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Edition 1.0 2020-02

TECHNICAL REPORT

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Durability test methods for electronic displays – Part 2-12: Environmental tests – Environmental conditions of use, storage and transportation of electronic displays

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Durability test methods for electronic displays –
Part 2-12: Environmental tests – Environmental conditions of use, storage and transportation of electronic displays

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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DURABILITY TEST METHODS FOR ELECTRONIC DISPLAYS –

Part 2-12: Environmental tests – Environmental conditions of use, storage and transportation of electronic displays

FOREWORD

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IEC TR 63211-2-12, which is a technical report, has been prepared by IEC technical committee 110: Electronic displays.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
110/1102/DTR	110/1122A/RVDTR

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

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

A list of all parts in the IEC 63211 series, published under the general title *Durability test methods for electronic displays*, can be found on the IEC website.

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

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- withdrawn,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

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

INTRODUCTION

The IEC 63211 series covers the durability test methods of electronic displays and related components. This series describes the evaluation of resistance of two or more electronic displays and their related components to environmental stress, mechanical stress, a combination of environmental and mechanical stress, contact with chemicals, and other stresses.

This part of IEC 63211 focuses on environmental aspects and describes the environmental conditions of displays, when in use, stored or transported.

The main environmental factors that influence the durability of electronic displays are the temperature and relative humidity of the air and the level of light exposure. These factors have been described in the IEC 60068 series as the general conditions of environmental testing for electrotechnical products. However, in the IEC 60068 series, the conditions are merely listed and cover an extremely wide range of diverse values. For example, the conditions of dry heat temperature are stipulated in IEC 60068-2-2 [1][1] as the range from 30 °C to 1 000 °C. They are merely listed as a series of temperature values such as, (30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 100, 125, 155, 175, 200, 250, 315, 400, 500, 630, 800 and 1 000) °C. Temperatures of several hundreds of degrees are too severe to maintain the original functions of most electronic displays, and so these elevated temperatures have no valuable meaning as a test condition.

Therefore, environmental tests for electronic displays have been documented for each type of technology, such as LCD, PDP and OLED, as shown in Table 1. They were originally created using the IEC 60068 series documents as a reference, and some modifications were introduced to be suitable for electronic displays. For example, the conditions of the dry heat temperature test are limited in IEC 61747-10-2 [2] to the range from 30 °C to 100 °C.

The environmental test documents for electronic displays summarised in Table 1 have two problems. The first is that each document focuses on a specific display technology. The second is that the conditions are merely listed so users are required to choose several conditions that are fit for their intended purpose.

Most environmental stresses are not very different, even if the technologies under test are different. The test methods and test conditions should be discussed, and the most appropriate test should be chosen based on the application and the intended usage, rather than the technology used in the displays.

This document describes the data and information on the environmental conditions relevant to how electronic displays are actually used, stored or transported in various use profiles. They are intended to be used as a reference when the test conditions are determined. Even though the test conditions should be harsher than the actual conditions, in order to accelerate the tests, it is important to consider the actual conditions when the accelerated test conditions are discussed.

[1] Numbers in square brackets refer to the Bibliography.

Table 1 – Documents related to environmental tests for electronic displays

IEC document (scope)	Title	Status and date of publication
IEC 61747-10-2 [2] (LCD)	Liquid crystal display devices – Part 10-2: Environmental, endurance and mechanical test methods – Environmental and endurance	Edition 1.0 2014-09-03
IEC 61988-4-1 [3] (PDP)	Plasma display panels – Part 4-1: Environmental testing methods – Climatic and mechanical	Edition 1.0 2015-03-25
IEC 62341-5 [4] (OLED)	Organic light emitting diode (OLED) displays – Part 5: Environmental testing methods	Edition 1.0 2009-11-20
IEC 62679-4-2 [5] (EPD)	Electronic paper displays – Part 4-2: Environmental test methods	Edition 1.0 2016-08-29
IEC 62715-6-2 [6] (FDD)	Flexible display devices – Part 6-2: Environmental testing methods	Edition 1.0 2017-05-24
IEC 62908-13-10 [7] (TID)	Touch and interactive displays – Part 13-10: Reliability test methods of touch displays – Environmental durability test methods	Edition 1.0 2016-11-25

DURABILITY TEST METHODS FOR ELECTRONIC DISPLAYS –

Part 2-12: Environmental tests – Environmental conditions of use, storage and transportation of electronic displays

1 Scope

This part of IEC 63211 provides data and information on the environmental conditions when electronic displays are used, stored and transported.

This document covers the temperature, relative humidity and light of the environment of electronic displays.

The information provided by this document is related to the following electronic displays:

a) indoor displays for consumer homes and offices, such as TVs or PC monitors,
b) indoor displays for commercial applications, such as signage and show cases,
c) mobile displays, such as smartphones, tablets, e-books and mobile PCs,
d) wearable displays, such as eyewear displays and smart watches,
e) in-vehicle displays, and
f) outdoor displays, such as signage for public information and advertising.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

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

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

4 Overview

4.1 Use cases and stress factors

Stress factors on electronic displays vary according to the type of use. An overview of the stress factors in each use case is shown in Table 2. The number of "+" symbols indicates how serious the stress factor is in each case; "+++++" means seriously affected, "+" means slightly affected and "-" means not affected. "Duration" indicates the typical length of time of exposition to the stress factor, "long" means several years to twenty years, "middle" means several months to a few years and "short" means several days to a few months.

