dynamic behaviour.

The main part of this standard deals primarily with the methods of controlling the test at specified points and details the test procedures. The requirements for vibration motion, choice of severities – including frequency ranges, amplitudes and endurance times – are also specified.

8.4.11.4 Test conditions

IEC 68.2.6 describes a method for detecting the effect on an item of equipment in terms of mechanical weakness and/or degradation in specified performance, when that equipment (during transportation or while in service) has been subjected to vibration of a harmonic pattern.

For the purposes of this test, the specimen is subjected to sinusoidal vibration whose vibration severity is determined by the combination of vibration, frequency range amplitude and duration of endurance.

The frequency changes exponentially with time and varies at a continuous rate of $\pm 10\%$, i.e. one octave per minute.

The maximum vibration amplitude (displacement or acceleration, or both) at the check points, in any axis perpendicular to the specified axis, is not normally allowed to exceed 50% of the specified amplitude for frequencies up to 500 Hz, or 100% for frequencies greater than 500 Hz.

The frequency range recommended for this test is provided in a series of tables (see the example in Table 8.17) and covers the range from 0.1 Hz to 5000 Hz.

The duration of the test depends on whether the test is intended to simply show the ability of a specimen to survive and/or operate at the appropriate amplitudes or whether the ability of an item of equipment to withstand the cumulative effects of vibration is to be shown.

8.4.11.5 Other standards

IEC 68.1	Environmental testing procedures – General and guidance
IEC 68.2.34	Environmental testing procedures – Test Fd: Random vibration wide band – General requirements
IEC 68.2.35	Environmental testing procedures – Test Fda: Random vibration wide band – Reproducibility high
IEC 68.2.36	Environmental testing procedures – Test Fdb: Random vibration wide band – Reproducibility medium
IEC 68.2.37	Environmental testing procedures – Test Fdc: Random vibration wide band – Reproducibility low
IEC 68.2.47	Environmental testing procedures – Mounting of components, equipment and other articles for dynamic tests including Shock (Ea), Bump (Eb), Vibration (Fc and Fd) and Steady state acceleration (Ga) and guidance
IEC 68.2.64	Environmental testing procedures – Vibration, broadband random (digital control) and guidance
IEC 721.1	Classification of environmental conditions – Environmental parameters and their severities
ISO 2041	Vibration and shock – Vocabulary

8.4.12 Impact, pendulum hammer test (IEC 68.2.62 Test Ef)

Standard No.	IEC 68.2.62
Title	Environmental testing procedures – Test Ef: Impact, pendulum hammer
Summary	Provides a standard method of test for determining the ability of a specimen of an electrotechnical product to withstand specified severities of impact (approximate range of standardised impact values 0.15 J to 0.5 J). It is mainly used to demonstrate an acceptable level of mechanical robustness when assessing the 'safety' of the product.
Equiv. Std	Identical to BS EN 60068 PT2-62 Identical to DIN EN 60068 PT2-62 Identical to EN 60068 PT2-62 Identical to NEN 10068-2-62 Identical to NF EN 60068-2-62

Table 8.17 Examples of test severities typically employed for various applications (taken from the equivalent standard EN 60068 PT2-6 by kind permission of the BSI)

Amplitude frequency range (Hz)	Number of sweep cycles to each axis			Examples of application
	$0.5 g_n$	$1 g_n$	$2 g_n$	
10–150	50	–	–	Stationary equipment such as large computers
10–150	–	20	20	Equipment intended for installation in or transported by railway vehicles and land vehicles
1–35	–	100	100	Equipment mounted adjacent to heavy rotating machinery
10–2000	–	10	–	Equipment for high speed trains, mounted close to (but not within) the engine compartment

8.4.12.1 Introduction

Electrical accessories such as switches, lampholders and wall mounted power outlets may, during operation, transportation or storage, be subjected to damage by impacting with foreign bodies. IEC 68.2.62 evaluates a component's capability of surviving these shocks.

8.4.12.2 Purpose of this test

The purpose of this test is to provide a standard method of test for determining the ability of an electrotechnical product to withstand specified severities of impact. It is mainly used to demonstrate an acceptable level of mechanical robustness when assessing the 'safety' of the product.

8.4.12.3 Test conditions

IEC 68.2.62 is primarily intended for the testing of specimens with electrical accessories, such as switches and lampholders. It consists of the application to the specimen of a prescribed number of horizontal impacts, each defined by the height of fall and mass of the pendulum hammer.

The test apparatus consists basically of a 1 m long pendulum comprising a rigid tube and a mass that strikes the specimen. This striking element, which is rigidly fixed to one end of the tube, comprises a steel body with a polyamide insert having a hemispherical face of 10 mm radius and a combined mass of 150 g $\pm$ 1 g.

The design of the apparatus is such that a force between 1.9 N and 2.0 N has to be applied to the striking element to maintain the tubular arm of the pendulum in a horizontal position.

8.4.12.4 Other standards

IEC 68.1	Environmental testing procedures – General and guidance
IEC 68.2	Environmental testing procedures – Tests
IEC 68.2.47	Environmental testing procedures – Mounting of components, equipment and other articles for dynamic tests including Shock (Ea), Bump (Eb), Vibration (Fc and Fd) and Steady state acceleration (Ga) and guidance
IEC 68.2.63	Environmental testing procedures – Impact, spring hammer
IEC 1052	Steels for general engineering purposes
IEC 1098	Veneer plywood for general use – General requirements
IEC 721	Classification of environmental conditions
IEC 817	Spring operated impact-test apparatus and its calibration
ISO 2039.2	Plastics – determination of hardness – Rockwell hardness
ISO 2041	Vibration and shock – vocabulary

8.4.13 Acceleration, steady state test (IEC 68.2.7 Test Ga)

Standard No.	IEC 68.2.7
Title	Environmental testing procedures – Test Ga and guidance: Acceleration, steady state
Summary	Proves the structural suitability and the satisfactory performance of components and equipment when subjected to forces produced by steady acceleration environments (other than gravity) that occur in moving vehicles, rotating parts and projectiles, and to provide a test of structural integrity for certain components. Coverage includes initial measurements, severity and final measurements.
Equiv. Std	Identical to AS 1099.2.7 Identical to BS 2011:PT2.1Ga(1984) Identical to BS EN 60068 PT2-7 Identical to DIN EN 60068 PT2-7 Identical to DIN IEC 68 PT2-7 Identical to EN 60068 PT2-7 Identical to HD 323.2.7 Identical to NEN 10068-2-7 Identical to NFC 20-707 Identical to NF EN 60068-2-7 Identical to SEN 43 16 07

8.4.13.1 Introduction

Equipment components and other electrotechnical products installed on moving bodies will normally be subjected to forces caused by steady accelerations. IEC 68.2.7 provides a standard procedure to prove the structural suitability of equipment.

8.4.13.2 Purpose of this test

The purpose of this test is to prove the structural suitability and the satisfactory performance of equipment, components and other electrotechnical products when subjected to forces produced by steady state environments (other than gravity) such as occur in moving vehicles.

8.4.13.3 General conditions

In many applications, the forces on a moving body giving rise to acceleration are invariably complex. These forces can be considered, at any one instant, to be a single force which can be described in direction by its angular position relative to the three main axes of the moving body. For design purposes, the maximum acceleration levels for a particular manoeuvre of the moving body need to be specified with respect to each major axis of the moving body.

This test may also be used for establishing the satisfactory design and manufacture of a component, insofar as its structural integrity is concerned. Certain components, notably from the semiconductor industry, are checked for structural integrity (i.e. sound mechanical assembly) by the application of a very high acceleration. The tests are used as a simple means of applying a high stress to reveal possible constructional weaknesses.

8.4.13.4 Test conditions

IEC 68.2.7 describes a test to prove the structural suitability and the satisfactory performance of equipment, components and other electrotechnical products when subjected to forces produced by steady state environments.

Table 8.18 is a list of typical test severities.

Table 8.18 Examples of test severities typically employed for various applications

Acceleration, a (m/s^2)	Application
$30 < a < 100$	Proof level for specimens to be mounted in aircraft
$50 < a < 200$	Structural or ultimate level for specimens to be mounted in aircraft and for crash safety of mountings
$100 < a < 1000$	General testing for aerospace applications
$a > 5000$	Structural integrity tests for semiconductor devices, integrated circuits, etc.

8.4.13.5 Other standards

IEC 68.1 Environmental testing procedures – General and guidance

Chapter 9

Electrical

9.1 Guidance

9.1.1 What is electrical?

Electrical and electronic engineering is recognised as probably the largest and most diverse field of engineering and is concerned with the development, design, application and manufacture of systems and devices that use electric power and signals. Among the most important subjects in the field are electric power and machinery, electronic circuits, control systems, computer design, superconductors, solid state electronics, medical imaging systems, robotics, lasers, radar, consumer electronics and fibre optics.

9.1.2 Introduction

Electrical engineering can be divided into two main branches: electric power and electronics.

Electric power
Electric power is concerned with the design and operation of systems for generating, transmitting and distributing electric power.

One of the most important developments in the last 30 years has been the ability to transmit power at extremely high voltages in both the direct current (d.c.) and alternating current (a.c.) modes, reducing power losses proportionately.

Electronics
Electronic engineering deals with the research, design, integration and application of circuits and devices used in the transmission and processing of information.

Electronic engineers design circuits to perform specific tasks, such as amplifying electronic signals, adding binary numbers and demodulating radio signals to recover the information they carry.

9.1.3 Test categories

9.1.3.1 Performance test

This sort of test requires the electronic assembly, or its subassemblies, to be subjected to a complete examination of its/their performance in order to determine whether it/they correspond to the specification.

Correct operation of all the electronic control equipment should be checked within the normal limits of system voltage, battery voltage and air pressure.

In particular, checks should be made to see that the operation of the equipment is not disturbed during start-up of any auxiliary services (e.g. lighting, an auxiliary set, compressor, etc.) and power circuits (e.g. a chopper, combustion engine, etc.). Checks should also be made to establish whether any interference produced by electronic control devices disturbs other equipment, in particular data transmission installations, safety devices, etc. (e.g. see EN 50155).

9.1.3.2 Dielectric test

The aim of this test which is carried out on printed board assemblies (by sampling) is to ensure components are not mounted too close to surrounding metal parts.

The test has to be carried out with the printed board connected in its place of operation. The test voltage (of a nominal frequency of 50 Hz or 60 Hz) is then applied for 1 minute between all the terminals (with the printed board short-circuited) and the metal rack of the electronic assembly.

For dielectric tests the r.m.s. value of the test voltage is as follows:

Table 9.1 r.m.s. test voltage values

500 V	For rated supply voltages up to and including 72 V
1000 V	For rated supply voltages between 72 V and 125 V

Note: The test is considered satisfactory if neither a disruptive discharge nor a flashover occurs.

9.1.3.3 Voltage surge test

All terminals of the electronic equipment which are directly connected magnetically or statically coupled to external circuits and which are likely to produce voltage surges that could cause damage to electronic equipment are normally subjected to a voltage surge test.

During this test a surge voltage of an agreed waveform (see Table 9.2) is applied at the points of connection between the electronic equipment and external circuits of the operating equipment.

The surge voltage should be applied in both directions (positive and negative) and in the case of power supply connections, the surge voltages should be superimposed on the nominal supply voltage.

The waveform parameters are normally agreed between the user and the manufacturer and are typically:

Table 9.2 Waveform of normally permitted voltage surges

$\hat{U}$	$1.5\,kV \pm 3\%$
Impedance (resistive)	$100\,\Omega \pm 20\%$
D	$50\,\mu s \pm 20\%$

The test should be considered as satisfactory if the equipment continues to operate without malfunction or damage both during and following application of the voltage surge.

9.1.3.4 Cooling test

The electronic assembly under test is placed, without any voltage applied, in a room where the temperature is progressively lowered from the ambient temperature (25°C ± 10°C) to −25°C, or to the lowest agreed temperature over a period of time equal to or greater than 30 minutes.

The assembly is then kept for a further period of 2 hours at this low temperature with a permitted tolerance of ± 3°C.

At the end of this period, a performance test (see 9.1.3.1) needs to be carried out with the equipment kept at this low temperature.

9.1.3.5 Temperature-rise test (dry heat)

For this particular test, the electronic assembly (which is normally supplied with power) is placed in a room where the temperature is progressively raised from the ambient temperature (25°C ± 10°C) to 70°C (with a tolerance of ± 2°C) or to the highest agreed temperature over a period of time equal to or greater than 30 minutes.

The assembly should then be kept for 6 hours at this temperature, at the end of which a performance test should be carried out.

9.1.3.6 Temperature-rise test (damp heat)

The electronic assembly is placed, without any voltage being applied, in a chamber where the temperature is raised from the ambient temperature

(25°C ± 10°C) to 55°C ± 2°C over a period of time between $1\frac{1}{2}$ hours and $2\frac{1}{2}$ hours. The relative humidity being stabilised between 80% and 100%.

The temperature is then maintained for a further period of 10 hours within the limits of 55°C ± 2°C, with a relative humidity of 95% to 100%.

At the end of this time, the temperature is lowered to the ambient temperature (25°C ± 10°C), over a period of 3 hours, with the relative humidity being between 80% and 100%. After this cycle, a performance test and a dielectric test needs to be completed.

Note: IEC Test 68.2.30: Damp heat, cyclic (12 + 12 hour) is the preferred test as it more closely represents those conditions in which equipment will be stored or operated. (See paragraph 4.4.3.)

9.1.3.7 Test in a corrosive atmosphere (e.g. salt mist)

In this test the test chamber is kept tightly closed and if the test includes the necessity for a salt solution, it should continue without interruption during the whole conditioning period. The duration of the test is chosen so as to suit the intended purpose and should be subject to an agreement between the user and the manufacturer.

At the end of the test, the equipment is then washed under a running tap for 5 minutes or rinsed in distilled or demineralised water. It is then shaken by hand (to remove any droplets of water) and stored under standard atmospheric conditions in the testing area for not less than 1 and not more than 2 hours.

After this storage period, the components are then subjected to a visual examination, followed by measurements and verification tests necessary to check their correct operation.

Note: IEC 68.2.11 and 68.2.52 are the recommended tests for salt mist and cyclic salt mist environmental parameters. (See paragraphs 6.4.1 and 6.4.3.)

9.1.3.8 Combined dust, humidity and heat test

The electronic assembly, in operating condition, is placed in a room where the temperature is progressively raised from the ambient temperature (25°C ± 10°C) to 70°C or to the highest agreed temperature (with a tolerance of ±2°C) for between $1\frac{1}{2}$ hours and $2\frac{1}{2}$ hours (depending on the customer), with a relative humidity of 80% to 100%.

Dust (which is normally specified and, if necessary, provided by the user at the time of specifying the item) is sprayed over the electronic assembly. The quantity and the method of application are subject to an agreement between the user and the manufacturer.

At the end of this test, a performance test and a dielectric test should be carried out.

Note: IEC 68.2.68: Environmental testing procedures – Dust and sand is a more stringent test than this basic test and is recommended (see paragraph 7.4.4).

9.1.3.9 Vibration, shock and bump test

The complete electronic assembly (or subassembly) together with any auxiliaries and mounting arrangements (including its shock absorbing devices if the equipment is designed for mounting on such devices) should be subjected to the tests in three orthogonal planes under the ambient temperature condition of the testing area.

For these tests, the equipment should be secured in a suitable position to a machine producing sinusoidal vibrations with an adjustable amplitude and frequency.

In order to determine the possible existence of critical resonant frequencies producing resonance during this test, the frequency should be varied progressively from 1 Hz to 100 Hz within a time of not less than 4 minutes. The amplitude of the oscillations being a function of the frequency.

If resonance is produced, the corresponding frequency should be maintained for a few minutes in each case.

The equipment is then subjected to a test with sustained vibrations for not less than 15 minutes (to be agreed between the user and the manufacturer), either at the critical frequencies or, otherwise, at a frequency of 10 Hz.

9.1.3.10 Watertightness test

As electronic equipment is generally mounted either inside a room or a vehicle or in external boxes, there is no real need to carry out watertightness tests. In exceptional cases, however, tests can be carried out in accordance with clause 7 of IEC 165 and clause 8 of IEC 490.

Note: Current thinking suggests that watertightness tests are, however, very relevant in some circumstances (e.g. equipment exposed to rain, water jets, etc.) and the reader is referred to Section 6.4 for the appropriate tests.

9.1.4 Other related tests and standards

This book, by its very nature, recommends numerous alternative tests to those shown above and the reader's attention is drawn to the relevant chapters.

9.2 Typical contract requirements – electrical

The requirement for equipment to conform to various environmental specifications is becoming commonplace in many of today's contracts. More and more specifications are being used to describe the various conditions that equipment is likely to experience when being used, stored or whilst in transit.

The following are the most common environmental requirements found in modern contracts concerning electrical conditions.

9.2.1 Supply voltages

Equipment will normally be required to operate on one particular voltage. There are, however, occasions when they may be required to be capable of being switched between various values (e.g. 110 V and 240 V). Equipment manufacturers should be aware (and users should specify) very precisely in the contract exactly what type and range of voltages, power consumption and so on have been taken into account.

9.2.1.1 Primary main (a.c.)

In today's world market the nominal supply voltage (U_n) of equipment can be any of the following values:

Table 9.3 Primary main (a.c.) requirements

50 Hz	3 × 230/400 V
	1 × 230 V
	1 × 127 V
	1 × 110 V
$16\frac{2}{3}$ Hz	1 × 220 V
	1 × 440 V
	(2 × 220 V)

9.2.1.2 Supply from an accumulator battery

The nominal voltage for equipment supplied by an accumulator battery is the voltage specified for that particular battery. This voltage range can be quite enormous (depending on the application of the equipment) and should be clearly specified in the technical annex attached to the contract. The following are some examples:

Table 9.4 Accumulator battery supplies

Either	24 V, 48 V, 72 V, 96 V, 110 V	For mobile/transportable equipment
Or	12 V, 24 V, 36 V, 48 V, 60 V, 72 V, 144 V	For fixed equipment

The reader should note that these nominal voltage values are provided only as standardised reference values to assist in the design of equipment.

They should *not* be considered as off-load battery voltages which are determined as functions of the type of battery, the number of cells and the operating conditions.

Another requirement is usually that all electronic equipment supplied by accumulator batteries without a voltage stabilising device must operate satisfactorily for all values of supply voltage within the range defined in Table 9.5 (measured at the input terminals of the equipment).

Table 9.5 Voltage supply variations

Nominal voltage	U_n
Minimum voltage	$0.7U_n$
Rated voltage	$1.15U_n$
Maximum voltage	$1.25U_n$

When equipment is supplied with power alternately from an accumulator battery and a stabilised source (d.c.), the equipment should operate satisfactorily under all conditions.

9.2.2 Variations in supply voltage

The following are the maximum CENELEC permitted variations

Table 9.6 Maximum permitted a.c./d.c. variations

AC/50 Hz: Voltage:	±10/15%
Frequency:	±2% (class 2 IEC 77B)
	±4% (class 3 IEC 77B)
AC/16⅔ Hz: Voltage:	±20% (catenary)
Frequency:	±2%
DC Voltage:	±10/20% without battery or by Pb battery
Ripple:	±16/29% by Ni/Cd battery

For supply voltages less than $0.7U_n$, every precaution must be taken to prevent any damage being caused to electronic equipment which may adversely affect its subsequent satisfactory operation.

One frequent contract requirement is that voltage fluctuations lying between $0.6U_n$ and $1.4U_n$ (and not exceeding 0.1 seconds) should not affect operating equipment – particularly during start-up of auxiliary equipment and/or voltage oscillations of battery chargers.

Also, voltage fluctuations lying between $1.25U_n$ and $1.4U_n$ (and not exceeding 1 second) should not cause damage to equipment.

Note: equipment need not be fully operational during these fluctuations.

9.2.2.1 d.c. ripple factor

All batteries on charge have a pulsating voltage of which the d.c. ripple factor, unless otherwise stated, should be no greater than 15% calculated from the following equation:

$$\text{d.c. ripple factor} = \frac{U_{max} - U_{min}}{U_{max} + U_{min}} \times 100$$

where U_{max} and U_{min} are the maximum and minimum values of the pulsating voltage.

9.3 Values and ranges

There are no specific values and ranges associated with this section other than those already indicated in the text or referenced standards.

9.4 Tests

There are no specific tests associated with this section other than those already indicated in the text or through referenced standards.

Chapter 10

Electromagnetic compatibility

10.1 Guidance

10.1.1 What is EMC?

Most car owners normally accept that when they drive near electric pylons, their listening pleasure will be interrupted by loud crackles and/or buzzing noises. With the increased use of electronic equipment, however, the problem of interference has become one of our prime concerns. Although most forms of interference are usually tolerated as being one of those things 'that you cannot do much about', the design of modern sophisticated equipment has become so susceptible to electromagnetic interference that some form of regulation has had to be agreed.

Within Europe, this regulation is contained in Council Directive number 98/336 which clearly states that all electronic equipment shall be constructed so that:

- the electromagnetic disturbance it generates does not exceed a level allowing radio and telecommunications equipment and other apparatus to operate as intended;
- the apparatus has an adequate level of intrinsic immunity to electromagnetic disturbance.

10.2 The EMC Directive (89/336/EEC)

The main requirement of the EMC Directive (89/336/EEC, as amended by Directives 92/31/EEC and 93/68/EEC) is to ensure that throughout Europe the use of electronic equipment does not interfere with the operation of other equipment.

Under the terms of these publications, as of 1 January 1996, all active electronic devices have had to comply with the EMC Directive and only

CE (Conformity Europe) marked equipment may be offered for sale. All active equipment connected to a network shall, therefore, be required to carry a CE mark and by virtue of this mark the user of such equipment has the suppliers' guarantee of compliance with the EMC Directive.

10.2.1 EMC Directive – main clauses

10.2.1.1 Objectives

To harmonise national provisions on electromagnetic disturbance levels by establishing protection requirements and referring the task of defining the characteristics of the products to European or national standards.

10.2.1.2 Application

The Directive applies to a wide sweep of equipment including in the widest sense all electrical apparatus, equipment and installations (including vehicles, electricity, transport and telecommunications distribution and transport networks) likely to cause, or be affected by, electromagnetic disturbance. The annex to the Directive includes a list of the equipment covered by the Directive as well as the equipment not covered.

10.2.1.3 Requirement

The Directive states that apparatus shall be so constructed that:

- the electromagnetic disturbance it generates does not exceed a level allowing radio and telecommunications equipment and other apparatus to operate as intended;
- the apparatus has an adequate level of intrinsic immunity to electromagnetic disturbance.

10.2.1.4 Assessment procedures

The Directive provides for three assessment procedures for the conformity of apparatus:

- a procedure for apparatus for which the manufacturer has applied harmonised standards;
- a procedure for apparatus for which the manufacturer has not applied, or has applied only in part, the harmonised standards, or where standards do not exist;
- a procedure for apparatus designed for the transmission of radio communications.

10.2.1.5 Assessment bodies

The Directive refers to three bodies with different functions:

- 'Competent authorities', represented by the national administrations, which are responsible for the application of the relevant obligations;
- 'Competent bodies', which meet the criteria listed in the Directive and

which are responsible for issuing the technical reports or certificates in accordance with the second procedure described in the assessment procedures;
- 'Notified bodies', which meet the criteria listed in the Directive and which are responsible for issuing the EC type examination certification in accordance with the third procedure described in the assessment procedures.

10.2.1.6 Conformity mark

All apparatus covered by the Directive (and accompanied by one of the attestations that the Directive provides for) must bear the CE conformity mark.

10.2.1.7 Emission limits

Emission limits are generally set depending upon the type of equipment, e.g.:

• IT equipment	emission limits set in EN 55022;
• Radio equipment and systems	emission limits set in prETS 300339;
• Residential, commercial and light industry	emission limits set in EN 50081.1;
• Industrial environment	emission limits set in EN 50081.2;
• Railway applications	emission limits set in ENV 50121.

10.3 Enforcement of the EMC Directive

In the UK, enforcement of the EMC Directive is principally carried out by Local Authority Trading Standards Departments and the Department of Trade and Industry (DTI). Enforcement is primarily complaints driven rather than by market surveillance. The DTI has also adopted a softly-softly approach in the initial years that the EMC Directive is mandatory. It expects Trading Standards Officers to use a fair degree of discretion in dealing with non-compliant products, helping manufacturers to comply without resorting to formal enforcement measures, wherever possible.

Although other European countries have different arrangements for enforcement, the situation is unlikely to be very different from the UK.

The European Commission is reported as saying that enforcement is a key factor in the successful implementation of the New Approach Directives. It has a formal procedure to ensure that Directives are properly implemented and enforced in each Member State and, against some people's expectations, the Commission is likely to take steps if it feels that Member States are not enforcing Directives!

A system has been set up, therefore, to allow administrative co-operation between officials in different countries. This will ensure, for example, the rapid circulation of information on non-compliant products or habitually offending companies.

Clearly, however, companies should not become complacent. The regulations exist and are now being implemented as European law and self-policing has proved to be one of the most cost effective ways of enforcing new laws.

10.4 Application of Council Directive 89/336/EEC

The guidelines for the 'Application of Council Directive 89/336/EEC' were first released in October 1993. In April 1996, government experts decided to rewrite them, a decision greatly influenced by industry and trade associations. The result was a document radically different from the original and considered by many as not being pragmatic.

In an effort to pacify Member States, a think-tank was set up to 'rework the rewrite', concentrating on areas in the text that caused concern due to translation problems. The revised document (which is officially only produced in English) is now available from the DTI but as the document is only intended to provide guidance when applying the Directive, it is bound to be seen as a means to an end for some manufacturers struggling with compliance.

However, whilst it should be remembered that the guidelines are only an interpretation of the Directive by a small group of representatives of the Member States, they do, nevertheless, represent an agreement between them on the most important points made in the Directive and are considered by the group to give a clear explanation on those points.

The definitions of components and systems also underwent a facelift and an area that was expected to be controversial was the addition of a clause that states a system made up of CE marked subassemblies can itself be CE marked automatically.

As Phillip Ling so poignantly pointed out in the 23 September 1997 issue of *New Electronics*, 'CE = CE = CE?'; this caused concern with members of the EMC community and quite rightly so. The fact that a single subassembly operates within the specified limits laid down by the relevant standards is no guarantee that a system containing two or more units will still comply.

Yet a system falling outside of the scope of the Directive has been covered by the statement that such a system should be considered as 'an optional combination of apparatus put together by an end user to perform a specific task' and, as such, could be assumed justifiably to be compliant to:

- the individual parts were CE marked; and
- were not placed on the market with the intention of operation together as a single functional unit.

10.5 Small businesses

Currently, the European Commission receives more angry mail about the EMC Directive than on any other subject. Most of these letters come from small businesses complaining about the additional burden being inflicted upon them.

However, whilst there is nothing in the Directive specifically aimed at the requirements of small businesses, being a New Approach Directive, it has been specifically designed so as not to handicap business or stifle innovation.

Thus while the Directive must contain a reference to harmonised standards, it does not need to state that any testing has been undertaken to these or to any other specifications. It is up to the signatory to consider whether the product would have passed if tested and to decide what risks are justified in the particular circumstances.

Enforcement of the EMC Directive works on the principle that action is taken by enforcers local to the manufacturer and non-compliant products are referred to the Trading Standards Officers who have a strict duty under EMC regulations to follow up these cases.

Already several cases have been investigated in the UK and the results have been expensive for 16 non-compliant companies. For instance, as a result of an official complaint from one of the company's competitors, a Warwickshire firm manufacturing a household product had that item removed from the market after the Trading Standards Officer found that it contravened EMC regulations.

Worst of all, it took three months to redesign the product and retool the factory!

In another similar case, two PC assemblers were successfully prosecuted and fined in Wales for a non-compliant one-off product. Although in these cases there was no stock to seize, if a mass produced item fails, Trading Standards Officers would seize the entire stock.

10.6 Interference and other contract considerations

10.6.1 Exposure to interference

The amount of time an equipment is exposed to interference is a direct relationship to the actual electrical environment in which it is situated. In particular, it should be noted that interference can penetrate equipment on the electrical boundaries between the equipment and the electrical environment. Typically, these boundaries are:

- power supply lines;
- input lines;
- output lines;
- equipment enclosures.

10.6.2 Nature of the interference

A feature of the electrical/electronic environment is the wide range of amplitudes and frequencies that can cause electrical interference. The most important being:

- supply frequency interference;
- high frequency burst interference;
- fast transient impulsive interference.

But the problems that can occur as a result of electromagnetic environmentally supported disturbances (such as electrical storms) should also be considered.

10.6.2.1 Supply frequency interference

This interference originates from equipment power supply lines and from the traction supply in electrified areas. In a.c. electrified areas the dominant frequency is 50 Hz, which may be subject to significant harmonic distortion.

In d.c. electrified areas frequencies of 300 Hz and 1200 Hz may be present. Supply frequency interference is characterised by being of generally constant long-term amplitude at each site, but with extreme short-term variations under load changes, fault conditions, or supply changeovers.

10.6.2.2 High frequency burst interference

High frequency burst interference is caused by a sequence of sinusoidal bursts with frequencies up to several hundred kHz. Each burst decays over several tens of microseconds, with intervals of about 10 milliseconds (i.e. half a cycle of 50 Hz a.c.) between bursts.

10.6.2.3 Fast transient impulsive interference

Fast transient impulsive interference is caused by several frequencies in the MHz frequency region. Each burst decays over several hundred nanoseconds, with intervals of a few microseconds between bursts and with intervals of about 10 milliseconds (i.e. half a cycle of 50 Hz a.c.) between each sequence of bursts.

10.6.3 Electromagnetic environmental supported disturbances

10.6.3.1 Atmospheric discharges

Within Europe, electrical storms are comparatively rare as can be seen in the following table:

Table 10.1 Atmospheric discharges

Storm frequency	12–36 stormy days per year
Average duration of storm	1.5 h
Number of discharges	1–5.5

Although relatively infrequent, these storms can produce atmospheric discharges in the region of 40–100 kA/μs, together with a discharging current of 10–100 kA. These storms can have an effect on power supplies and communication lines and overvoltages may appear at connection points.

10.7 Typical contract requirements – EMC

10.7.1 Transients

All electronic equipment should be capable of withstanding transients (either directly induced or indirectly coupled) so that no damage or failure occurs during operation – assuming, that is, that the equipment will be used *only* for its intended purpose.

10.7.1.1 Power supplies

The following transients may be encountered on the power supply:

Table 10.2 Power supply transients

Voltage	Duration	Source impedance	Energy
1.5 kV	10 μs	200 W	0.1 mJ
3.5 kV	0.1 μs	500 W	3 mJ
600 V	1 ms	15 W	6 J
300 V	1 ms	2 W	20 J

Note
The power supply may also be subject to considerable harmonic distortion.

10.7.1.2 Permitted transient surges

The electronic equipment should withstand, without damage or abnormal operation, transient non-repetitive surges with an interval greater than 5000 times the duration of the surge. The transient surges should, with respect to the zero potential of the supply, be applied at the points of connection with external circuits, having $\ddot{U}$ amplitudes in accordance with Table 10.3.

Table 10.3 Permitted transient surges

Amplitude $\ddot{U}$ (kV)	$D(^*)$ (μs)
7.0	0.1
4.0	1.0
3.0	5.0
1.5	50
0.8	100

Note
$(^*)$ = time during which the overvoltage exceeds half the amplitude $\ddot{U}$.

10.7.2 Atmospheric disturbances

To counteract the effects of storms, it is generally recommended that all equipment should be capable of withstanding (as a minimum) the following overvoltages.

Table 10.4 Overvoltage characteristics

Magnitude	2000 V
Rise time	1.2 μS
Middle voltage time	50 μS

If the electronic equipment is not earthed, the voltage should be measured with respect to the vehicle frame.

10.7.2.1 Interference coupling paths

The interference coupling paths to be considered are as follows:

- power supply;
- input/output connections;
- data transmission lines;
- internal equipment wiring and printed circuit tracks.

10.7.3 Equipment immunity levels

10.7.3.1 Input/output lines

Most contracts will state that:

- 'equipment should be immune to induced common-mode voltages with respect to earth up to and including 110 V r.m.s. per kilometre length of input/output line on any line or combination of lines';
- 'if an induced common-mode voltage (with respect to earth), greater than 110 V r.m.s. per kilometre length of In Out (I/O) line, but less than

or equal to 440 V r.m.s. per kilometre length of I/O line, appears on any I/O line or combination of I/O lines, then the equipment will be permitted to adopt a temporary loss of availability';
- 'the equipment should not experience a permanent loss of availability or suffer component damage for any induced common-mode voltage within this range'.

10.7.3.2 Power supply lines

Contracts will normally state that equipment should be immune to high frequency bursts (see Table 10.5) generated as specified above and which will be coupled into the power supply lines (also see Test specifications).

Table 10.5 Test severity – power supply lines

Initial peak to peak voltage	1 kV
Burst repetition rate	5 kHz

The test procedure and the resulting evaluation for each item of equipment should be as specified for that particular equipment in the contract.

10.7.4 Power consumption

The supplier of the electronic equipment is normally required by the purchaser to specify its power consumption in order to enable calculations for the battery cabling.

10.7.5 Magnetic field

As low frequency fields can influence cathode ray tubes most contracts will recommend that equipment should be capable of withstanding these intensities, as follows:

Table 10.6 Magnetic field intensities

Hz	A/m
5	0.8
50	3.0
250	1.5

10.7.6 Harmonics

The harmonic contents shown in Table 10.7 are the usual permitted values.

Table 10.7 Harmonic contents

Rank (n)	Public network – Vh(%)[1] (class 2)	Railway network – Vh(%)[1] (class 3)
Even rank		
2	2.0	3.0
4	1.0	1.5
6	0.5	1.0
8	0.5	1.0
10	0.5	1.0
12	0.2	1.0
>12	0.2	1.0
Inter-harmonic components		
<11	0.2	2.5
11–13	0.2	2.25
13–17	0.2	2.20
17–19	0.2	2.0
19–23	0.2	1.75
23–25	0.2	1.5
>25	0.2	1.0
Odd rank not multiple of three		
5	6.0	8.0
7	5.0	7.0
11	3.5	5.0
13	3.0	3.5
17	2.0	4.0
19	1.5	4.0
23	1.5	3.5
25	1.5	3.5
>25	0.2	5.0
Odd rank multiple of three		
3	5.0	6.0
9	1.5	2.5
15	0.3	2.0
21	0.2	1.75
>21	0.2	1.0

Vh: Max relative r.m.s. fundamental ratio.
1 IEC 77 values.

10.7.7 Input/output connections from apparatus cases

Input/output connections from apparatus cases should always be of non-screened, non-balanced signalling cable and are normally restricted in length.

10.7.8 Local data transmission links

All local data transmission links (up to 10 km) are normally required to use screened, twisted-pair cables.

10.7.9 Long distance, point to point, data transmission

All long distance, point to point, data transmission using normal telecommunications cable are usually required to use balanced quad pairs.

10.7.10 Special precautions

The manufacturer should always draw attention to any precaution that is necessary with respect to the wiring external to the equipment.

10.7.11 Earthing

The requirement to earth exposed metalwork is normally specifically requested by the user in the contract.

10.8 EMC related standards

The following are the main standards associated with EMC, details of which have been extracted (with permission) from Infonorme London Information's (ILI) Standards Information Disk.

10.8.1 EN 45001

Standard No.	EN 45001
Title	General criteria for the operation of testing laboratories
Summary	Describes general criteria for the technical competence of testing laboratories including calibration laboratories. Intended for the use of testing laboratories and their accreditation bodies as well as other bodies concerned with recognising the competence of testing laboratories. May have to be supplemented when applied to a particular sector. Covers definitions, legal identity, impartiality, independence and integrity and technical competence.
Equiv. Std	Identical to BS 7051(1989) Identical to DIN EN 45001 Identical to DIN V 45688(PT1) Identical to DIN V 45688(PT2) Identical to DIN V 45688(PT3) Identical to ISO/IEC Guide 25

	Identical to NBN EN 45001
	Identical to NEN EN 45001
	Identical to NF EN 45001
	Identical to SS EN 45001
	Identical to UNI CEI EN 45001

10.8.2 EN 45002

Standard No.	EN 45002
Title	General criteria for the assessment of testing laboratories
Summary	Provides general criteria for the procedures used in the assessment of testing laboratories including calibration laboratories. Intended for the use of testing laboratories and their accreditation bodies as well as other bodies concerned with recognising the competence of testing laboratories. May have to be supplemented when applied to a particular sector. Covers definitions, accreditation criteria, scope of accreditation, application for accreditation and accreditation process.
Equiv. Std	Identical to BS 7052(1989)
	Identical to DIN EN 45002
	Identical to DIN V 45688(PT1)
	Identical to DIN V 45688(PT2)
	Identical to DIN V 45688(PT3)
	Identical to ISO/IEC Guide 28
	Identical to NBN EN 45002
	Identical to NEN EN 45002
	Identical to NF EN 45002
	Identical to SS EN 45002
	Identical to UNI CEI EN 45002

10.8.3 EN 45003

Standard No.	EN 45003
Title	Calibration and testing laboratory accreditation system – General requirements for operation and recognition
Summary	Sets out the general requirements for the operation of a system for accreditation of calibration and/or testing laboratories. Gives advice for the setting up and operation of an accreditation body and to help with agreements on mutual recognition of accreditation of laboratories between these bodies.
Equiv. Std	Identical to BS EN 45003
	Identical to DIN EN 45003
	Identical to DIN V 45688(PT1)
	Identical to DIN V 45688(PT2)

	Identical to DIN V 45688(PT3)
	Identical to ISO/IEC Guide 58
	Identical to NBN EN 45003
	Identical to NEN EN 45003
	Identical to NF EN 45003
	Identical to SS EN 45003
	Identical to UNI CEI EN 45003

10.8.4 EN 45004

Standard No.	EN 45004
Title	General criteria for the operation of various types of bodies performing inspection
Summary	Specifies general criteria for the competence of impartial bodies performing inspection irrespective of the sector involved. Meant for the use of inspection bodies and their accreditation bodies as well as other bodies concerned with recognising the competence of inspection bodies. Does not cover testing laboratories, certification bodies or the supplier's declaration of conformity.
Equiv. Std	Identical to BS EN 45004 Identical to DIN EN 45004 Identical to NF EN 45004 Identical to UNI CEI EN 45004

10.8.5 EN 45011

Standard No.	EN 45011
Title	General criteria for certification bodies operating product certification
Summary	Provides general criteria that a certification body operating product certification follows in order to be recognised at a national or European level as competent and reliable. Intended for the use of bodies concerned with recognising the competence of certification bodies. May have to be supplemented when applied to a particular sector. Covers definitions, general requirements, administrative structure, terms of reference of governing board, organisational structure, certification personnel and documentation and change control.
Equiv. Std	Identical to BS 7511(1989) Identical to DIN EN 45011 Identical to NBN EN 45011 Identical to NEN EN 45011 Identical to NF EN 45011 Identical to UNI CEN EN 45011

10.8.6 EN 45012

Standard No.	EN 45012
Title	General criteria for certification bodies operating quality system certification
Summary	Provides general criteria that a certification body operating quality system certification has to follow in order to be recognised at a national or European level as competent and reliable. Intended for the use of bodies concerned with recognising the competence of certification bodies. Covers definitions, general requirements, administrative structure, terms of reference of governing board, organisational structure, certification personnel, documentation and change control and records.
Equiv. Std	Identical to BS 7512(1989) Identical to DIN EN 45012 Identical to NBN EN 45012 Identical to NEN EN 45012 Identical to NF EN 45012 Identical to UNI CEN EN 45012

10.8.7 EN 45013

Standard No.	EN 45013
Title	General criteria for certification bodies operating certification of personnel
Summary	Gives general criteria that a certification body operating certification of personnel shall follow in order to be recognised at a national or European level as competent and reliable. Intended for the use of bodies concerned with recognising the competence of certification bodies. Covers definitions, general requirements, administrative structure, terms of reference of governing board, organisational structure, certification personnel, documentation and change control and records.
Equiv. Std	Identical to BS 7513(1989) Identical to DIN EN 45013 Identical to NBN EN 45013 Identical to NEN EN 45013 Identical to NF EN 45013 Identical to UNI CEN EN 45013

10.8.8 EN 45014

Standard No.	EN 45014
Title	General criteria for supplier's declaration of conformity
Summary	Describes general criteria for supplier's declarations of conformity in cases where it is desirable (and even necessary) that conformity of products with standards or other normative documents be indicated, irrespective of the sector involved. Covers definitions, normative document standard, declaration of conformity supplier, objective of declaration, general requirements, contents of declaration and form of declaration.
Equiv. Std	Identical to BS 7514(1989) Identical to DIN EN 45014 Identical to NBN EN 45014 Identical to NEN EN 45014 Identical to NF EN 45014 Identical to UNI CEN EN 45014

10.8.9 EN 50081.1

Standard No.	EN 50081.1
Title	ElectroMagnetic Compatibility – Generic emission standard – Residential, commercial and light industry
Summary	Describes electrical and electronic apparatus for use in a residential, commercial and light-industrial environment where no dedicated product or product-family emission standard exists. Apparatus designed to radiate electromagnetic energy for radio communications purposes is excluded. Disturbances in the frequency range 0 Hz to 400 GHz are covered. Where a relevant dedicated product or product-family EMC emission standard exists, this shall take precedence. Fault conditions of apparatus are not taken into account. Apparatus installed in the locations covered by this standard are considered to be connected to low voltage public mains supplies or to a dedicated d.c. source.
Equiv. Std	Identical to AS 4251.1 Identical to BS EN 50081 PT1 Identical to DIN EN 50081 PT1 Identical to NBN EN 50081-1 Identical to NEN EN 50081-1 Identical to NF EN 50081-1 Identical to VDE 0839(PT81-1)

10.8.10 EN 50082.1

Standard No.	EN 50082.1
Title	ElectroMagnetic Compatibility – Generic immunity standard – Residential, commercial and light industry
Summary	Describes electrical and electronic apparatus for use in a residential, commercial and light-industrial environment for which no dedicated product or product-family immunity standard exists. Apparatus designed to radiate electromagnetic energy for radio communications purposes is excluded. Where a relevant dedicated product or product-family EMC immunity standard exists, this shall take precedence over all aspects of this generic standard. The immunity requirements have been selected so as to ensure an adequate level of immunity for apparatus at residential, commercial and light-industrial locations. The levels do not, however, cover extreme cases which may occur in any location but with an extremely low probability of occurrence.
Equiv. Std	Identical to AS 4252.1 Identical to BS EN 50082 PT1 Identical to DIN EN 50082 PT1 Identical to NBN EN 50082-1 Identical to NEN EN 50082-1 Identical to NF EN 50082-1 Identical to VDE 0839(PT82-1)

10.8.11 EN 50082.2

Standard No.	EN 50082.2
Title	ElectroMagnetic Compatibility – Generic immunity standard – Industrial environment
Summary	Describes electrical and electronic apparatus for use in an industrial environment for which no dedicated product or product family immunity standard exists.
Equiv. Std	Identical to BS EN 50082 PT2 Identical to DIN EN 50082 PT2 Identical to NEN EN 5008-2 Identical to NF EN 50082-2 Identical to SS EN 50082-2 Identical to VDE 0839(PT82-2)

10.8.12 EN 55020

Standard No.	EN 55020
Title	ElectroMagnetic Immunity of broadcast receivers and associated equipment.
Summary	Gives immunity requirements, in the 0 Hz to 400 GHz

	frequency range, for television broadcast receivers, sound broadcast receivers and associated equipment meant for use in commercial, residential and light industrial environment.
Equiv. Std	Identical to BS EN 55020 Identical to DIN EN 55020 Identical to NBN EN 55020 Identical to NEN EN 55020 Identical to NF EN 55020 Identical to NFC 91-022 Identical to SS EN 55020 Identical to VDE 0872(PT20)

10.8.13 EN 55022

Standard No.	EN 55022
Title	Limits and methods of measurement for radio disturbance characteristics for information technology equipment
Summary	Gives procedures for measuring the levels of spurious signals generated by information technology equipment (ITE). Specifies limits in the frequency range 0.15 MHz to 1000 MHz for both Class A and Class B equipment. Also includes detailed definitions.
Equiv. Std	Identical to BS 6527(1988) Identical to BS EN 55022 Identical to CISPR 22 Identical to DIN EN 55022 Identical to NBN EN 55022 Identical to NEN EN 55022 Identical to NFC 91-022 Identical to NF EN 55022 Identical to VDE 0878(PT2) Identical to VDE 0878(PT3)

10.8.14 EN 61000.2.4

Standard No.	EN 61000.2.4
Title	ElectroMagnetic Compatibility (EMC) – Environment – Compatibility levels in industrial plants for low frequency conducted disturbances
Summary	Gives the requirements for compatibility levels for industrial and non-public networks. Applies to low voltage and medium voltage a.c. power supplies at 50 Hz/60 Hz. Deals with the parameters of voltage deviations from the ideal sinusoidal voltage that may be expected at the Inplant Point of Coupling (IPC) within

	industrial plants or other non-public networks. Is a classification of the a.c. supplies associated with industrial and non-public networks.
Equiv. Std	Identical to BS EN 61000 PT2-4 Identical to DIN EN 61000 PT2-4 Identical to IEC 1000 PT2-4 Identical to NEN 11000-2-4 Identical to NF EN 61000.2.4 Identical to SS EN 61000-2-4 Identical to VDE 0839(PT2-4)

10.8.15 EN 61000.2.9

Standard No.	EN 61000.2.9
Title	ElectroMagnetic Compatibility (EMC) – Environment – Description of HEMP environment – Radiated disturbance – Basic EMC publication
Summary	Specifies the High Altitude Electromagnetic Pulse (HEMP) environment which is one of the consequences of a high altitude nuclear explosion, considering high and low altitude explosions. Defines a common reference for the HEMP environment to select realistic stresses for application to victim equipment for evaluation of their performance.
Equiv. Std	Identical to BS EN 61000 PT2-9 Identical to DIN EN 61000 PT2-9 Identical to IEC 1000 PT2-9 Identical to NF EN 61000-2-9 Identical to SS EN 61000-2-9 Identical to VDE 0839(PT2-9)

10.8.16 EN 61000.3.2

Standard No.	EN 61000.3.2
Title	ElectroMagnetic Compatibility (EMC) – Limits – Limits for harmonic current emissions (equipment input current $\ll$16 A per phase)
Summary	Deals with the limitation of harmonic currents injected into the public supply system. Specifies the harmonic limits of the input current which may be produced by equipment tested under specified conditions. Applies to all electrical and electronic equipment having an input current up to and including 16 A per phase and meant to be connected to public low voltage distribution systems.
Equiv. Std	Identical to BS EN 61000 PT3-2 Identical to DIN EN 61000 PT3-2

Similar to IEC 1000 PT3-2
Similar to NEN 11000-3-2
Identical to NF EN 61000-3-2
Identical to SS EN 61000-3-2
Similar to VDE 0838(PT2)

10.8.17 EN 61003.3

Standard No.	EN 61003.3
Title	ElectroMagnetic Compatibility (EMC) – Limits – Limitation of voltage fluctuations and flicker in low voltage supply systems for equipment with rated current ≪16 A.
Summary	Deals with the limitation of voltage fluctuations and flicker impressed on the public low voltage system. Specifies limits of voltage changes which may be produced by an equipment tested under specified conditions and gives advice on assessment methods. Applies to all electrical and electronic equipment having an input current up to and including 16 A per phase and meant to be connected to public low voltage distribution systems of between 220 V and 250 V at 50 Hz line to neutral.
Equiv. Std	Similar to BS EN 61000 PT3-3 Similar to DIN EN 61000 PT3-3 Similar to IEC 1000 PT3-3 Similar to NEN 11000-3-3 Similar to NF EN 61000-3-3 Identical to SS EN 61000-3-3 Similar to VDE 0838(PT3)

10.8.18 EN 61000.4.1

Standard No.	EN 61000.4.1
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Overview of immunity tests – Basic EMC publication
Summary	Considers immunity tests for electric and/or electronic equipment and its electromagnetic environment. Coverage includes: list of immunity tests, environmental conditions and selection of severity levels. Also gives detailed definitions, tables and annexes.
Equiv. Std	Identical to BS EN 61000 PT4-1 Identical to DIN EN 61000 PT4-1 Identical to IEC 1000 PT4-1 Identical to NEN 11000-4-1 Identical to NF EN 61000-4-1

	Identical to SS EN 61000-4-1
	Identical to VDE 0847(PT4-1)

10.8.19 EN 61000.4.2

Standard No.	EN 61000.4.2
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Electrostatic discharge immunity test and basic EMC publication
Summary	None available.
Equiv. Std	Identical to BS EN 61000 PT4-2
	Identical to DIN EN 61000 PT4-2
	Identical to IEC 1000 PT4-2
	Identical to NEN 11000-4-2
	Identical to NF EN 61000-4-2
	Identical to SS EN 61000-4-2
	Identical to VDE 0847(PT4-2)

10.8.20 EN 61000.4.3

Standard No.	EN 61000.4.3
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Radiated, radio frequency, electromagnetic field immunity test
Summary	Applies to immunity of electrical and electronic equipment to radiated electromagnetic energy. Gives test levels and test procedures.
Equiv. Std	Identical to BS EN 61000 PT4-3
	Identical to DIN EN 61000 PT4-3
	Similar to IEC 1000 PT4-3
	Identical to NF EN 61000-4-3
	Identical to VDE 0847(PT4-3)

10.8.21 EN 61000.4.4

Standard No.	EN 61000.4.4
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Electrical fast transient/burst immunity test and basic EMC publication
Summary	Establishes a common and reproducible basis for evaluating the performance of electrical and electronic equipment when subjected to repetitive fast transients. Also defines ranges of test levels and establishes test procedures.
Equiv. Std	Identical to BS EN 61000 PT4-4
	Identical to DIN EN 61000 PT4-4

	Identical to IEC 1000 PT4-4 Identical to NEN 11000-4-4 Identical to NF EN 61000-4-4 Identical to SS EN 61000-4-4 Identical to VDE 0847(PT4-4)

10.8.22 EN 61000.4.5

Standard No.	EN 61000.4.5
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Surge immunity test
Summary	Establishes a common and reproducible basis for evaluating the performance of electrical and electronic equipment when subjected to repetitive fast transients.
Equiv. Std	Identical to BS EN 61000 PT4-5 Identical to IEC 1000 PT4-5 Identical to NEN 11000-4-5 Identical to NF EN 61000-4-5 Identical to SS EN 61000-4-5

10.8.23 EN 61000.4.6

Standard No.	EN 61000.4.6
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Immunity to conducted disturbances, induced by radio frequency fields
Summary	Refers to the conducted immunity requirements of electrical and electronic equipment to electromagnetic disturbance from radio frequency (RF) transmitters in frequency range 9 kHz to 80 MHz. Does not include equipment not having at least one conducting cable (i.e. mains supply, signal line or earth connection) which can couple to equipment to the disturbing RF.
Equiv. Std	Identical to BS EN 61000 PT4-6 Identical to DIN EN 61000 PT4-6 Identical to IEC 1000 PT4-6 Identical to NEN 11000-4-5 Identical to NF EN 61000-4-6 Identical to SS EN 61000-4-5 Identical to VDE 0847(PT4-6)

10.8.24 EN 61000.4.7

Standard No.	EN 61000.4.7
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – General guide on harmonics

	and inter-harmonic measurement and instrumentation, for power supply systems and equipment connected thereto
Summary	Applies to instrumentation meant for measuring voltage or current components with frequencies in the range of d.c. to 2500 Hz that are superimposed on the voltage or current at the power supply frequency. Also applies to measurement instrumentation meant for testing individual items of equipment in accordance with the emission limits given in standards as well as for the measurement of harmonic voltages and currents in actual supply systems.
Equiv. Std	Identical to DIN EN 61000 PT4-7 Identical to IEC 1000 PT4-7 Identical to NBN EN 61000-4-7 Identical to NEN 11000-4-7 Identical to NF EN 61000-4-7 Identical to SS EN 61000-4-7 Identical to VDE 0847(PT4-7)

10.8.25 EN 61000.4.8

Standard No.	EN 61000.4.8
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Power frequency magnetic field immunity test – Basic EMC publication
Summary	Establishes a common and reproducible basis for evaluating the performance of electrical and electronic equipment for household, industrial and commercial applications when subjected to magnetic fields at power frequency. Does not consider disturbances due to capacitive or inductive coupling in cables or other parts of the field installation. Gives detailed definitions, diagrams and annexes.
Equiv. Std	Identical to BS EN 61000 PT4-8 Identical to DIN EN 61000 PT4-8 Identical to IEC 1000 PT4-8 Identical to NBN EN 61000-4-8 Identical to NEN 11000-4-8 Identical to NF EN 61000-4-8 Identical to SS EN 61000-4-8 Identical to VDE 0847(PT4-8)

10.8.26 EN 61000.4.9

Standard No.	EN 61000.4.9
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Pulse magnetic field immunity test – Basic EMC publication
Summary	Establishes a common and reproducible basis for evaluating performance of electrical and electronic equipment for commercial, household and industrial applications when subject to pulse magnetic fields. Does not consider disturbances due to capacitive or inductive coupling in cables or other parts of the field installation. Also gives detailed definitions, diagrams and annexes.
Equiv. Std	Identical to BS EN 61000 PT4-9 Identical to DIN EN 61000 PT4-9 Identical to IEC 1000 PT4-9 Identical to NBN EN 61000-4-9 Identical to NEN 11000-4-9 Identical to NF EN 61000-4-9 Identical to SS EN 61000-4-9 Identical to VDE 0847(PT4-9)

10.8.27 EN 61000.4.10

Standard No.	EN 61000.4.10
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Damped oscillatory magnetic field immunity test – Basic EMC publication
Summary	Establishes a common and reproducible basis for evaluating the performance of electrical and electronic equipment for medium voltage and high voltage substations when subject to damped oscillatory magnetic fields. Relates to the immunity requirements of equipment, only under operational conditions, to damped oscillatory magnetic disturbances related to medium and high voltage substations. Includes detailed definitions, annexes and diagrams.
Equiv. Std	Identical to BS EN 61000 PT4-10 Identical to DIN EN 61000 PT4-10 Identical to IEC 1000 PT4-10 Identical to NBN EN 61000-4-10 Identical to NEN 11000-4-10 Identical to NF EN 61000-4-10 Identical to SS EN 61000-4-10 Identical to VDE 0847(PT4-10)

10.8.28 EN 61000.4.11

Standard No.	EN 61000.4.11
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Voltage dips, short interruption, and voltage variations immunity tests
Summary	Defines the immunity test methods and the range of preferred test levels for electrical and electronic equipment connected to low voltage power supply networks for voltage dips, short interruptions, and voltage variations. Applies to electrical and electronic equipment having a rated input current not over 16 A per phase. Also provides definitions, diagrams and annexes.
Equiv. Std	Identical to BS EN 61000 PT4-11 Identical to DIN EN 61000 PT4-11 Identical to IEC 1000 PT4-11 Identical to NBN EN 61000-4-11 Identical to NF EN 61000-4-11 Identical to SS EN 61000-4-11 Identical to VDE 0847(PT4-11)

10.8.29 EN 61000.4.12

Standard No.	EN 61000.4.12 Title ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Oscillatory waves immunity test – Basic EMC publication
Summary	Relates to immunity requirements and test methods for electrical and electronic equipment, under operational conditions, to oscillatory waves. Establishes the immunity requirements and a common reference for evaluating in a laboratory the performance of electrical and electronic equipment meant for commercial, residential and industrial applications.
Equiv. Std	Identical to BS EN 61000 PT4-12 Identical to DIN EN 61000 PT4-12 Identical to IEC 1000 PT4-12 Identical to NEN 61000-4-12 Identical to NF EN 61000-4-12 Identical to SS EN 61000-4-12 Identical to VDE 0847(PT4-12)

10.8.30 EN 61000.4.24

Standard No.	EN 61000.4.24
Title	ElectroMagnetic Compatibility (EMC) – Testing and measurement techniques – Test methods for protective devices for HEMP conducted disturbance – Basic EMC publication

Summary	Concerned with methods for testing of protective devices for HEMP conducted disturbance. Mainly describes voltage breakdown testing and voltage limiting characteristics, but in addition covers methods of measuring the residual voltage under HEMP conditions for the case of very fast voltage changes and current as a function of time.
Equiv. Std	Identical to BS EN 61000 PT4-24 Identical to IEC 1000 PT4-24 Identical to SS EN 61000-4-24

10.8.31 EN 61000.5.5

Standard No.	EN 61000.5.5
Title	ElectroMagnetic Compatibility (EMC) – Installation and mitigation guidelines – Specification of protective devices for HEMP conducted disturbance – Basic EMC publication
Summary	Specifies protective devices for conducted disturbances for use in the harmonisation of existing or future specifications issued by protective device manufacturers, electronic equipment manufacturers, administrations and other ultimate buyers. Describes protective devices currently in use for protection against induced HEMP transients on signal and low voltage power lines (nominal voltages to 1 kV a.c.).
Equiv. Std	Identical to BS EN 61000 PT5-5 Identical to DIN EN 61000 PT5-5 Identical to IEC 1000 PT5-5 Identical to NF EN 61000-5-5 Identical to SS EN 61000-5-5 Identical to VDE 0847(PT5-5)

10.8.32 IEC 801.1

ElectroMagnetic Compatibility for industrial-process measurement and control equipment – General introduction.

Applies to electromagnetic compatibility of industrial process measurement and control equipment. Deals with general considerations in the context of the complexity of electromagnetic compatibility and the problems with which manufacturers and users of industrial process measurement and control equipment may be confronted. Ensures that manufacturers and users of industrial process measurement and control equipment are aware of the problems involved in achieving and maintaining electromagnetic compatibility. In addition provides the background information necessary to understand the development of the different parts of the standard on electromagnetic compatibility in the field of industrial process measurement and control.

10.8.33 IEC 801.2

ElectroMagnetic Compatibility for industrial-process measurement and control equipment – Electrostatic discharge requirements.

Applies to the susceptibility of industrial process measurement and control instrumentation to electrostatic discharges generated by operators touching this instrumentation and to electrostatic discharges generated between objects in the proximity of this instrumentation and establishes severity levels and the required test procedures. Establishes a common reference for evaluating the performance of industrial process measurement and control instrumentation when subjected to electrostatic discharges. Includes electrostatic discharges which may occur between electrostatically charged objects brought together near to the vital instrumentation.

10.8.34 IEC 801.3

ElectroMagnetic Compatibility for industrial-process measurement and control equipment – Radiated electromagnetic field requirements.

Applies to the susceptibility of industrial process measurement and control instrumentation to radiated electromagnetic energy. Establishes severity levels and the required test procedures. Establishes a common reference for evaluating the performance of industrial process measurement and control instrumentation when subjected to electromagnetic fields such as those generated by portable radio transceivers or any other device that will generate continuous wave radiated electromagnetic energy.

10.8.35 IEC 801.4

ElectroMagnetic Compatibility for industrial process measurement and control equipment – Electrical fast transient/burst requirements.

Relates to immunity of industrial process measurement and control instrumentation to repetitive electrical fast transients. Additionally establishes severity levels and test procedures. Establishes a common and reproducible basis for evaluating the performance of electronic instrumentation when this is subjected to repetitive fast transients (bursts), on either supply, signal or control lines. The test is intended to demonstrate the EMI of the instrumentation when subjected to types of transient interference such as that originating from switching transients (interruption of inductive loads, relay contact bounce, etc.).

10.9 Railway specific requirements

In addition to the generic requirements contained in 89/336/EEC, railway product specific requirements are detailed in ENV 50121 (Railway applications – ElectroMagnetic Compatibility), which consists of five sections, as follows:

ENV 50121.1	Railway applications – ElectroMagnetic Compatibility – General. (General description of the electromagnetic behaviour of a railway.)
ENV 50121.2	Railway applications – ElectroMagnetic Compatibility – Emission of the whole railway system to the outside world. (Sets the emission limits from the railway to the outside world at radio frequencies.)
ENV 50121.3	Railway applications – ElectroMagnetic Compatibility – Rolling stock – Trains and complete vehicles. (Specifies the emission and immunity requirements for all types of rolling stock.)
ENV 50121.4	Railway applications – ElectroMagnetic Compatibility – Emission and immunity of the signalling and telecommunications apparatus. (Emission and immunity aspects of EMC for electrical and electronic apparatus intended for use on railway rolling stock.)
ENV 50121.5	Railway applications – ElectroMagnetic Compatibility – Fixed power supply installations. (Applies to emission and immunity aspects of EMC for electrical and electronic apparatus and components for use in railway fixed installations associated with power supply.)

Notes:

1 These limits for electromagnetic compatibility are set so that the railway as a whole satisfies EC Directive 89/336/EEC regarding electromagnetic compatibility and so that electromagnetic compatibility is achieved between the various parts of the railway.

2 The standard specifies the limits for electromagnetic emission of the railway as a whole to the outside world together with immunity for equipment operating within the railways.

3 The frequency (covered by ENV 50121) is in the range of d.c. to 400 GHz.

4 Testing is limited to frequencies not exceeding 1 GHz.

10.10 Other related standards and specifications

EN 50083.2	Cabled distribution systems for television and sound signals – Electromagnetic compatibility for equipment
EN 50090.2.2	Home and building electronic systems (HBES) – System overview – General technical requirements

EN 50091.2	Uninterruptible power systems (UPS) – General safety and requirements for UPS used in operator access areas
EN 50130.4	Alarm systems – Electromagnetic compatibility – Product family standard – Immunity requirements for components of fire, intruder and social alarm
EN 50199	Electromagnetic compatibility – Product standard for arc welding
EN 55103.1	Electromagnetic compatibility – Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use – Emission
EN 55103.2	Electromagnetic compatibility – Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use – Immunity
EN 55104	Electromagnetic compatibility – Immunity requirements for household appliances, tools and similar apparatus – Product family standard
EN 60439.1	Low voltage switchgear and controlgear assemblies – Requirements for type tested and partially tested assemblies
EN 60521	Class 0.5, 1 and 2 alternating current watthour meters
EN 60601.1.2	Medical electrical equipment – General requirements for safety – Collateral standard: Electromagnetic compatibility – Requirements and tests
EN 60730.1	Specification for automatic electrical controls for household and similar use – General requirements
EN 60730.2.11	Automatic electrical controls for household and similar use – Particular requirements for energy regulators
EN 60730.2.5	Automatic electrical controls for household and similar use – Particular requirements for automatic electrical burner control systems
EN 60730.2.6	Automatic electrical controls for household and similar use – Particular requirements for automatic electrical pressure sensing controls including mechanical requirements
EN 60730.2.7	Automatic electrical controls for household and similar use – Particular requirements for timers and time switches
EN 60730.2.8	Automatic electrical controls for household and similar use – particular requirements for electrically operated wire valves, including mechanical requirements
EN 60730.2.9	Automatic electrical controls for household and similar use – Particular requirements for temperature sensing controls
EN 60870.2.1	Telecontrol equipment and systems – Operating conditions – Power supply and electromagnetic compatibility

EN 60945	Maritime navigation and radio communication equipment and systems – General requirements – Methods of testing and required test results
EN 60947.1	Low voltage switchgear and controlgear – General rules
EN 60947.2	Low voltage switchgear and controlgear – Circuit breakers
EN 60947.3	Low voltage switchgear and controlgear – Switches, disconnectors, switch-disconnectors and fuse-combination units
EN 60947.4.1	Low voltage switchgear and controlgear – Contractors and motor-starters – Electromechanical contractors and motor-starters
EN 60947.5.1	Low voltage switchgear and controlgear – Control circuit devices and switching elements – Electromechanical control circuit devices
EN 60947.5.2	Low voltage switchgear and controlgear – Control circuit devices and switching elements
EN 60947.6.1	Low voltage switchgear and controlgear – Multiple function equipment – Automatic transfer switching equipment
EN 60947.6.2	Low voltage switchgear and controlgear – Multiple function equipment – Control and protective switching devices (or equipment) (CPS)
EN 61008.1	Residual current operated circuit breakers without integral overcurrent protection for household and similar uses (RCCBs) – General rules
EN 61009.1	Residual current operated circuit breakers with integral overcurrent protection for household and similar uses (RCBOs) – General rules
EN 61131.2	Programmable controllers – Equipment requirements and test
EN 61543	Residual current operated protective devices (RCDs) for household and similar use – Electromagnetic compatibility
EN 61547	Equipment for general lighting purposes – Electromagnetic compatibility immunity requirements
EN 61800.3	Adjustable speed electrical power drive systems – Electromagnetic compatibility product standard including specific test methods

10.11 EMC testing: a comparison of the test alternatives

Table 10.8 EMC testing: a comparison of the test alternatives

Facility	Advantages	Disadvantages
Approved EMC type – test laboratory	• Should be able to provide comprehensive testing facilities • Able to provide a high level of confidence in the product's conformity to EMC standards • Likely to have experts to advise on design issues and clarification of standards • Should be up to date with the latest changes and thinking in relation to European and IEC standards • May also be an approved body capable of reviewing technical instruction files	• Unlikely to be of a particular advantage for periodic testing design and developments phase • May require an average of 3 days testing for products • As demand for test house facilities increases, the availability may impact upon the product's development and introduction timetable • Likely to be an expensive option if a large number of products have to be considered • An expensive/inconvenient facility if a test house is used to analyse competitors' products and designs • Not a realistic option for production, quality control, incoming goods inspection or evaluation after repair, maintenance or rebuild
Expert System	• Greatly reduces the cost associated with approval • Provides high levels of flexibility for development and production testing • Low cost units enable allocations to a number of engineers and the possibility of equipping various development laboratories within a company • Expert System greatly reduces the need for high levels of expertise and knowledge updated at regular intervals to the latest standards • Low cost permits duplication of test equipment in production/manufacturing or incoming good areas • A facility available for comparative testing of competitors' products	• May not in every case provide a high level of confidence in conformance to standard type approval house testing; however, likely to be adequate in most cases for reasonable commercial judgement • Will still require the occasional visit to test houses to obtain approval of a golden product

continued

Table 10.8 (*cont.*)

Facility	Advantages	Disadvantages
	• Immediate availability of the equipment and the Expert System enables product variations to be created without excessive cost • Combined use of test house for 'golden product route' increases level of confidence in test results and compliance with the directive	
Own full in-house test facility	• Continuously available for design and development • A valuable aid in providing flexibility in type approval timetables and assisting in reducing new product introduction periods • A useful marketing tool to assist in providing customers with confidence in the company's capabilities • A facility could be used at little additional cost to carry out full evaluation of competitors' products • May be used for batch inspection of products/ incoming goods • Enables product variables to be produced and tested without a disproportionate cost	• Significant financial investment and depreciation charge • Likely to require dedicated land or building space facility to be created and maintained • Likely to require a high level of in-house engineering expertise • For larger companies the facilities may not always be available for development testing owing to the prioritisation of type approval, production testing and competitor analysis • Owing to the cost of the equipment it is unlikely to be able to provide a bench facility for more than a very limited number of development engineers • An ongoing cost for maintenance, calibrations and equipment updating

10.12 Test and evaluation

When equipment is being tested to ensure conformance with EMC requirements the following standards also need to be conformed with:

EN 45001	General criteria for the operation of testing laboratories
EN 45002	General criteria for the assessment of testing laboratories
EN 45003	Calibration and testing laboratory accreditation system – General requirements for operation and recognition
EN 45004	General criteria for the operation of various types of bodies performing inspection
EN 45011	General criteria for certification bodies operating product certification
EN 45012	General criteria for certification bodies operating quality system certification
EN 45013	General criteria for certification bodies operating certification of personnel
EN 45014	General criteria for suppliers' declaration of conformity

Chapter 11

Ergonomics

11.1 Guidance

11.1.1 What is ergonomics?

In general, ergonomics concerns the 'application of a human system interface technology to the design or modification of systems to enhance performance, safety, health, comfort, effectiveness and quality of life'. As such, there are four major components:

- Hardware ergonomics (i.e. man–machine technology). This concerns the study of human, physical and perceptual characteristics and its application to the design of controls, displays, tools, seating, work surfaces and workspace arrangements, and so on.
- Environmental ergonomics (i.e. man–environment technology). This was first studied in the late 1930s as concern grew about the effects of noise, vibration, lighting, climate, chemical substances and other physical agents on human performance and health. Since then the media in particular have made people more aware of the relationship of humans with their natural and constructed environments. International awareness has also heightened the understanding of the importance of ecological issues to human health and effectiveness.
- Software ergonomics (i.e. user–system interface technology). This is a change from the physical and perceptual characteristics (i.e. hardware ergonomics) and focuses on the psychological and emotional aspects of work. As more people use computers and computer based systems in their daily work their manner of thinking and working has become an important aspect of system design.
- Macroergonomics (i.e. organisation–machine interface technology). This involves the human's approach and interface with work in order to make the best use of the system. It deals with the overall

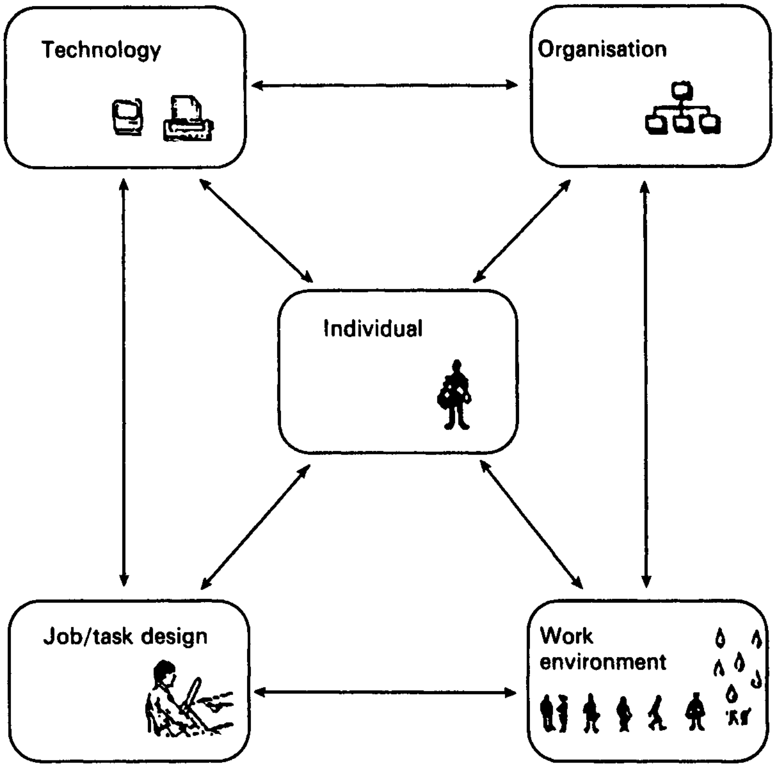


Fig. 11.1 Model of the work system

structure of the work system as it interfaces with the system's technology.

There are no 'perfect' jobs or workplaces that are totally free of ergonomic hazards and which can provide complete psychological satisfaction to all employees. Most workplaces can only provide a balance between design and efficiency and trade-offs must be made to achieve the best overall ergonomic solution for a job.

Several guidelines and standards have been developed to increase employers' awareness of ergonomics to help them in the purchase of office equipment and the design of computerised offices. Such guidelines highlight the need to train employees and employers in the field of ergonomics.

11.1.2 Introduction

It is all very well stipulating the requirements for the manufacture, use, storage and transportation of equipment, but what about the person using it? Equally it is no use producing a very high-tech piece of

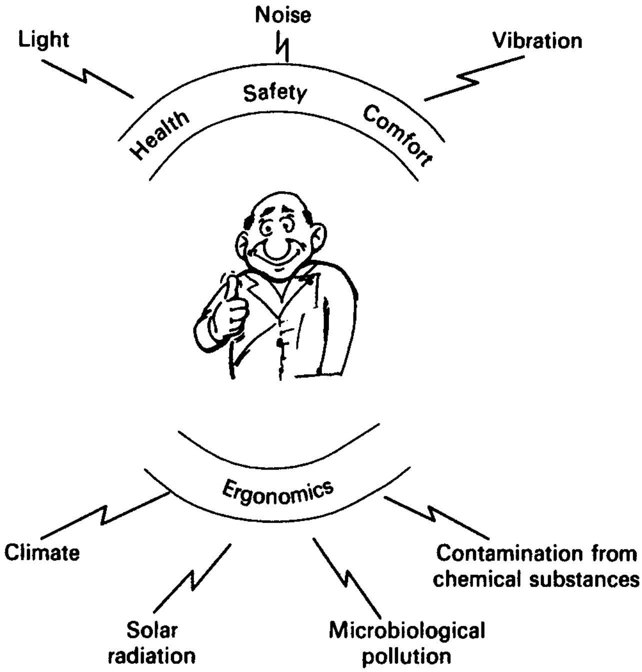


Fig. 11.2 The operator/technician's environment

equipment if the operator cannot make it work and if the technicians cannot quickly, efficiently and cost effectively maintain it.

Consideration should be given (but rarely is) to the Man–Machine Interface (MMI) and in this respect the following three criteria have to be considered. They are:

- those aimed at protecting the health and safety of the operator/technician;
- those aimed at the comfort of the operator/technician;
- those aimed at achieving maximum task effectiveness.

Light (i.e. illumination), noise and vibration are the three main factors concerning an operator/technician's safety, health and comfort. From an ergonomic point of view, the type of climate, the amount of solar radiation, the possibility of microbiological pollution and contamination from chemical substances must also be considered.

11.1.3 Light

11.1.3.1 VDU screens

When using a monitor or Visual Display Unit (VDU) the availability of a screen with inverse presentation possibilities (i.e. light day screen, dark night screen) and good built-in contrast control, will permit the effective and comfortable use of the information screen by the operator at any time of day or night.

Although it is appreciated that the requirement not to allow the sun to directly radiate onto the information screen may be difficult to achieve in some circumstances, the following should, nevertheless, be considered:

- no windows should be allowed to reflect within the visual field of the VDU. For existing offices/workshops this requirement can mean that some side windows will have to be fitted with blinds;
- direct beaming of light from the lighting systems inside the office/workshop onto the screen should be prevented by smart positioning and/or the usage of blinds and/or mirror systems;
- operators/technicians should be advised to wear dark coloured clothes/garments on the head, trunk and arm regions. The wearing of flat or glossy materials like leather or plastics and white shirts is to be avoided;
- the use of polarising screen filters will greatly reduce unwanted reflections on a VDU screen. They will also assist in conforming to the Health & Safety (Display Screen Equipment) Regulations 1993.

11.1.3.2 Illuminance

The amount of light (i.e. light intensity) which falls on the work surface is an important environmental aspect. Whilst it must be sufficiently high to enable visual tasks to be carried out rapidly, with precision and ease, it must also avoid (where possible) reflections, dazzling light and shadows.

Whenever practicable, lighting should provide sufficient light intensity without incurring excessive brightness differences in the visual field such as may occur from the actual light source itself, windows, reflections and shadows. Apart from light intensity, differences in contrast and luminance (i.e. the amount of light reflected back to the eyes from the surface of objects in the visual field) are also extremely important.

11.1.3.3 Visual field

The visual field can be divided into three zones. The task area, the immediate surroundings and the wider environment. Generally speaking the brightness of the task area should:

- be no more than three times greater or less than that of the immediate surroundings;
- not differ significantly from that of the immediate surroundings;
- not differ from that of the wider surroundings by more than a factor of 10.

Differences in brightness that are too small should also be avoided because this makes a room appear dull.

Excessive differences in brightness between objects or surfaces in the visual field should also be avoided whenever possible as these can result in reflections, dazzling light and shadows.

Except for orientation tasks, the required light intensity on a work surface can be achieved by a combination of limited ambient lighting and more intense localised (task) lighting. The level of lighting is determined by the criteria concerning the brightness difference between task and surroundings.

11.1.3.4 Methods of improving light intensity and contrast

Excessive reflections can be avoided by:

- using indirect (e.g. diffused) lighting in the ceiling;
- ensuring that whenever possible the workstation surface, walls, etc., have a matt finish to diffuse reflections;
- using blinds to mask the large variations in daylight intensity from direct sunlight.

Blinding by direct sunlight can be avoided by screening although this can often result in vertical surfaces being less illuminated and there being an additional requirement for an interior light source.

Fluorescent tubes produce a flickering light which can be disturbing. Whenever possible, two or more tubes shall be placed in a mounting so that they alternate out of phase. The use of a single fluorescent tube to reduce power consumption is to be avoided.

11.1.4 Noise

Loss of hearing, even when very slight, can (in most circumstances) have an adverse effect on the ability of a person to perform a specific task. Difficulties in hearing speech, telephone conversations and radio communication in noisy environments (e.g. a workshop) lead to a reduction in concentration and thus limit task effectiveness.

11.1.5 Sound

For health reasons CEN/CENELEC recommend a maximum 8 hour averaged exposure of 80 dB(A). Within the UK, the Health and Safety regulations state that a clear warning must be given in the workplace for noise over 85 dB. Above 90 dB, hearing protection must be issued.

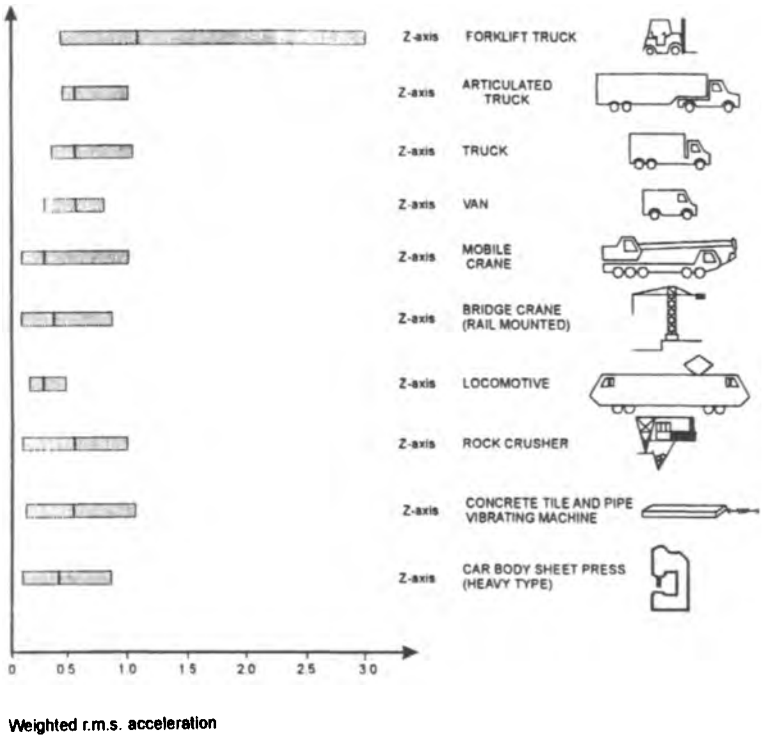


Fig. 11.3 Examples of external noise sources (Courtesy INRS 1989)

Table 11.1 Maximum (annoyance) noise levels

	dB
Birds	30–40
Crowded pub	75–110
Shotgun	120
Hi-fi sound system in small room	110–120
Chainsaw	120
Night club dance floor	Up to 140

Unexpected loud or high frequency noises produced by others are one of the main causes of annoyance. If a room or an enclosure's ambient noise level drops below 30 dB(A), this too can cause annoyance and lack of concentration. The design of all new offices/workshops, etc. should be required to recognise this fact.

11.1.5.1 Audible warnings

A large amount of electronic equipment relies to some degree on audible signals to prompt the operator. Signals originating from an audio unit

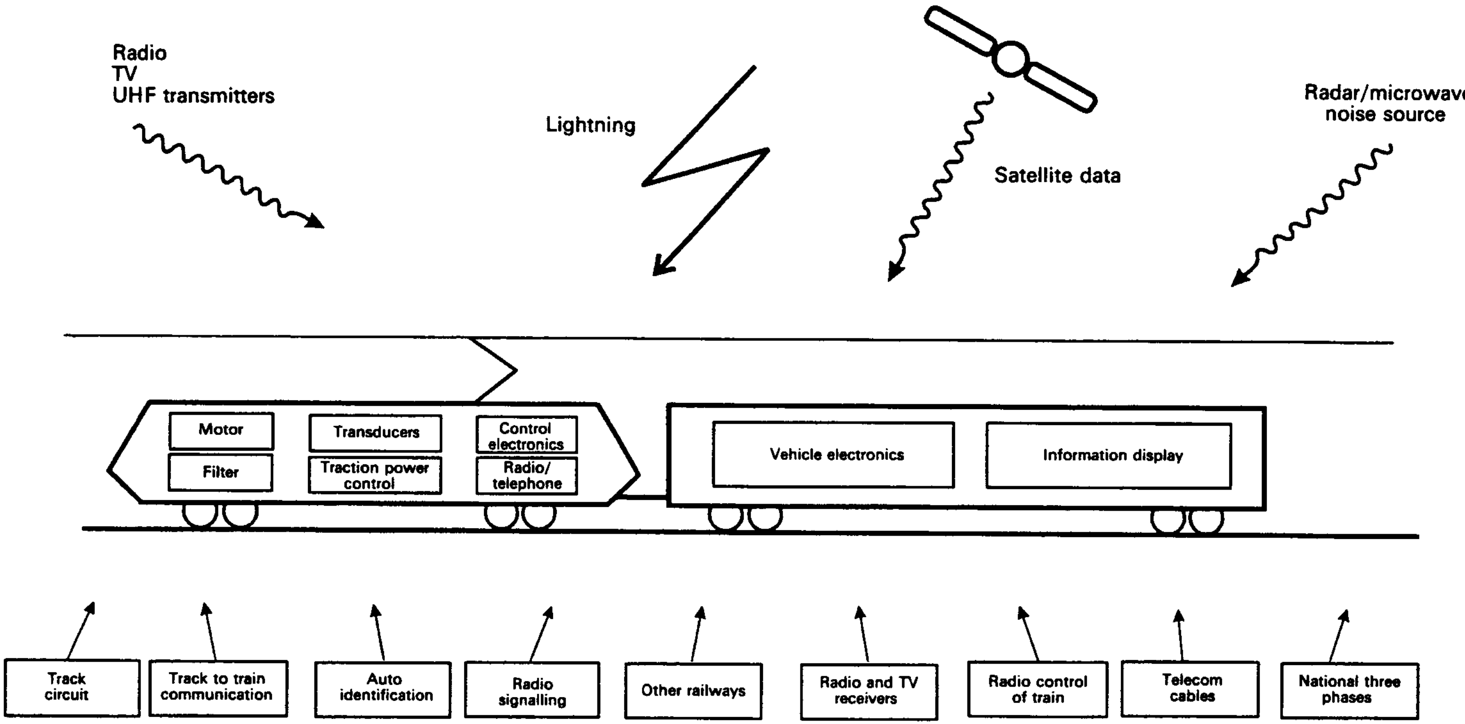


Fig. 11.4 Examples of noise sources and disturbances in the railway environment – all elements are at the same time noise source and disturbed object

(e.g. system failure alerts, audible signals from computers, etc.) must comply with the requirements set forward in ISO 7731. This means that the signal/noise (S/N) ratio (i.e. the difference in level between the acoustic signal from the audio unit and the background noise in the room from all other sources) should be at least + 15 dB(A), when there is no frequency orientated information available. For an audio system with fixed output levels this will mean a level of at least 98 dB(A) for the worst probable case, which means that the general background noise level has to be lower than 76 dB(A). The choice of an audio unit with self-adjusting possibilities for the output level (e.g. level triggering with a dB(A) measurement) is preferable. In this case a signal/noise requirement of + 15 dB(A) will demand a maximum environmental level of 79 dB(A) (rounded) to fulfil the health requirement.

The best option is to take care that, before designing new workshops and/or operating environments, there is enough information available concerning the frequency composition of the environmental noise at that particular site. The next best option is for this frequency orientated information to be gathered in advance by measurements for the worst case situations. ISO 7731 states that a (masked) signal/noise ratio of + 10 dB in one octave band is enough for audibility. One method is to build a fast (simple) frequency analysing system into the audio unit to generate the necessary information at the moment that this information is useful. A combination of two microphones (one measuring in dB(A) and one in dB) in the audio unit is probably sufficient for this purpose.

The more sophisticated the audio unit, the lower the requirements for the environmental noise levels. However, the audio unit obviously has to comply with the requirements for the danger/safety signals as stated in ISO 7731, such as a:

- minimum level of 65 dB(A);
- minimum duration of 2 seconds, in the 300–3000 Hz range;
- pulse repetition between 0.2 Hz and 5 Hz;
- smart usage of the temporal pattern or modulation, etc.

11.1.6 Operator/technician comfort

The presence of high noise levels at a workplace or during a task can, at best, be annoying, at worst it can be extremely harmful and may, in some circumstances, result in hearing loss and/or impaired hearing (e.g. tinnitus).

For the comfort of the operator/technician, the noise levels inside rooms and workshops should be as low as possible by limiting the noise at source. Some noise absorbing surfaces (e.g. in the roof) are recommended so that a pleasant acoustic environment inside the offices, etc. can be achieved and which will be useful for telephone communication purposes.

Table 11.2 provides a few examples of noise levels found in everyday life whilst Table 11.3 provides the maximum permissible noise levels that can be tolerated without undue annoyance during various activities.

Table 11.2 Noise levels found in everyday life

Type of noise	dB(A)
Night club	140
Jet engine at 25 m	130
Chainsaw	120
Jet aircraft starting at 50 m	120
Hi-fi	120
Pop group	110
Crowded pub	110
Pneumatic drill	100
Shouting, understandable only at short distances	90
Normal conversation, understandable at 0.5 m	80
Radio playing at full volume	70
Loud conversation	70
Group conversation	60
Radio playing quietly	50
Quiet conversation	50
Library reading room	40
Birds	40
Slight domestic noise	30
Gentle rustling of the leaves	20
Threshold of hearing	0

Constant noise can impair hearing and as indicated in paragraph 11.1.4 above, the maximum, average, noise level allowed during an 8 hour working day should not exceed 80 dB(A).

Table 11.3 gives details of the maximum (annoyance) noise levels normally permitted.

Although the human ear can accept occasional instantaneous high level noises (as shown in Figure 11.5), even reasonably low noise levels over a lengthy period can seriously affect the human ear.

Table 11.3 Maximum (annoyance) noise levels

Activity	dB(A)
Unskilled physical work (e.g. cleaning)	80
Skilled physical work (e.g. workshop)	75
Precision physical work (e.g. machinery shop)	70
Routing administrative work (not full time)	70
Physical work with high precision requirements	60
Drawing and design work	55
Concentrated intellectual work (e.g. office)	45
Concentrated intellectual work (e.g. library)	35

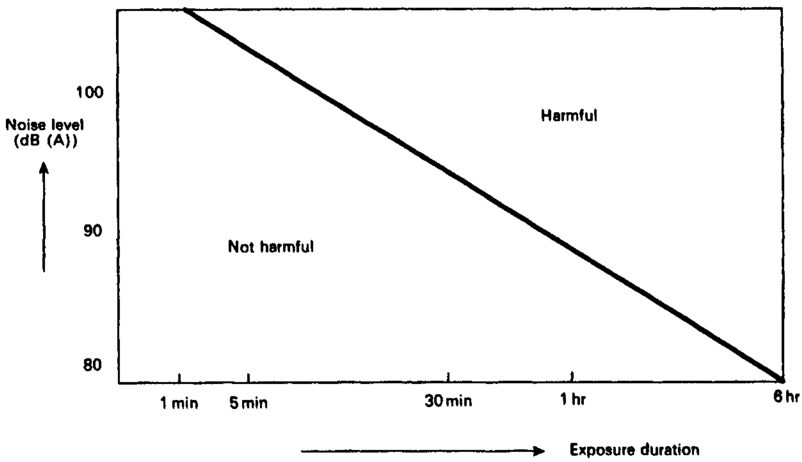


Fig. 11.5 Harmful and non-harmful noise levels

11.1.6.1 Methods of tackling noise

Generally speaking there are three measures that can be applied to reduce (and in some cases even eliminate) the detrimental effects of noise:

- eliminate or reduce the noise at source;
- isolate the transmission media between the noise source and the receiver (i.e. isolate either the source or the operator);
- Protect the operator.

11.1.6.2 Elimination/reduction at source

By far the most effective measure of achieving noise reduction is to tackle it head on at source. There are quite a number of ways of achieving this source reduction and the list below, whilst not extensive, provides some examples:

- use quieter machines;
- better maintenance of machines. Poor fit, eccentricity and imbalance cause vibration, wear and noise. Regular maintenance of machines and equipment is, therefore, of great importance;
- enclose noisy machines. Noisy machines can be placed inside a sound-proof container or enclosure. The disadvantage to this method, however, is that the machines will be less accessible to the operator and for maintenance purposes.

11.1.6.3 Isolate the transmission media between noise source and receiver

Noise reduction can be achieved in most cases by:

- eliminating, or preventing the transmission of noise between the source and the receiver (e.g. man). In effect, better workplace design;

- separating noisy work from quiet work, selecting a noise source that is as far away as possible from the operator's working place and using quieter machines;
- using a noise absorbing ceiling and/or walls, employing an acoustic screen and/or sound dampers.

11.1.6.4 Protect the operator

At the individual level, the exposure duration can be reduced. Protection can be provided from the environmental effects by a shield, or personal protective equipment (e.g. ear defenders).

11.1.7 Bodily vibration

11.1.7.1 Introduction

'Vibration' is rarely of a constant duration and normally consists of a series of separate vibrations occurring at different frequencies and in different directions.

Depending on the vibration source and level of vibration, the body can vibrate to a level that can cause severe discomfort. Figure 11.6 shows the limit for various combinations of exposure, the duration and the average vibration level for whole body vibrations for standing and seated work.

'White finger' vibration (sometimes called 'dead finger') is caused by a hand–arm vibration. Figure 11.7 shows the various combinations of exposure, duration and average hand–arm vibration level which can lead to white finger. The condition is aggravated by cold and humidity.

Large machines and motorised tools often constitute a source of

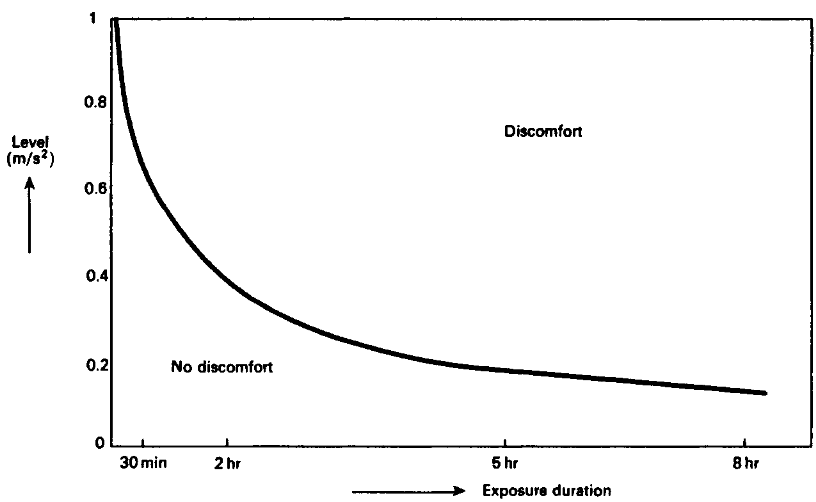


Fig. 11.6 Body vibration levels (comfort and discomfort)

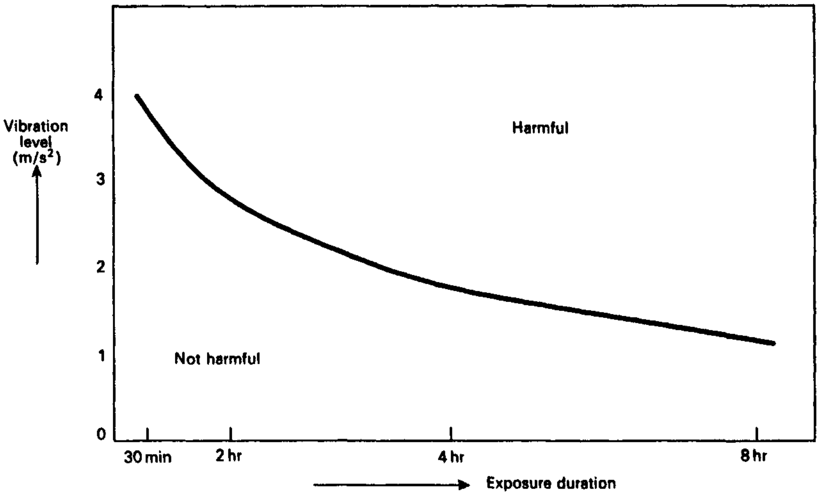


Fig. 11.7 White finger vibration

vibration. Rotating movements generally cause less vibration than reciprocating movements. Likewise, hydraulic and pneumatic transmissions are superior to mechanical transmission in this respect. Heavy machines (i.e. those with a large mass) also generally cause less vibration.

11.1.7.2 Methods of preventing vibration

Vibration can be prevented:

- at source;
- during the transmission between source and the exposed person;
- to a limited extent at an individual level.

Machines and hand-held tools sometimes display loose fits, eccentricity or imbalance, all of which cause vibration, noise and wear. Regular maintenance is, therefore, essential.

Damping the vibration where it enters the body, for instance by fitting floors, seats and handgrips with a damping material, should also be considered.

11.1.7.3 Vibration test conditions

The three variables that have to be considered when assessing the effects of vibrations are the:

- magnitude (expressed in m/s^2);
- frequency (expressed in Hz);
- duration of exposure (expressed in time).

The various test specifications for vibration are described in Chapter 8

Table 11.4 Results of vibration on the human body

	Frequency	Result
Body vibration	1–100 Hz	Feeling of seasickness
	4–8 Hz	Can lead to short pains, difficulty in breathing, back pain and impaired breathing
Hand and/or arm vibration	8–100Hz	Reduced sensitivity and dexterity of the fingers (i.e. white finger), muscles, joints and bone disorders

Note
The most common frequency range for hand-held tasks is between 25 Hz and 150 Hz.

Mechanical. Designers and specifiers should ensure that equipment is designed with due consideration to Figures 11.6 and 11.7.

Table 11.4 indicates some results of vibration on the human body.

11.1.8 Climate

The indoor climate needs to satisfy several conditions if work is to be carried out in comfort. Four climatic factors are significant in this respect:

- ambient temperature;
- radiation temperature of cold and hot surfaces;
- relative humidity;
- air pressure.

Details of all the above are included in the relevant sections of this book.

11.1.9 Chemical substances

Chemical substances occur in the environment as liquids, gases, vapours or solids. Some substances can cause discomfort or even present a health hazard if inhaled, ingested or if they come in contact with the skin or eyes.

Many substances are irritants, carcinogens (i.e. lead to cancer defects), mutagens (i.e. damage genes) or teratogens (i.e. lead to birth defects). The body must, therefore, be exposed as little as possible to such chemical substances.

The international Threshold Limit Values (TLV) lists (which are regularly maintained and updated) contain details of several hundred chemical substances. The TLV is an 8 hour weighted average concentration figure that should not be exceeded in any one 24 hour period and is an exceedingly useful tool when considering the MMI.

In order to prevent adverse health effects (as opposed to being uncomfortable through the effects of pungent smells, etc.), international limits for chemical substances in air have been agreed and these are published as TLVs. It should be noted that short-term exposure to high concentrations of a chemical substance can affect health even if the TLV is, on average, not exceeded over an 8 hour period.

11.1.10 Test standards

Ergonomic tests have, for simplicity, already been included within the test specifications of the other relevant subsections.

11.2 Typical contract requirements – ergonomics

The requirement for equipment to conform to various environmental specifications is becoming commonplace in today's contracts. More and more specifications are being used to describe the various conditions that equipment is likely to exert on the human body when being used.

The following are the most common environmental requirements found in modern contracts concerning ergonomics.

Most ergonomic requirements fall under two headings, 'General' and 'MMI':

- General: buildings and cabinets in which equipment is located or maintained and where personnel can work. The environment consequently has a direct influence on personal well-being, e.g. in an office block, maintenance workshop, etc.
- MMI: specific to the ergonomic environment which exists between the operator and the equipment.

11.2.1 General

11.2.1.1 Illumination

The visual field within an office can be divided into three zones: the task area, the immediate surrounding and the more wider environment. The normal requirements for their brightness are as follows:

11.2.1.1.1 Lighting and brightness within the office/workshop

- Workplaces should have built-in devices (e.g. screens) to enable operators and technicians to protect themselves from being dazzled by sunlight or artificial lighting.
- It is recommended that the office and workshop incorporate a general lighting scheme guaranteeing 200 lux continuously at the level of the operator's desk.
- Even when the general lighting has been switched off, there should be sufficient light in the workplace to enable an operator/technician to find his way around. Generally, the lighting from instruments is considered adequate for this purpose.

- All indicator lights should be designed so that they can be read, without error, either using natural or artificial incidental lighting. In addition, they should not cause reflections on the windows when staff are in their normal working position.

11.2.1.1.2 Light sources

Most contracts insist that:

- light sources should be located relative to the workplace so as to prevent reflections, blinding light and shadows and whenever available, daylight should be used for general lighting;
- at VDU workstations, special care should be taken to prevent:
  - reflections on the screen;
  - large differences in light intensities between screen and background/surroundings;
  - dazzling sunlight.

11.2.1.1.3 Light intensity

The recommended light intensity for various tasks is shown in Table 11.5.

11.2.1.1.4 Reflectance

The optimum amount of light reflected from a surface (reflectance) depends on the purpose of that surface. This reflectance is a value between zero and one, with a zero value meaning that no light is reflected (dark surface) and a value of one meaning that all the light is reflected (light surface).

The recommended reflectance values and luminance ratios are provided in Tables 11.6 and 11.7.

Table 11.5 Light intensity

Usage	Light intensity (m^2)	Remarks
Orientation tasks	10–200 lux	Where visual aspect is unimportant – e.g. corridors of buildings, general activities in storerooms, etc
Normal activities	200–800 lux	Reading normal print, operating machines and carrying out maintenance
Special applications	800–3000 lux	Localised task lighting to compensate for shadows or reflections on the work surface

Notes

1 Small differences in light intensity should always be avoided as this can make a room look too dull.

2 For readability (contrast and detail) the location height is of more importance than lighting level.

Table 11.6 Recommended values for the reflectance of various surfaces

Surface	Reflectance
Ceiling	0.70–1.00 ('light')
Walls	0.40–0.60
Table tops	0.25–0.45
Floor	0.20–0.40 ('dark')

Table 11.7 Luminance (contrast) ratios

Luminance ratio	Perception in the task area
1	None
3	Moderate
10	High
30	Too high
100	Far too high
300	Extremely unpleasant

11.2.1.1.5 Task area

Where possible, the brightness of the task area should not:

- be more than three times larger, or smaller, than that of the close surroundings;
- differ from that of the close surroundings;
- differ from that of the wider surroundings by more than a factor of 10.

11.2.1.2 Vibration and shocks

Shocks and jolts often occur when equipment is vibrated. Shocks and jolts with peak intensities of more than three times higher than the average vibration level should be avoided as they will increase the total vibration.

11.2.1.3 Climate

Whether people find a climate pleasant depends very much on the individual. The aim, therefore, should always be to allow people to control the climatic factors as far as possible themselves.

Table 11.8 provides recommended guidelines on air temperature for tasks requiring different levels of physical effort assuming that the air humidity is 30%, the air velocity is less than 0.1 m/s and that normal clothing is worn.

Table 11.8 Recommended air temperature for tasks requiring different levels of physical effort

Type of work	Air temperature (°C)
Seated, thinking task	18–24
Seated, light manual work	16–22
Standing, light manual work	15–21
Standing, heavy manual work	14–20
Heavy work	13–19

11.2.1.4 Humidity

Humid or very dry conditions can affect thermal comfort, therefore a reflective humidity (RH) in excess of 70% or less than 30% should be avoided.

11.2.1.5 Air-conditioning facilities (in workplaces, etc.)

It is recommended that air-conditioning equipment is installed in rooms that are frequently occupied and which have ambient temperatures above 30°C and/or high humidity levels. The rating of such systems should be designed so that the following temperatures are maintained:

$$t_{\text{int}} = 20 + 0.5(t_{\text{ext}} - 20) \text{ in } ^\circ\text{C} \quad t_{\text{ext}} => 20^\circ\text{C}$$

whilst ensuring a flow of fresh air into the room of at least $30\,\text{m}^3$ per hour.

In case of the air-conditioning system failing, adequate ventilation of the working environment should always be provided and assured.

11.2.1.6 Heating

The operator should be able to regulate the temperature as and when required within the range 18–23°C (measured 1.5 m above floor level around the seats). The difference in temperature between the upper and lower zones of the workplace should not exceed 10°C (measured in a zone 10 cm above floor level and 10 cm below the ceiling).

When outside temperatures are low, a reduced temperature range is permissible. Heating power should, however, be designed to obtain at least 18°C.

With the heating switched on, the installation should be capable of supplying an external air flow of at least $30\,\text{m}^3$ per person, per hour.

11.2.1.7 Radiating surfaces

Ideally, hot and cold radiating surfaces (e.g. hot roofs and cold windows) should not differ from the air temperature by more than a few (say 5) degrees.

11.2.1.8 Draughts

Draughts caused by ventilation, etc. should not exceed 0.1 m/s. If this is unavoidable, then facilities should be available to increase the air temperature.

11.2.1.9 Ventilation

The ventilation system should be designed to ensure that at least 30 m^3 per person, per hour is blown into the office without causing unpleasant draughts.

Under normal conditions it should be possible for the operator/technician to adjust the air flow and the air velocity provided that it does not exceed 0.3 m/sec, level with the operator's head.

In order to ensure rapid evacuation of accumulated heat, the ventilation system should be designed so as to enable the external air flow to be increased by the operator to at least 300 m^3 per hour.

11.2.1.10 Fresh air

The required volume of fresh air per person and the rate of air change depends very much on how physically demanding the work is and on personal choice. Table 11.9 provides some examples.

Table 11.9 Recommended rate of air change

Nature of work	Volume per person m^3	Fresh air supply rates m^3h^3
Very light	10	30
Light	12	35
Moderate	15	50
Heavy	18	60

11.2.1.11 Chemical substances

Certain airborne substances (see Table 11.10) are known to cause cancer (i.e. carcinogens) and exposure to these substances should be avoided at all times.

Certain substances which have a rapid toxic effect are covered by an internationally agreed list called the TLV-C or Threshold Limit Values – Ceiling list. These agreed values should never be exceeded under any circumstances and the design of the working environment must always reflect this. In addition (and by international agreement), the TLV 8 hour (weighted) average concentration figure should never be exceeded in any one 24 hour period.

When it is impossible to stop the release of chemical substances, then all harmful substances should be extracted at source and released external to the work area having, of course, paid due attention to the inter-

Table 11.10 Examples of chemical substances that are known to produce cancer

Substance	Example of use
Asbestos	Thermal insulation
Benzene (benzol)	Solvent
Chrome compounds	Pigment
Polycyclic hydrocarbons	Component of tar (diesel exhaust)
Vinylchloride	Raw material for PVC

nationally agreed environmental laws (e.g. ISO 14001) on the emission of harmful substances into the air!

Indoor environments always need to be adequately ventilated even if no dangerous substances are present.

11.2.1.12 Microbiological pollution

The most obvious requirements for microbiological pollution are contained in Chapter 7 Pollutants and contaminants.

11.2.2 MMI requirements

In most workplaces, the Man–Machine Interface (MMI) consists of an information screen/unit (sometimes complete with touch screen facilities), a control unit (e.g. keyboard) and an audio unit.

The maximum normally permitted exposure for each of the ergonomic environmental factors is as described below.

11.2.2.1 Illumination (lighting)

As no specific requirements are deemed necessary for protecting the health of the operator from the effects of light, MMI environmental light requirements are mainly concerned with the operator/technician's ability to complete a task (task effectiveness) and with the operator's comfort:

- in all circumstances there should be no direct radiation of the sun on the information screen. For existing offices this requirement can mean that some (side) windows will have to be fitted with blinds;
- direct beaming of light from internal room lighting systems onto the information screen should be prevented by use of blinds, mirror systems or positioning;
- sunlight should be prevented from reflecting on internal room surfaces by the use of diffuse reflecting (e.g. not flat, not shiny, not polished, not glossy) materials for the surfaces;
- the lowest reflection grades are normally accepted as 0.3 for doors and walls, 0.15 for the floor, 0.5 for the roof and 0.3 for the surface of the operator's desk around the screen;

- the information screen itself should have a maximum reflectance grade of no more than 0.02, preferably lower (±0.005), by the use of a $\frac{1}{4}$ lambda coating;
- side window panes should be constructed from dark tinted glass with a maximum light transmission factor of 60% (0.6). The use of light absorbing foils on the inside windows with a maximum light transmission factor of 35% (0.35) is also a possibility;
- alternatively, windows can be constructed of light tinted glass with a light transmission factor of 80% (0.80). Ensuring that whenever possible, there is no colour distortion of outside signals.

11.2.2.2 Noise

It is internationally accepted that:

- the maximum, *average*, noise level over an 8 hour working day should not exceed 80 dB(A);
- as annoyance levels well below 80 dB(A) can still have a detrimental effect during thinking and communication tasks, in all cases, equipment should be designed so that the maximum noise level at *any one time* is below 80 dB(A);
- by international agreement, audio signals originating from the audio unit shall comply with the requirements set forward in ISO 7731, namely:
  - the signal/noise ratio shall be at least + 15 dB(A) when there is no frequency orientated information available;
  - for an audio system with fixed output levels this will mean a level of at least 98 dB(A) (83 + 15) for the probable worst case situation;
  - the audio unit should also comply with the other requirements for the danger/safety signals as stated in ISO 7731 (i.e. minimum level of 65 dB(A), minimum duration of 2 seconds).
- high frequency sounds from electronic parts (peeps, wheezy sounds, etc.) in the frequency range 8000 Hz to 20 000 Hz should also be eliminated at source.

11.2.2.3 Vibration

The average level of the vibration amplitude (weighted and summed over three orthogonal directions) should never be more than $0.7\,m/s^2$ and preferably always less than 0.5 m/s.

11.2.2.4 Structural safety

The fastenings of all equipment and other components mounted inside a vehicle (i.e. car, train or aircraft) should be designed to withstand accelerations of at least 3 g in case of frontal impact. It is recommended, however, that the design should allow for a maximum acceleration value of 5 g.

11.2.2.5 Equipment design

All equipment should be designed in such a manner that maintenance and/or repair tasks can always be achieved in a safe and healthy manner and (probably more importantly) without being physically difficult or unacceptable to the worker.

11.2.2.6 Colours and surface coatings

The colour scheme used in workplaces should, wherever possible, harmonise and not cause eyestrain.

Paint and surface coatings should not reflect light in a way that might inconvenience the operator/technician. Grey is preferred as the basic colour for all MMI equipment.

Workplace components (e.g. tables, desks, etc.) with which hands or legs come in contact continuously or repeatedly, should not induce a 'cold metal' sensation and should be coated with material that is pleasant to touch, or provided with surface heating.

Materials which come into contact with the skin should be neither too cold (minimum temperature 5°C) nor too hot. Table 11.11 shows the maximum temperature normally allowed depending on the duration of the exposure and the type of material.

Table 11.11 Materials – maximum temperature

Duration of contact	Type of material	Maximum temperature (°C)
Up to 1 min	metals	50
	glass, ceramics, concrete	55
	plastics (perspex, Teflon), wood	60
Up to 10 min	All materials	48
Up to 8 hours	All materials	43

11.2.3 Other considerations

The possible effect of electromagnetic emission causing cancer (a popular belief in some European countries) should be considered.

11.3 Values and ranges

There are no specific values and ranges associated with this section other than those already indicated in the text or referenced standards.

11.4 Tests

11.4.1.1 Test specifications

In addition to the relevant standards mentioned in the previous sections, all candidate equipment should also be tested for:

ISO 2631	Guide for the evaluation of human exposure to whole body vibration
ISO 5349	Mechanical vibration – Guidelines for the measurement and assessment of human exposure to hand transmitted vibration
ISO 7726	Thermal environments – Instruments and methods for measuring physical quantities
ISO 7730	Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort
ISO 7731	Danger signals for workplaces – Auditory danger signals

Chapter 12

General

12.1 Introduction

This section of the book is designed to include topics that apply to all of the other sections (e.g. the requirements for quality) or topics that are generally applicable to the majority of sections.

12.2 Design

Equipment needs to be designed to survive and work in a wide range of environments, from severe (i.e. one to which no controls or conditions are applied) to benign (i.e. one in which the ambient conditions are closely controlled at a predetermined level – for example, in a temperature controlled room).

It is usually a mandatory requirement of contracts that all equipment that is provided shall be expected meet all of the performance requirements for the environment in which that equipment is intended to operate.

The design of equipment shall be an optimum between:

- the environmental resistance of unprotected equipment;
- the protection of equipment from environmental influences;
- the restrictions found during transportation, storage and use of that equipment.

12.2.1 Equipment survival

Equipment needs to be designed so that it can operate in and survive:

- the effects of short-term extreme environmental conditions which may directly cause malfunction or might normally destroy the equipment.

Note: Short-term environmental conditions may occur at any time during an equipment's lifetime and whilst equipment may be unaffected by an extreme condition when new, it may fail when subjected to the same condition after being used for a long period, due to the effect of ageing.

- the effects of long-term non-extreme environmental stresses that may slowly degrade the product and finally cause malfunction or destruction;
- the effects of extreme environmental conditions that may only affect the equipment when operational, when being transported or when stored.

12.2.2 Earthquakes

Equipment during transportation or whilst in service, may be subjected to short duration, random, dynamic forces (e.g. stresses induced in the equipment as a result of earthquakes, explosions and during some phases of transportation).

Normally equipment suppliers will be required to provide proof of their equipment's capability of withstanding a specified severity of transient vibration. This is in order to determine any possible mechanical weakness and/or degradation in specified performance and to demonstrate the mechanical robustness of specimens.

The time-history method described in IEC 68.2.57 is normally recommended for this purpose.

12.2.3 Lightning

Consideration should be given to the effects of lightning on the equipment. For protection against lightning, contracts frequently refer to EN 50124.2 which is a CENELEC requirement.

12.2.4 Flammability and fire hazardous areas

Another CENELEC recommendation concerns equipment being used in fire hazardous areas and for this three classes are foreseen by CENELEC for fixed installations.

1. Class FO – no special fire hazard envisaged. This is considered a normal service condition and except for the characteristics inherent to the design of the equipment, no special measures need to be taken to limit flammability.
2. Class F1 – equipment subject to fire hazard. This is considered an abnormal condition and restricted flammability is required. Self-extinction of fire shall take place within a specified time period. Poor burning is permitted with negligible energy consumption.

The emission of toxic substances shall be minimised. Materials and products of combustion shall, as far as possible, be halogen free and shall contribute with a limited quantity of thermal energy to an external fire.

3 Class F2 – equipment subject to external fire. This is considered an abnormal condition and in addition to the requirements of Class F1, the equipment shall (by means of special provisions) be able to operate for a given time period when subjected to an external fire.

12.2.5 Fire protection

Materials shall be expected to conform to those requirements defined in EN 60721 or have the agreement of the customer concerned.

12.2.6 Health and safety

12.2.6.1 Health

Under European law, suppliers and their contractors are required to ensure compliance with European legislation No. Cr 296: 'Health and safety at the workplace' when designing and developing equipment.

12.2.6.2 Safety

Under all environmental conditions, equipment will be expected to achieve the required industrial equipment safety standards.

12.2.7 Protection

As far as possible all circuits shall be designed so that in the event of a component fault consequential damage is confined to a minimum.

12.3 RAMS

RAMS is an acronym for Reliability, Availability, Maintainability and Safety. Each term is defined as follows:

- Reliability. The probability that a piece of equipment can perform a required function under given conditions for a specified period of time.
- Availability. The ability of a product to be in a state to perform a required function under given conditions at a given instant in time or duration.
- Maintainability. The probability that a given maintenance action can be carried out within a stated time interval, when that maintenance is carried out under stated conditions and using stated procedures and resources.
- Safety. Freedom from unacceptable risk or harm.

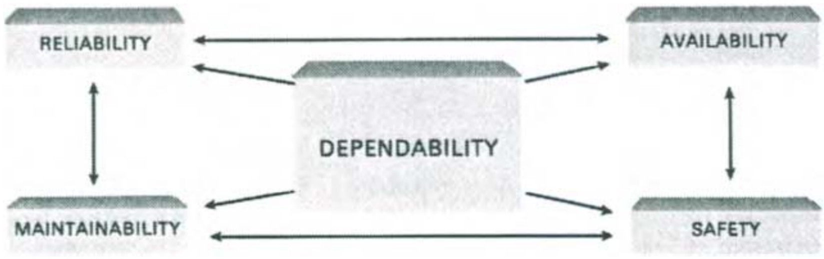


Fig. 12.1 RAMS and dependability

As a subject RAMS could form the basis of an entire book, but basically it covers all the criteria which make a piece of equipment dependable. Dependability is defined as being the ability of a product to perform one or several required functions under given conditions.

Equipment dependability is a major contributor to the quality of service offered by a device and the four major criteria that produce a dependable device are all inextricably linked. For example, you cannot have a safe device if it requires dangerous procedures to maintain it. Similarly, you would only expect a piece of equipment to be instantly available if it had good reliability.

Further reading on RAMS can be found in the following specifications:

- IEC 60300 – Reliability and maintainability management.
- BSI Handbook No. 22 Part 2 (1992) *Reliability and Maintainability.*
- BS EN 61069 – Dependability for industrial process measurement and control systems.
- EN 50126 – Railway applications: The specification and demonstration of dependability, Reliability, Availability, Maintainability and Safety (RAMS).

The following subsections offer only a small selection of typical requirements you may expect to find in a contract concerning RAMS requirements.

12.3.1 Reliability

The required reliability for each module is usually specified (by the end user) in individual specifications consistent with their requirements for overall system reliability.

The manufacturer will be required to provide reliability data for all equipment together with supporting evidence for the figures used.

12.3.2 Maintainability

For ease of maintenance, all equipment provided needs to have easily accessible test points to facilitate fault location and modules should be constructed so as to facilitate the connection of test equipment such as logic analysers or emulators, as well as test ROMs.

To assist with testing and fault location provision shall be made for isolating functional areas within each module.

Under workshop conditions it should be possible to gain access to all circuitry while operating, with a minimum of effort required, to partially dismantle the module concerned with the assumption that there will be a minimum of risk to the components, or the testing maintenance staff.

Special connecting leads, printed wiring extension boards and any other special items required for maintenance purposes, together with the mating half of all necessary connectors, will be assumed to be supplied by the manufacturer.

During operation, the storage of data obtained from the various systems and modules shall indicate each technical event and any perceived malfunction. The technical events may be overwritten after an agreed period. This data shall be stored in a way that is easily accessible by maintenance staff at first line and shall be readable from a remote position.

It should be noted that certain environmental tests may weaken electronic equipment and cause greater susceptibility to failure from the effects of the next or following environmental tests.

12.3.3 First line maintenance

It is normally stipulated that all equipment should be maintained at first line, on a European scale, without having to rely on the availability of multiple types of test installations.

12.3.4 Life

Equipment is normally expected to have been designed to have a useful life of not less than 20 years. 'Useful life' normally means 'the period for which the equipment will continue to operate with the specified level of reliability'.

No components should, therefore, be used (so far as can be ascertained at the time of manufacture) for which spares cannot be fully guaranteed to be available throughout the life of the equipment.

12.3.5 Modifications

Modification states should be encoded such that they appear in all test reports printed at first line and (where possible) indicated on the equipment itself.

12.3.6 Protection against unauthorised access

The 'access' level defines who has access, reason for access and how access shall be achieved, thereby guarding against unauthorised access by others.

For each of the particular operations below, personnel performing these functions will require to meet certain criteria. CENELEC states that these shall be defined in respect of:

- skill discipline;
- skill level;
- equipment specific training.

CENELEC also states that 'protective measures should guard against access which is:
- accidental by unauthorised personnel;
- intentional by unauthorised personnel'.

12.3.7 External conditions

Protection, as recommended by CENELEC, can normally be achieved by means additional to the equipment itself. For example:

- housing;
- security;
- accessibility.

12.3.8 Waste

Under new regulations currently being discussed and finalised by the European Commission, all suppliers will be required to provide details of any waste that their equipment (and/or the processes that manufactured their equipment) will generate for the following circumstances:

- at the time of production;
- whilst in service;
- when destroyed.

It is normally incumbent upon the supplier to prove their capability for not only producing environmentally acceptable equipment but also their ability to eventually destroy time expired or unusable equipment so that it does not cause any waste that is not easily degradable.

In all cases, the requirements of ISO 14001 concerning environmental protection and the prevention of pollution must be met.

12.3.9 Railway equipment

The railway requirements for Reliability, Availability and Maintainability are very closely linked with their exceptional safety record and because of this they are very specific in their contracts particularly with regard to the installation of equipment.

12.3.9.1 Railway (track) equipment

The physical size of the equipment is restricted so as to allow staff to pass unhindered and shall not cause any interference with minor track maintenance activities.

Track equipment needs to be sufficiently robust to allow their survival in the railway environment.

Track equipment has to be capable of withstanding, without deterioration or malfunction, all vibrations and shocks that occur in service.

Track equipment must be capable of meeting the Vibration, Shock and Bump tests as described in the IEC 68.2.6/27/29/57 standards.

12.3.9.2 Trainborne equipment

Trainborne equipment has to be capable of transmitting data to the trackside and/or contain a removable data storage unit. A single industry standard is required for access to each individual recorded data file.

For diagnostic purposes, the railways require that all trainborne modules can be exercised from depot based equipment using a standardised interface.

12.3.9.3 Installation of railway equipment

The installation and arrangement of equipment on the vehicles is usually determined by agreement between the manufacturer of the electric equipment, the manufacturer of the vehicle and the end user concerned.

With due regard to its location and the method of installation on the vehicle, the electronic equipment must be capable of operating correctly in spite of snow (especially powdery snow), dust and other conditions to which rolling stock is normally exposed whilst in service.

In addition to vibrations, shocks and bumps, operation of electronic equipment should not be influenced by any electromagnetic fields present inside the vehicles.

The supply to the equipment should, if possible, be provided by a separate conductor connected as directly as possible to the source. This conductor should be used only for the supply to electronic circuits.

The installation of the electronic equipment should be arranged so as to reduce the effects of external electrical disturbances. Protection at the source is recommended if this method presents no major disadvantage.

The railway concerned will be expected to inform the manufacturer if one pole of the battery of the vehicle is earthed to the frame.

If several manufacturers supply electronic equipment having common direct connections, a reference potential needs to be established by mutual agreement between the users and the manufacturers.

12.3.9.4 Initialisation
Initialisation routines that exercise all functions and display in-service data to the driver and a confirmation of the results, at any supplementary test position, shall be made available.

12.3.9.5 General provisions governing acceptance of railway products – technical approval
The general conditions governing acceptance of railway products for use is contained in Table 12.1.

12.3.9.5.1 Technical approval
The technical approval procedure defined in UIC leaflet XY draft No. 5 specifies the conditions to be observed and the procedure to be used to authorise certain products for use in railway operation as well as the measures to be taken prior to their use or commissioning.

12.3.9.5.2 Manufacturer's responsibility
The manufacturer is expected to retain responsibility for the quality of products delivered and for observance of all regulatory or contractual requirements defined in the technical documents concerning the product.

12.3.9.5.3 Component certification
In addition to the CENELEC Electronic Components Committee (CECC) and the International Electrotechnical Commission, Quality Assessment System for Electronic Components (IECQ) procedures for component certification, each product listed shall be accompanied by the identification of the manufacturer, a description of the product, the conditions for use, the relevant definition and the associated documents.

12.4 Fire

A fire will normally start when sufficient thermal energy from, for example, a burning cigarette or an electric short circuit is supplied to a combustible material. Following ignition, the fire will then produce its own thermal energy. Some of which will be used as feedback to maintain combustion and some transferred via radiation and convection to other materials. These materials may also ignite and spread the fire.

The environmental conditions relating to the occurrence, development and spread of fire within a building and its effect on electrotechnical products exposed to fire is primarily covered by Section 8 (Fire Exposure) of IEC 721.2. This section provides background information for selecting the appropriate parameters and severities related to exposure of products to fire. More detailed information on fire condition characteristics and fire hazard testing is contained in specialist documentation.

Table 12.1 Conditions governing acceptance of railway products for use

Function performed	Technical approval (UIC leaflet XY)		Conditions governing acceptance of railway products for use (UIC leaflet XZ)				
			Manufacturer qualification	Product qualification	Product quality control		
					Quality system	Quality plan	Quality inspection
Procedure	Verification of the fitness for use of a product in a given domain – examination of plans (drawings, specifications, etc.) – validation of the prototype – validation of series production, process and tools[1] Means of validation laboratory tests carried out on the prototype or on the series production product		Appraisal of the ability to manufacture products complying with requirements on the basis of: – manufacturing – installations – quality – organisation[2] – technical qualifications	Verification of conformity of the first series production samples with the requirements set out in drawings and/or approved specifications – laboratory tests – tests in operation	Assessment of the quality system of the manufacturer and surveillance of the manufacturer's quality organisation by an independent body	Assessment and approval of the quality plan	Control of products manufactured in relation to specified requirements
Result on completion of procedure	Authorisation for use in the domain of use planned, if this authorisation is necessary	Attestation/ certificate of fitness for use in the domain of use defined	Attestation/ certificate of qualification of the manufacturer	Attestation/ certificate of qualification of the series production product of a manufacturer	Attestation/ certificate of quality assurance	Attestation/ certificate of approval	Declaration of conformity by the manufacturer Attestation/ certificate of product conformity on delivery

continued

Table 12.1 (*cont.*)

Responsibility for critical products	Public authority	Body accredited by the European rail sector committee and notified, if necessary, by the State	Railway enterprise on body nominated by the railway enterprise, or body accredited by the European rail sector committee	Body accredited by the European rail sector committee and notified by the State if necessary	Body belonging to the railway enterprise and accredited by the European rail sector committee, or body accredited by a national accreditation system, or body notified by the State	Approval body accredited by the European rail sector committee (and notified by the State if necessary), or body mandated by the approval body In all cases, the relevant action shall be carried out with adjudicating entity in the event of any additional provisions	Body belonging to the railway enterprise and accredited by the Europe rail sector committee, body notified by the State if necessary
Responsibility for non-critical products			Railway enterprise or body nominated by the railway enterprise	Body accredited by the national accreditation system or by the European rail sector committee, if product qualification is required	Body belonging to the railway enterprise, and recognised by the European rail sector committee, or body accredited by a national accreditation system	Adjudicating entity or body mandated by the adjudicating entity	Body belonging to the railway enterprise, and recognised by the European rail sector committee or body accredited by a national accreditation system

Notes
1 The manufacturer must be qualified beforehand.
2 The quality organisation may be a quality system.

12.4.1 Introduction

12.4.1.1 The development of fire

The development of the fire generally consists of three processes:

- thermal;
- aerodynamic;
- chemical.

As a rule, radiation, convection and flame spread are the dominant physical factors.

12.4.1.2 Fire growth

Once a fire has started in a space (e.g. a room) its growth and spread is determined by:

- site;
- volume;
- arrangement of the fuel or fire load, its distribution, continuity, porosity and combustion properties;
- aerodynamic conditions of the space;
- shape and size of the space;
- thermal properties of the space.

During the growth of a fire, a hot layer of gas builds up under the ceiling of the space. Under certain conditions, this gas layer can give rise to a rapid fire growth and flashover might occur.

12.4.1.3 Flashover

One normally defines flashover as the time when flames begin to emerge from the openings of the space, which correlates, with a temperature of 500°C to 600°C in the upper gas layer.

Flashover marks the transition from the growing fire (pre-flashover) to the fully developed fire (post-flashover).

12.4.1.4 Pre-flashover

A pre-flashover fire primarily concerns the operation and function of products (e.g. detectors, alarm systems, associated cables and sprinklers, etc.) that are vital to maintaining the level of safety required for escape and/or the rescue of people caught in a fire.

12.4.1.4.1 Characteristics of pre-flashover fire

The ignitability properties of exposed material depends on:

- the heat supplied;
- the exposure time;
- the presence or not of flames;
- the geometrical location;
- the thermal data;

together with time variations such as:

- rate of heat release;
- rate of flame spread;
- gas temperature.

12.4.1.4.2 Fire hazard of a pre-flashover

The fire hazard of a pre-flashover situation is normally considered in terms of a series of probabilities, which depends on:

- the presence of ignition sources;
- the presence of products;
- the product fire performance properties;
- the environmental factors;
- the presence of people;
- the presence/operation of detection and suppression devices;
- the availability of escape.

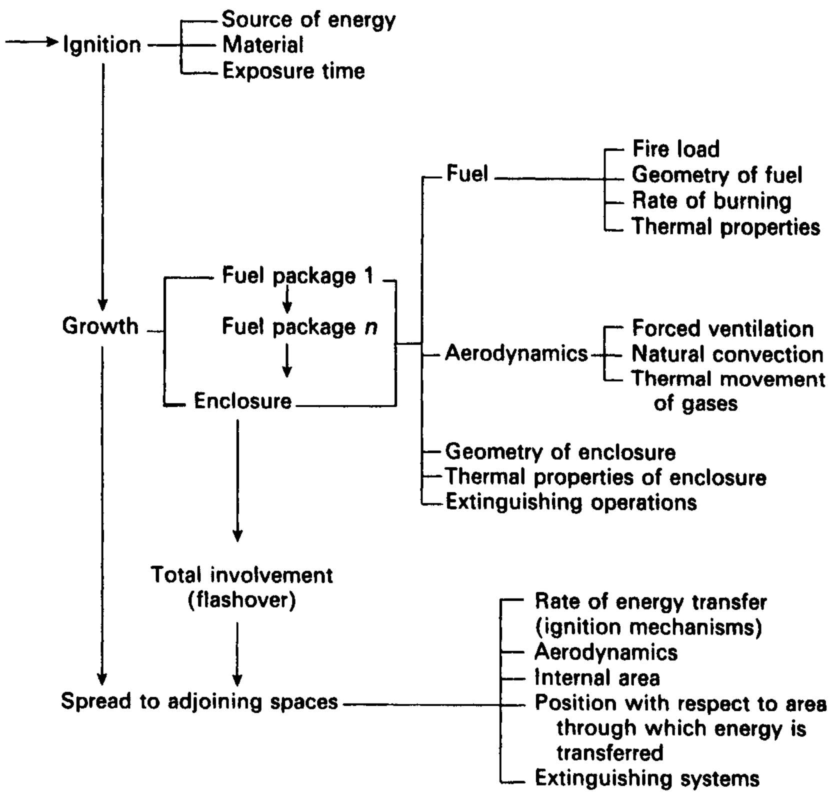


Fig. 12.2 Factors affecting ignition, growth and spread of fire in a building (reproduced from the equivalent standard BS EN 60721.2.8 by kind permission of the BSI)

12.4.1.5 Post Flashover

Whilst most standards are normally concerned with conditions during the pre-flashover stage of a fire, conditions following flashover must also be considered. A post-flashover fire can seriously damage some of the structural and load bearing elements of a building and the fire can then, quite easily, spread from one fire space to another via partitions and ventilation systems. This can, of course, seriously damage electrical equipment located in these voids. For example, in a large space it is quite possible that a fire, small in relation to that space, could be large enough to damage some of the structural elements in the post-flashover state. An important factor of the post-flashover fire, which is often overlooked, is the amount of smoke and toxic gases that can affect people in escape routes and remote safety areas in a building. Smoke and toxic gases can also significantly affect equipment.

12.4.1.5.1 Characteristics of post-flashover fire

The main characteristics of a post-flashover fire are:

- the rate of heat release;
- the gas temperature;
- the geometrical and thermal data for external flames;
- the smoke and its optical properties;
- the composition of the combustion products, particularly corrosive and toxic gases.

The possibility of a large external fire spreading from one storey to another in the same building (and eventually from one building to another) must also be considered. For these cases the first three characteristics – i.e. primarily gas temperature, geometrical and thermal data for the flames emerging from the window openings – are the most relevant.

12.4.1.5.2 Characteristics of smoke and gases as a fire product

Smoke is a mixture of heated gases, small liquid drops, and solid particles from the combustion. During a fire (pre- and post-flashover), smoke will be distributed within the building through the air flow between rooms and via ventilation ducts, etc. In most circumstances this can have disastrous effects because smoke can not only damage and in some cases even destroy property, it can also prevent the functioning of critical equipment. Most of the effects of smoke are of a chemical nature and the most prevalent is destruction or damage to electrotechnical products, in particular corrosion caused by hydrogen chloride, which is a substance in smoke.

Metal surfaces, exposed to air under normal (non-fire) conditions, often have a chloride deposit up to $10\,mg/m^2$. Such an amount is normally not harmful. However, after exposure to smoke from a fire involving polyvinyl chloride (PVC), a surface contamination of up to thousands of milligrams per square metre can be found, often causing significant damage. Chloride contamination of electrotechnical equipment can be removed by, for instance, detergents, solvents, neutralising agents, ultrasonic vibrations, and clean air jets, but the procedures are not always effective, sometimes giving a temporary but not permanent cure.

Experiments, involving PVC coated electrical wires and carried out on a scale large enough to be representative of real fires, are currently in hand.

12.4.2 Building designs

In the design of buildings, the fire design of load bearing structural elements and partitions is normally considered as a national problem and directly related to the results of standard national (and when available) international fire resistance tests. In such tests, the specimen is exposed, in a furnace, to a temperature rise, which is varied with time and within specified limits, according to the particular test being used.

Over the last decades, rapid progress has been made in the development of analytical and computational methods for determining the fire design of load bearing and separating structures and structural elements. In the long term, it is foreseeable that this will develop into an analytical and/or computational design, directly based on a natural fire exposure. These will be specified with regard to the combustion characteristics of a fire load and the geometrical, ventilation and thermal properties of the fire space.

12.4.3 Test standards

Fire tests on building materials, components and structures normally focus on the characteristics of pre-flashover fire. Simplified full-scale (i.e. room) tests for surface products against smoke and in particular toxic combustion products are already available, but considerable development work needs to be completed before a useful small-scale test is available.

If no mathematical model of a small-scale test is available, the test results should be statistically correlated directly to full-scale test data. If a validated mathematical model of a small-scale test exists, important material characteristics controlling the space fire growth can be given quantitative values which can then be used as input data in mathematical models of full-scale pre-flashover space fire for specified scenarios.

With a view to practical, long-term use the results of small-scale reaction to fire tests to predict fire hazard should be based on a fundamental and scientific approach.

Figure 12.4 outlines the structure of such an approach.

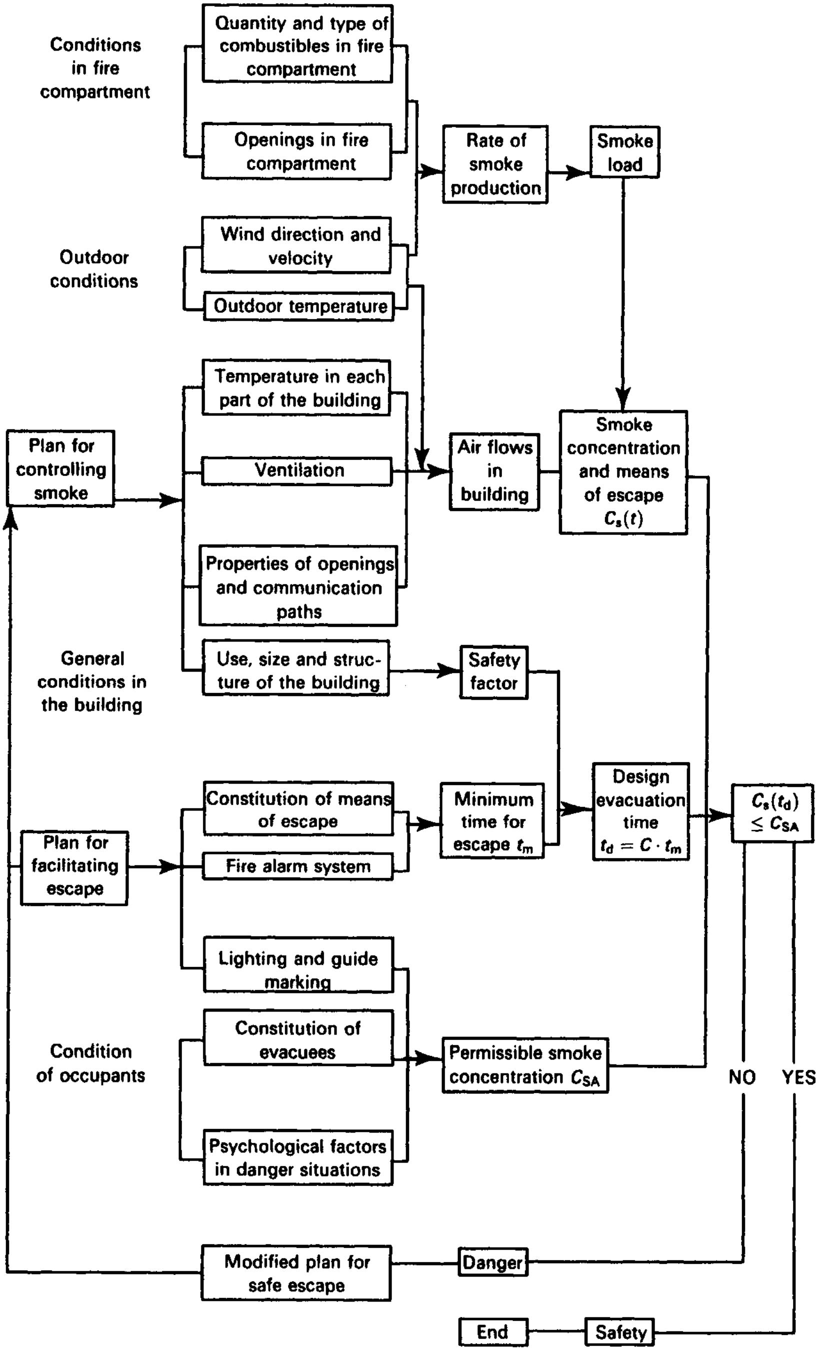


Fig. 12.3 Flow diagram of a smoke control design system in a building (reproduced from the equivalent standard BS EN 60721.2.8 by kind permission of the BSI)

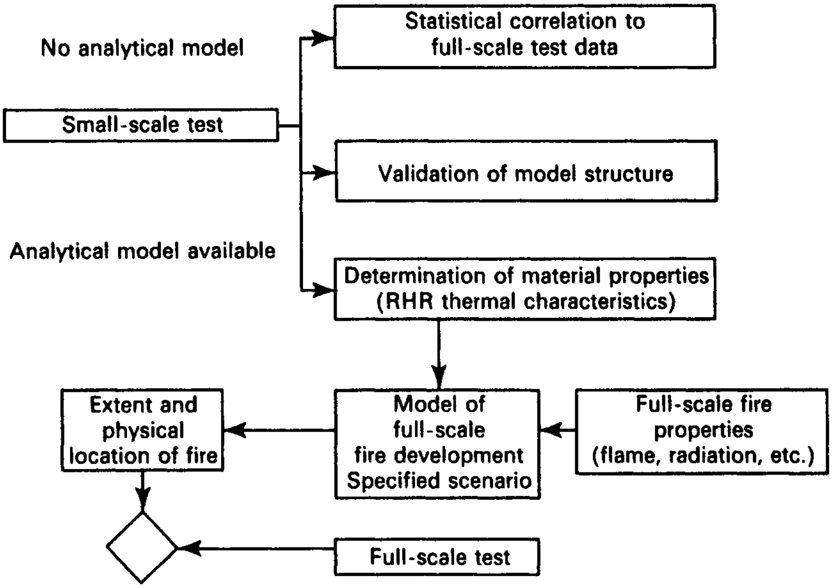


Fig. 12.4 Combination of basic property tests and mathematical models for assessing the contribution of a tested material or product to the overall fire safety (reproduced from the equivalent standard BS EN 60721.2.8 by kind permission of the BSI)

12.4.4 Other related standards and specifications

IEC 60695 Series	Fire hazard testing – Guidance, tests and specifications for assessing fire hazard of electrotechnical products
ISO 5657	Fire tests – Reaction to fire – Ignitability of building products
ISO 5658	Reaction to fire tests – Spread of flame on building products and vertical configuration
ISO 5660	Fire tests – Reaction to fire – Rate of heat release from building products
ISO 9705	Fire tests – Full scale room test for surface products
ISO TR 5924	Fire tests – Reaction to fire – Smoke generated by building products (dual-chamber test)
ISO TR9112.1	Toxicity testing of fire effluents – General

12.4.5 Typical contract requirements – fire

In most contracts reference is made to the IEC 60695 series of standards which cover the assessment of electrotechnical products against a nominated fire hazard.

CENELEC, on the other hand, show the requirement for equipment to operate in fire hazardous areas as three distinct clauses, as follows:

- Class FO – no special fire hazard envisaged. This is considered a normal service condition and except for the characteristics inherent to the design of the equipment, no special measures need to be taken to limit flammability.
- Class F1 – equipment subject to fire hazard. This is considered an abnormal condition and restricted flammability is required. Self-extinction of fire shall take place within a specified time period. Poor burning is permitted with negligible energy consumption.
  The emission of toxic substances shall be minimised. Materials and products of combustion shall, as far as possible, be halogen free and shall contribute with a limited quantity of thermal energy to an external fire.
- Class F2 – equipment subject to external fire. This is considered an abnormal condition and in addition to the requirements of Class F1, the equipment shall (by means of special provisions) be able to operate for a given time period when subjected to an external fire.

Materials are normally expected to confirm to those requirements defined in EN 60721.3.3 and EN 60721.3.4.

12.4.6 Values and ranges – fire

The relevant values and ranges are found in the standards listed in paragraph 12.4.4.

12.4.7 Tests

The main tests used for equipment and material are contained in the IEC 60695 series of standards supported by EN 60721.

12.5 Quality Control and Quality Assurance

12.5.1 Introduction

The principles of Quality Assurance and applications of standards in the ISO 9000 series are now widely accepted and the need has emerged for contracts to define common provisions concerning:

- general rules for acceptance for use of products adapted to the risks associated with their use;
- technical approval procedures for products;
- conditions for quality surveillance on the premises of product manufacturers;
- qualification of manufacturers.

Requirements with regard to quality are dependent on the level set by the end user in the contract. They normally fall into one of four levels.

12.5.2 Manufacturers

Manufacturers of products falling within quality levels 1, 2 and 3 (see Table 12.3) need to be qualified.

For requirement levels 1 and 2, qualification of the manufacturer shall require an evaluation of its quality system and its technical capabilities.

Level 3 requires only the evaluation of the manufacturer's inspection, organisation and verification of its technical capabilities.

Level 4 requires the manufacturer to maintain documented proof that tests and inspections have been carried out and that they conform to the specific technical requirements contained in the relevant standards and specifications.

12.5.3 Products

Unless otherwise stated, all products are normally assumed to be qualified. This qualification will consist of verification of product conformity with the technical characteristics specified (drawings, specifications, etc.) and will be verified during initial series production.

12.5.4 Quality documents required

12.5.4.1 Quality plan

In accordance with the requirements of ISO 9000:

- the manufacturer shall draw up a quality plan describing the specific measures taken by the manufacturer to achieve and master the quality of their product;
- the plan shall specify the resources and the sequences of specific quality actions for the product and should include an inspection and audit schedule;
- inspection and test documents concerning the product shall be drawn up (test reports, inspection records, etc.) by the manufacturer/supplier.

12.5.4.2 Validation of the quality plan

Validation of the quality plan by the customer is normally carried out in two stages:

- formal validation of the document on completion of examination;
- validation of application of the document (on completion of an audit) and verification of implementation of any corrective action undertaken.

Table 12.2 Quality requirements

Requirements	Requirements of manufacturers		Product requirements		Quality documents		Quality surveillance	
Level of requirements	Quality management	Component certification	Conformity with specified technical characteristics[1]	Serviceability	Quality plan	Test and inspection documents	Manufacturers' quality system	Product inspection
1	X	X	X	X	X	X	X	X
2	X	X	X	*	X	X	X	X
3	*	X	X	*	*	X	*	X
4	*	*	X	*	*	X	*	X

X Provision required by the railway.
* This provision or vertification is not required.
1 Technical characteristics may include specific tests carried out on initial parts, the definition and contents of which shall be specified in the technical document for the product.

Validation of the quality plan is not anticipated to relieve the manufacturer of its responsibility for quality!

12.5.4.3 Manuals, documents and drawings

Manuals, documents and drawings shall be in accordance with the principles of ISO 9000.

12.5.5 Test routines

Test routines shall run in the background of every processor following initialisation to verify its serviceability and that of its associated equipment.

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Appendix

Glossary of terms

As international trade increases, it is becoming more important than ever to know the exact meaning of some of the basic definitions when referred to the quality of a product or service – especially when used in the vernacular! To overcome this problem an international standard (ISO 8402-1986 'Quality Vocabulary') was published in three languages (English, French and Russian) that 'defines the basic and fundamental terms relating to quality concepts, as they apply to products and services, for the preparation and use of quality standards and for mutual understanding in international communications'.

ISO 8402 was developed within ISO/TC 176/SC 1 Quality Terminology (Secretariat France). It was developed by first screening existing quality standards and publications that were available to determine the quality terms that could be included and then producing internationally acceptable definitions of them. Because of this 'international acceptability' many of these definitions and terms have specific meanings and applications as opposed to generic definitions that are normally to be found in dictionaries.

Acceptable quality level A measure of the number of failures that a production process is allowed. Usually expressed as a percentage.

Acceptance Agreement to take a product or service as offered.

Ambient temperature The temperature of the air measured under standardised conditions and with certain recognised precautions against errors introduced by radiation from the sun or other heated body.

Application environment The overall environment in which the equipment is designed to operate, be stored or transported within.

Approval of a distributor Recognition that a distributor has a competent organisation for the storage, repacking, distribution and release of particular components in accordance with BS CECC or IECQ.

Approval of an independent assessor (of electronic components) Recognition that an assessor has a competent organisation for the purchase, assessment, storage, repacking, distribution and release of unencapsulated components for incorporation into components covered by a BS 9000, CECC or IECQ generic specification.

Approval of an independent test laboratory (of electronic components) Recognition that a test laboratory has a competent organisation for the inspection and release of components in accordance with BS 9000, CECC or IECQ.

Approval of a manufacturer (of electronic components) Recognition that a manufacturer has a competent organisation for the production and inspection of particular components in accordance with BS 9000, CECC or IECQ.

Assessment procedures A procedure used by Competent Authorities and Competent Bodies for assessment of equipment conformity against harmonised standards.

Batch A quantity of some commodity that has been manufactured or produced under uniform conditions.

Basic assessment (of electronic components) The lowest level of assessment recognised by the BS 9000 system. Obtained by performing a series of minimum mandatory tests for basic assessment.

Basic specification A specification that is applicable to all electronic components or to a large group of electronic components.

Blank detail specification A pro-forma document which is derived from the requirements of a generic and/or sectional specification. When completed this becomes the detail specification for that particular component.

Bonded store A secure place in which only supplies that have been accepted as satisfactory by the inspection staff are held.

Calibration The operation that is required to determine the accuracy of measuring and test equipment.

Capability approval Approval that is granted to a manufacturer when they have demonstrated that their declared design capability, manufacturing processes and quality control meets the requirements of the relevant generic specification.

Capability qualifying components A group of components and/or test pieces which are collectively used to demonstrate that the declared capability meets the requirements that have been specified in the generic specification.

CEN (European Committee for Standardisation) European equivalent of ISO.

CENELEC (European Committee for Electrotechnical Standardisation)
Certification Body An impartial body which has the necessary competence and reliability to operate a certification scheme.

Certification system A system for carrying out conformity certification.

Certificate of conformity A document stating that, at the time of the assessment, the product or service met the stated requirements.

Certified test record A summary of the results of specified tests that have been carried out on components that were released over the last six month production period.

Characteristic A property that helps to distinguish between items of a given population.

Chief inspector An individual who is responsible for the manufacturer's Quality Management System (also referred to as the Quality Manager).

Company Term used primarily to refer to a business first party, the purpose of which is to supply a product or service.

Competent authorities As defined by Council Directive 98/336 refer to those bodies represented by the national administrations, which are responsible for the application of the relevant obligations.

Competent bodies Those bodies which meet the criteria listed in Council Directive 98/336 and which are responsible for issuing the technical reports or certificates in accordance with the second procedure described in the Assessment Procedures.

Compliance The fulfilment of a Quality Management System or quality procedure of specified retirements.

Concession Written authorisation to use or release a quantity of material, components or stores already produced but which do not conform to the specified requirements.

Configuration The complete technical description that is required to make, test, equip, install, operate, maintain and logistically support a product.

Conformance The fulfilment of a product or service of specified requirements.

Contractor assessment The formal examination by a National Quality Assurance Authority to determine the ability of a contractor or potential contractor to meet requirements.

Consignment Products (or goods) that are issued or received as one delivery and covered by one set of documents.

Corrective maintenance The maintenance that is carried out after a failure has occurred and which is intended to restore the item to a state where it can perform its original function.

Customer Ultimate consumer, user, client, beneficiary or second party.

Delivery lot A quantity of components that are delivered at the same time.

Design authority The approved firm, establishment or branch representative responsible for the detailed design of material to approved specifications and authorised to sign a certificate of design, or to certify sealed drawings.

Design capability The ability of a manufacturer to translate a customer requirement into a component that can be manufactured by their particular technology.

Design review A formal, documented, comprehensive and systematic examination of a design to evaluate the design requirements and the capability of the design to meet these requirements and to identify problems and propose solutions.

Deviation permit Written authorisation, prior to production or before provision of a service, to depart from specified requirements for a specified quantity or for a specified time.

Direct surveillance Surveillance carried out on premises that come under the direct control of the chief inspector by reason of his appointment.

Distributor An organisation that is contractually authorised by one or more manufacturers to store, repack and sell completely finished components from these manufacturers.

Detail specification A specification which is derived from a generic or sectional specification, which covers and describes a particular component or a recognised range of components.

Economic quality The economic level of quality at which the cost of obtaining higher quality would exceed the benefits of the improved quality.

Effect The non-fulfilment of intended usage requirements.

Electronic component A device that is part of an electronic circuit and that has a distinctive function in that electronic circuit.

Endurance test A test in which an item is subjected to a specified stress (or stresses) over a specified period of time, or number of operations, or both.

Evaluation The systematic examination of the effectiveness of a contractor's Quality Management System.

Environment All of the external physical conditions that may influence the performance of a product or service.

Environmental condition The characteristics (such as humidity, pressure, vibration, etc.) of the environment in which the product is operating.

Environmental stress The stress to which a product is exposed that is solely due to its presence in an environment.

Facilities The tools, materials, supplies, instruments, equipment and other resources that are available to manufacture a product or perform a service.

Fail safe A designed property of a product that prevents any failures becoming critical failures.

Failure tree analysis (FTA) The study, with the use of diagrammatic algorithms, of the possible sequence of events leading up to the failure of a product.

Final inspection The last inspection by a manufacturer or supplier before delivery.

Firmware Computer logic that is either hardwired or in a state that cannot be readily modified.

Full assessment A degree of quality assessment that is higher than basic assessment level. Obtained by tighter inspection levels, tighter acceptable quality levels and more stringent tests.

Functional specification A document that describes, in detail, the characteristics of the product with regard to its intended capability.

Functional stress The stress to which a product is exposed that is solely due to its intended function.

Generic specification A specification that is applicable to a family or subfamily of electronic components.

Grade An indicator of category or rank related to features or characteristics that cover different sets of needs for products or services intended for the same functional use.

Graded standard Defines the particular grade of an item of material or product for a particular application.

In-progress-inspections QA Inspectors perform these on a random basis or while assisting the technician. They may also be considered as 'training' inspections and are meant to help the technician perform better maintenance whilst actually learning about the equipment.

Independent test laboratory An organisation that has the facilities and capability to carry out tests and measurements on electronic components in accordance with the relevant specification, and which does not form part of the manufacturing organisation producing these components.

Inspection Activities such as measuring, examining, testing, gauging one or more characteristics of a product or service and comparing these with specified requirements to determine conformity.

Inspection by attributes Inspection whereby certain characteristics of an item are assessed, without measurement, as either conforming or not conforming to the requirements of the product or service.

Inspection by variables Inspection whereby certain characteristics of an item are evaluated against a numerical scale and are expressed as points along that scale.

Inspection lot A collection of components or 'units' from which a sample is taken and inspected to determine conformance with the acceptability criteria.

Inspection system The established management structure, responsibilities, methods, resources that together provide inspection.

Interchangeability Versions of the same component type covered by a detail specification.

International Organisation for Standardisation (ISO) Comprises the national standards bodies of more than 50 countries whose aim is to co-ordinate the international harmonisation of national standards.

Lot A quantity of some commodity that has been manufactured or produced under uniform conditions.

Maintenance The combination of technical and administrative actions that are taken to retain or restore an item to a state in which it can perform its stated function.

Manufacturer An organisation, which carries out or controls such stages in the manufacture of electronic components that enable it to accept responsibility for capability approval or qualification approval, inspection and release of electronic components.

Manufacturers' specification The specification that a Manufacturer has agreed to meet at all costs and that has been accepted by the Design Authority as being sufficient to meet the User Requirement.

Material A generic term covering equipment, stores, supplies and spares which form the subject of a contract.

Minimum mandatory requirements A list of the essential parameters and characteristics for which values or requirements have to be given in the detail specification.

National Supervising Inspectorate (NSI) The authority that is responsible for completing an initial appraisal of inspection organisations, test laboratories, distributors and assessors, and the supervision of their operations subsequent to approval.

Non-conformity The non-fulfilment of specified requirements.

Non-standard item An item which authorities have agreed not to make a standard item.

Notified bodies Are those bodies which meet the criteria listed in Council Directive 98/336 and which are responsible for issuing the EC type examination certification in accordance with the third procedure described in the Assessment Procedures.

Operational cycle A repeatable sequence of functional stresses.

Operational requirements All the function and performance requirements of a product.

Operating temperature range The specified operating temperature for the equipment which must always be the lowest and the highest ambient temperature expected to be experienced by the equipment during its normal operation.

Organisation A company, corporation, firm or enterprise, whether incorporated or not, public or private.

Outgoing inspections These are performed after a job or task has been completed to verify that everything has been done correctly on a repaired equipment that is ready for return to the Customer. The QA Inspector is normally required to check the item to see how it compares against the manufacturer's specification. Any item failing an outgoing inspection has to be returned to the Technician or his Section Chief for corrective action. It will then be subject to a further outgoing inspection by the QA Inspector. Where possible these inspections should be carried out on all equipment leaving the Workshop.

Pre-inspections This is an inspection for any obvious or physical damage such as broken meter glasses, knobs, bad dents to the case, broken fuseholders, disconnected wires, etc. Where possible pre-inspections should be carried out on every equipment entering the Workshop.

Preventive maintenance The maintenance that is carried out at pre-determined intervals and is intended to reduce the probability of a failure occurring.

Process average (estimated) The average percentage defective or average number of faults per 100 items.

Product liability A generic term used to describe the onus on a producer or others to make restitution for loss related to personal injury, property damage or other harm caused by a product or service.

Production lot A quantity of components that have been manufactured continuously within a given period of time under uniform conditions.

Production permit Written authorisation, prior to production or before provision of a service, to depart from specified requirements for a specified quantity or for a specified time.

Qualification approval The status given to a manufacturer's product unit, whose product has been shown to meet all the requirements of the product detail specification and Quality Plan.

Qualification approval certificate A certificate that is issued to a component manufacturer that confirms qualification approval in respect of a specific electronic component or range of components.

Qualified products list A list that is maintained by BSI and published as PD 9002 of all components that have been given qualification approval under the BS 9000 system. This includes names and addresses of the manufacturers, manufacturer's identification code, lists manufacturers who have capability approval together with a description of the capability. The CECC also maintains and publishes a qualified products list in their CECC 00200 series.

Quality The totality of features and characteristics of a product or service that bear upon its ability to satisfy stated or implied needs.

Quality Assurance All those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.

Quality Assurance representative The authorised representative of the National QA authority designated in the contract.

Quality audit A systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives.

Quality control The operational techniques and activities that are used to fulfil requirements for quality.

Quality control system The established management structure, responsibilities, methods and resources that together provide quality control to demonstrate the attainment of quality.

Quality conformance inspection Measures that are demanded in the specification to show that the components produced by a manufacturer fulfil the requirements of a particular specification.

Quality level A general indication of the extent of the products departure from the ideal.

Quality manual A document setting out the general quality policies, procedures and practices of an organisation.

Quality manager A person who is responsible for the manufacturer's Quality Management System (also referred to as the Chief Inspector).

Quality loop Conceptual model of interacting activities that influence the quality of a product or service in the various stages ranging from the identification of needs to the assessment of whether these needs have been satisfied.

Quality management That aspect of the overall management function that determines and implements the quality policy.

Note: The terms 'quality management' and 'quality control' are considered to be a manufacturer/supplier (or first party) responsibility. 'Quality Assurance' on the other hand has both internal and external aspects which in many instances can be shared between the manufacturer/supplier (first party), purchaser/customer (second party) and any regulatory/certification body (third party) that may be involved.

Quality plan A document setting out the specific quality practices, resources and sequence of activities relevant to a particular product, service, contract or project.

Quality policy The overall quality intentions and direction of an organisation as regards quality, as formally expressed by top management.

Quality programme A documented set of activities, resources and procedures which implement the organisation's Quality Management System.

Quality spiral Conceptual model of interacting activities that influence the quality of a product or service in the various stages ranging from the identification of needs to the assessment of whether these needs have been satisfied.

Quality management system The organisational structure, responsibilities, procedures, processes and resources for implementing quality management.

Quality management system review A formal evaluation by top management of the status and adequacy of the Quality Management System in relation to quality policy and new objectives resulting from changing circumstances.

Quality surveillance The continuing monitoring and verification of the status of procedures, methods, conditions, processes, products and services, and analysis of records in relation to stated references to ensure that specified requirements for quality are being met.

Quality verification inspections These are performed prior to, during and after the job or task has been concluded. They are sometimes referred to as Pre-inspections, In-progress-inspections and Outgoing-inspections.

Quarantine store A secure place to store supplies that are awaiting proof that they comply with specified requirements.

Ratification Formal acceptance of a NATO document (e.g. STANAG) as national implementing document.

Redundancy The existence, in a product, of more than one means of performing a function.

Reliability The ability of an item to perform a required function under stated conditions for a stated period of time.

Related documents Documents referred to in a standard that form part of that standard.

Requirements of society Requirements including laws, statutes, rules and regulations, codes, environmental considerations, health and safety factors, and conservation of energy and materials.

Safety The freedom from unacceptable risks of personal harm.

Sample An item (or group of items) that have been taken from a larger collection (or population) of items to provide information relevant to that collection or population.

Sampling scheme The overall system containing a range of sampling plans and procedures.

Sampling plan An indication of the sample sizes and the acceptance/rejection criteria.

Sampling procedure The operational requirements and instructions relating to the use of particular sampling plans or schemes.

Sampling size The number of specimens in a sample.

Scheme of surveillance A system to ensure that the quality of the product meets the requirements of the relevant specification.

Screening test A test or combination of tests, intended to remove unsatisfactory items, or those likely to exhibit early failure.

Sealed pattern A specimen electronic component that is taken from a lot which has successfully passed the qualification approval process and which is kept for subsequent reference.

Section A part of a Workshop carrying out a repair on a general type or style of equipment. A number of sections (e.g. HF Radio, Relay, Microwave, Fabrication and Ground Power) make up a Workshop.

Section chief Responsible for ensuring that all aspects relating to safety, quality, workmanship and in-house training are active and every Technician under his supervision is aware of their required performance. Section chiefs are also responsible for Pre-inspections if not already performed by the QA Inspector. The quality control of maintenance performed in their respective work area. Co-operation with the QA Inspector to assure that only quality maintenance is done. It is essential that section chiefs and QA personnel maintain a friendly and co-operative attitude to each other. If difficulties arise that cannot be resolved between them then the matter should be brought directly to the notice of the Workshops Superintendent.

Service liability A generic term used to describe the onus on a producer or others to make restitution for loss related to personal injury, property damage or other harm caused by a product or service.

Software Covers all instructions and data which are input to a computer to cause it to function in any mode. This includes operating systems, supervisory systems, compilers and test routines, as well as application programmes. The words embrace the documents used to define and describe the programmes (including flow charts, network diagrams and programme listings), and also cover specifications, test plans, test data, test results and user instructions.

Specification The document that describes the requirements with which the product, material or process has to conform.

Specimen A representative item or quantity of material.

Standard The result of a particular standardisation effort that has been approved by a recognised authority. When this word – in capital letters – appears in relation to a clause, letter or form, it means that the wording shall not be altered.

Standardisation The process of formulating and applying rules for the benefit of all concerned.

Standard item An item which authorities agree should be used in preference to all others.

Statistical quality control That part of quality control in which statistical methods are used.

Statistical quality control chart A method used to ensure that the performance of a product is maintained during manufacture whereby samples of the production (or process) are regularly analysed against a control chart that has the upper and lower permissible limits for that particular product or process already plotted.

Stress cycle A repeatable sequence of stresses.

Storage life The specified length of time prior to use for which items (which are known to be subject to deterioration) are deemed to remain fit for use.

Storage temperature range The specified storage temperature that is always the lowest and the highest ambient temperature that the equipment is expected to experience (with the power turned off) during storage or from exposure to climatic extremes.

Structurally similar electronic component Components which are made in one factory using virtually the same design, material, process and method of fabrication.

Supervising inspector An inspector acting on behalf of the National Supervising Inspectorate.

Supplier evaluation Assessment of a supplier's capability to control quality.

Supplier rating An index related to the performance of a supplier.

System review The contractor's independent examination of the effectiveness of their system.

Technician An individual who is responsible for the actual maintenance modification or repair of an item of equipment or product.

Test A critical trial or examination of one (or more) of the properties/characteristics of a material, product or service.

Test plan A management document which addresses all aspects related to the test. It should include the test schedule and define the necessary support tools.

Test procedure A document that describes each step that is necessary to conduct a test. The steps shall be in sequence with all the inputs and outputs defined.

Test specification Describes the test criteria and the methods to be used in a specific test to assure that the performance and design specifications have been specified. The test specification identifies the capabilities or programme functions to be tested and identifies the test environment.

Traceability The ability to trace the history, application or location of an item or activity, or similar items or activities, by means of recorded identification.

Type approval The status given to a design that has been shown by type tests to meet all the requirements of the product specification and which is suitable for a specific application.

User requirement The documented product or service requirements of a customer or user.

Variable A characteristic that is appraised in terms of values on a continuous scale.

Vendor appraisal Assessment of a potential supplier's capability of controlling quality.

Walk through A review process in which the designer or programmer leads one or more other members of the development team through a segment of design or code that he or she has written, while the other members ask questions and make comments about technique, style, possible errors, violation of development standards and other problems.

Waiver Written authorisation to use or release a quantity of material components or stores already produced but which do not conform to the specified requirements.

Workmanship The level of the art or skill used in the repair process or manufacturing process as demonstrated by the characteristics of the product which cannot be specified in measurable terms.

Workshop superintendent Is responsible both for co-ordinating all aspects of Workshop activity and for determining that sufficient procedures and equipment are available to do the required task.

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Ref 1	'Operating Degradations during the in-service stages'; a paper by Herne Consultancy Group, 1994

Ref. 2 UIC/ERRI A118 Report No. 4. Use of electronic components in signalling

'ISO 9000 for Small Businesses – a guide to cost effective compliance' by Ray Tricker

'Quality & Standards in Electronics' by Ray Tricker

Acronyms and abbreviations

a.c.	Alternating Current
ADP	Automatic Data Processing
AVI	Automatic Vehicle Identification
ASD	Accelerated Spectral Density
AQL	Acceptable Quality Level
BS	British Standard
BSI	British Standards Institution
CAD	Computer Aided Design
CECC	CENELEC Electronic Components Committee
CEN	Comité Européen de Normalisation
CENELEC	Comité Européen de Normalisation Electrotechnique
CER	Community of European Railways
CGPM	Conférence Générale des Poids et Mesures
CPS	Control and Protective Switching Device
d.c.	Direct Current
DTI	Department of Trade and Industry
EU	European Community
EEC	European Economic Commission
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
EN	European Normalisation
ENV	European pre-standards
ERRI	European Rail Research Institute
HBES	Home and Building Electronic Systems
HEMP	High Altitude ElectroMagnetic Pulse
HV	High Voltage
IEC	International Electrotechnical Commission
ILU	Integrated Logistic Unit
IPC	Implant Point of Coupling

ILI	Infonorme London Information
I/O	Input/Output
ISM	Industrial, Scientific and Medical
ISO	International Standards Organisation
IT	Information Technology
ITCZ	International Conveyance Zone
ITE	Information Technology Equipment
LUR	Logical User Requirement
MDD	Medical Devices Directive
MMI	Man Machine Interface
MKS	Metre-Kilogram-Second
MTBF	Mean Time Between Failures
NSO	National Standards Organisation
PCB	Printed Circuit Board
prEN	European draft standards
QA	Quality Assurance
QC	Quality Control
QMS	Quality Management System
QP	Quality Procedure
r.m.s.	Root Mean Square
RAH	Relative Air Humidity
RAM	Reliability, Availability and Maintainability
RCBO	Residual Current Operated Circuit Breaker without integral overcurrent protection
RCCB	Residual Current Operated Circuit Breaker with integral overcurrent protection
RCD	Residual Current Operated Protective Device
RF	Radio Frequency
RH	Relative Air Humidity (alternative abbreviation)
SI	Système International d'Unités
S/N	Signal Noise Ratio
T&E	Time and Expense
TLV	Threshold Limit Values
TVL-C	Threshold Limit Values – Ceiling List
TQM	Total Quality Management
UPS	Uninterruptible Power System
VDU	Visual Display Unit
WAUILF	Workplace Applied Uniform Indicated Low Frequency (application)
WI	Work Instruction
YFR	Yearly Forecast Rationale

List of symbols

Symbol	*Description*
%	percentage
β°	tube oscillating angle
°C	degrees Celsius
Ω	ohm
μg	microgram
$\mu g/m^3$	micrograms per cubic metre
μm	micrometre
μs	microsecond
a	amplitude
α°	spray/tilt angle
A	ampere
A/m	amperes per metre
am	attometre
atm	standard atmosphere
C	coulomb
cd	candela
cd/m^2	candelas per square metre
dB	decibels
dB(A)	decibel amps
dBm	decibel metres
dm^3	cubic decimetre
dm^3/mm	cubic decimetres/millimetre – flow
Em	exametre
eV	electronvolt
f	frequency
F	farad
fm	femtometre
ft	foot
g	gram
G	gauss
G	shock

g^2/Hz	accelerated spectral density
GHz	gigahertz – frequency
Gm	gigametre
g/m^3	grams per cubic metre
g_n	peak acceleration
G_s	setting value of a characteristic quantity
h	hour
H	henry
ha	hectare
hp	horsepower
hr(s)	hour(s) – alternative to h
Hz	Hertz
I	amps
I^2R	power
in	inch
J	joule
k	constant of the relay
K	kelvin
kA	kiloamps
kA/μs	kiloamps per microsecond
kg	kilogram
kg/m^3	kilograms per cubic metre
kgf	kilogram force
kHz	kilohertz
kPa	kilopascal – pressure
ks	kilosecond
kV	kilovolts
kW	kilowatt
kW/m^2	kilowatts per square metre – irradiance
l	litre
lb	pound
lb/in^2	pounds per square inch
m	metre
m/s	metres per second
m/s^2	metres per second per second – amplitude
m^2	square metres
m^3	cubic metres
mbar	millibar – pressure
MHz	megahertz
min	minute
mm	millimetre
Mm	megametre
mm/h	millimetres per hour
mm/m^2	millimetres/square metre – exposure
mol	mole
ms	millisecond

mV	millivolts
MVA	megavolt amps
N	newton
N/m^2	newtons per square metre
NaCl	sodium chloride
nF	nanofarad
nm	nanometre
pH	alkalinity/acidity value
pm	picometre
Pm	petametre
R	intensity of dropfield in mm/h
R	resistance
rad/s	radians per second
s	second
S	siemens
t	tonne
T	time
T	tesla
Tm	terametre
$\hat{u}$	amplitude of voltage surge
U_n	nominal voltage
V	volt
V/µs	volts per microsecond
V/km	volts per kilometre
Vm	volts per metre
W	watt
Wb	weber
W/m^2	watts per square metre – irradiance
yd	yard
ym	yocotmetre
Ym	yottametre
zm	zeptometre
Zm	zettametre

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SI units for existing technology

As Gregor M. Grant explained in his article published in the April/May 1997 issue of *Electro Technology*, the Système International d'Unités (SI) was a child of the 1960s, a creation of the 11th General Conference on Weights and Measures (Conférence Générale des Poids et Mesures (CGPM)). This assembly endorsed the Italian physicist Professor Giovanni Giorgi's MKS (i.e. metre-kilogram-second) system of 1901 and decided to base the SI system on it. Seven basic units were adopted, as shown in Table A, each of which was harmonised to a standard value.

Of the seven units, only the kilogram (kg) is represented by a physical object, namely a cylinder of platinum–iridium kept at the International Bureau of Weights and Measures at Sèvres, near Paris, with a duplicate at the US Bureau of Standards.

The metre (m), on the other hand, 'is the length of the path travelled by light in a vacuum during a time interval of 1/2999 792 458 of a second'.

The second (s) has been defined as 'the duration of 9 192 631 770 periods of radiation corresponding to the energy-level change between the two hyperfine levels of the ground state of caesium-133 atom'.

The ampere (A) is 'that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section and placed 1 m apart in vacuum, would produce between these conductors a force equal 2×10^{-7} newtons per metre length'.

The unit of temperature is the kelvin (K), which is a thermodynamic measurement as opposed to one based on the properties of real material. Its origin is at absolute zero and there is a fixed point where the pressure and temperature of water, water vapour and ice are in equilibrium, which is defined as 273.16 K.

The mole (mol) is 'that quantity of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon-12'. For definition purposes the entities *must* be specified (e.g. atoms, electrons, ions or any other particles or groups of such particles).

Finally there is the candela (cd), the unit of light intensity. This is defined as 'the luminous intensity, in the perpendicular direction, of a surface of 1/6000 000 m^2 of a black body at the temperature of freezing platinum under a pressure of 101 325 N/m^2'.

Two years before the creation of SI units, another international agreement had made the prefixes mega and micro official and introduced some new ones, such as the nano whose name derives from the Greek 'nanos' meaning dwarf (see Table B). Its symbol is n, and its mathematical representation is 10^{-9}, indicating the number of *digits* to the right of the decimal point, in this case 0.000 000 001.

Even these minute quantities, however, soon became inadequate and, by 1962, it was decided that a thousandth of a picometre be designated a femtometre and one-thousandth of this new measurement be termed an attometre. Later on, the zeptometre and yoctometre were introduced.

Basic SI units

Many SI units are named after people but when these units are written in full, they do not necessarily require initial capital letters, e.g. amperes, coulombs, newtons, siemens.

All the above examples are expressed in the plural, but note that siemens does not drop the final 's' in the singular as this was derived from a person's name (i.e. Siemens) thus we have one newton, but one siemens.

Table A Basic SI units

SI nomenclature	Abbreviation	Quantity
metre	m	length
kilogram	kg	mass
second	s	time
ampere	A	electrical current
kelvin	K	temperatures
mole	mol	amount of substance
candela	cd	luminous intensity

Small number SI prefixes

Within the SI units there is a distinction between a quantity and a unit. Length is a quantity, but metres (abbreviated to m) is a unit.

Table B Small number SI units

Measurement	Symbol	Equivalent to
millimetre	mm	0.001 m or 10^{-3} m
micrometre	μm	0.000 001 m or 10^{-6} m
nanometre	nm	0.000 000 001 m or 10^{-9} m
picometre	pm	0.000 000 000 001 m or 10^{-12} m
femtometre	fm	0.000 000 000 000 001 m or 10^{-15} m
attometre	am	0.000 000 000 000 000 001 m or 10^{-18} m
zeptometre	zm	0.000 000 000 000 000 000 001 m or 10^{-21} m
yoctometre	ym	0.000 000 000 000 000 000 000 001 m or 10^{-24} m

Large number SI prefixes

Table C Large number SI prefixes

Measurement	Symbol	Equivalent to
megametre	Mm	1 000 000 m or 10^{6} m
gigametre	Gm	1 000 000 000 m or 10^{9} m
tarametre	Tm	1 000 000 000 000 m or 10^{12} m
petametre	Pm	1 000 000 000 000 000 m or 10^{15} m
exametre	Em	1 000 000 000 000 000 000 m or 10^{18} m
zettametre	Zm	1 000 000 000 000 000 000 000 m or 10^{21} m
yottametre	Ym	1 000 000 000 000 000 000 000 000 m or 10^{24}

Deprecated prefixes

Some non-SI fractions and multiples are occasionally used (see below), but they are not encouraged.

Table D Deprecated prefixes

Fractions	Prefix	Abbreviation	Multiple	Prefix	Abbreviation
10^{-1}	deci	d	10	deka	da
10^{-2}	centi	c	10^{2}	hecto	h

Derived units

Some units, derived from the basic SI units, have been given special names, many of which originate from a person's name (i.e. Siemens).

Table E Derived units

Quantity	Name of unit	Abbreviation (symbol)	Expression in terms of other SI units
energy	joule	J	Nm
force	newton	N	–
power	watt	W	J/s
electric charge	coulomb	C	As
potential difference (voltage)	volt	V	W/A
electrical resistance (or reactance or impedance)	ohm	Ω	V/A
electrical capacitance	farad	F	C/V
magnetic flux	weber	Wb	Vs
inductance (note that the plural of henry is henrys)	henry	H	Wb/A
magnetic flux density	tesla	T	Wb/m^2
admittance (electrical conductance)	siemens	S	$A/V(=\Omega^{-1})$
frequency	hertz	Hz	cycles per second (or events per second)

Units without special names

Other derived units, without special names, are listed below.

Table F Units without special names

Quantity	Unit	Abbreviation
area	square metres	m^2
volume	cubic metres	m^3
density	kilograms per cubic metre	kg/m^3
velocity	metres per second	m/s
angular velocity (angular frequency)	radians per second	rad/s
acceleration	metres per second per second	m/s^2
pressure	newtons per square metre	N/m^2
electric field strength	volts per metre	Vm
magnetic field strength	amperes per metre	A/m
luminance	candelas per square metre	cd/m^2

Tolerated units

Some non-SI units are tolerated in conjuntion with SI units.

Table G Tolerated units

Quantity	Unit	Abbreviation (symbol)	Definition
area	hectare	ha	$10^4\ m^2$
volume	litre	1	$10^{-3}\ m^3$
pressure	standard atmosphere	atm	101 325 Pa
mass	tonn	t	10^3 kg (Mg)
energy	electronvolt	eV	1.6021×10^{19} J
magnetic	gauss	G	10^{-4}T

Obsolete units

For historical interest (as well as for completeness), the following table gives a list of obsolete units.

Table H Obsolete units

Quantity	Unit	Abbreviation (symbol)	Definition
length	inch	in	0.0254 m
	foot	ft	0.3048 m
	yard	yd	0.9144 m
	mile	m	1.60394 km
mass	pound	lb	0.4539237 kg
force	dyne	erg	10^{-5} N
	poundal	elg	0.138255 N
	pound force	lbf	4.44822 N
	kilogram force	kgf	9.80665 N
pressure	atmosphere	atm	$101.325\ kN/m^2$
	torr	torr	$133.322\ N/m^2$
	pounds per square inch	lb/in	$6894.76\ N/m^2$
energy	erg	erg	10^{-7} J
power	horsepower	hp	745.700 W

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