Table 2 – Overview of the stress factors for each type of use case

Use case		Environmental stress factors			Duration
		Heat	Humidity	Light	
Usage	Indoor/home and office	++	++	+	long
	Indoor/commercial	+	+	++	middle to long
	Mobile	+++	++++	+++	middle
	Wearable	+++	++++	+++	middle
	In vehicle	+++++	+++	++++	middle
	Outdoor/not exposed to rain	++++	+++++	++++	middle
	Outdoor/exposed to rain	++++	+++++	+++++	middle
Storage	With air conditioning	++	++	-	middle
	Without air conditioning	++++	++++	-	middle
Transportation of products		+++	++	-	short

4.2 Test conditions in existing standards

A summary of the test conditions described in the standards for electronic displays issued by IEC/TC 110 is shown in Annex A. The standards for each type of display technology, such as LCD, PDP and OLED, have been documented. Originally, the standards were created by reference to a document of the IEC 60068 series, which describes the environmental testing of electrotechnical products in general. The related documents of the IEC 60068 series are shown in Annex B.

The test conditions of the standards for electronic displays are stipulated by IEC/TC 110 with reference to the IEC 60068 series, with some modification if necessary. They are applicable to each sort of display in general, but each set of conditions covers too wide a range for any single specific usage.

The data and information on the environmental conditions when electronic displays are actually used, stored or transported in various situations are described in Clause 5 to Clause 8 of this document. These clauses provide a reference for when testing conditions need to be determined. Even though the test conditions should be harsher than the actual conditions, in order to reduce the time to perform the test, it is indispensable to consider the actual conditions whenever accelerated test conditions are discussed.

5 Indoor

5.1 General

In the case of indoor use, the structures of houses or buildings divide the atmosphere into either inside or outside. Inside houses or buildings, the atmosphere is intentionally conditioned for living, meaning that the indoor temperature, humidity and light conditions are largely different from the outdoor climatic conditions.

5.2 Temperature and humidity

5.2.1 Consumer homes

Temperature and humidity data in consumer homes over a year was collected in eight cities around the world [8][9]. The cities where data was collected are shown in Table 3, and the results are shown in Table 4. Many documents of IEC/TC110 stipulate the measuring conditions for various types of testing; these are 25 °C ± 3 °C for temperature and from 25 % to 85 % for relative humidity. It is assumed that these documents cover around four times the standard deviation in consumer homes in the real world.

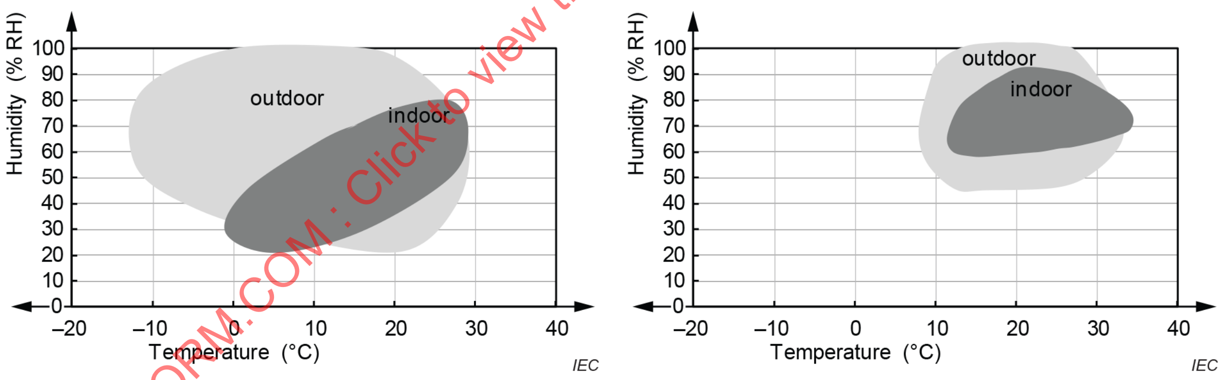
Table 3 – Collection of condition data of consumer homes in eight cities

No.	Region	Country	City
1	Europe	United Kingdom	London
2	North America	United States	Rochester
3			Los Angeles
4			Atlanta
5	South America	Brazil	Sao Paulo
6	Asia	Japan	Tokyo
7		China	Shanghai
8	Oceania	Australia	Melbourne

Table 4 – Results of temperature and relative humidity of consumer homes

	Temperature (°C)	Relative humidity (%RH)
Average	21,1	54
Standard deviation (σ)	3,9	13

The variation inside consumer homes was not large, even in severe climates, because any direct air flow from outdoors is shut out and air conditioners are used to keep the inhabitants comfortable. For example, a comparison of the outdoor and indoor conditions is shown in Figure 1 [10]. Sapporo is a northern Japanese city of subarctic climate, and Okinawa is a southern Japanese city of temperate but near subtropical climate. In both cities, the range in the variation in climate was smaller indoors than outdoors.



a) **Sapporo**

b) **Okinawa**

Figure 1 – Range of year-round temperature and humidity in Sapporo (left) and Okinawa (right) in Japan

5.2.2 Office and commercial buildings

In many countries, guidelines for temperature and humidity are set by each government to keep a healthy and comfortable environment for workers and visitors in office spaces and/or commercial buildings. Table 5 shows some examples of these guidelines [11].

Table 5 – Examples of guidelines for temperature and humidity

Country	Title	Temperature (°C)		Relative humidity (% RH)	
		Summer	Winter	Summer	Winter
USA (HHS)	PHS Facilities Manual	21,1 to 26,7	18,3 to 20,0	-	
USA (OSHA)	Technical Manual	20,0 to 24,4		20 to 60	
Canada	CSA Z412-00	24,5 to 28,9 (30 % RH) 23,0 to 25,5 (60 % RH)	20,5 to 25,5 (30 % RH) 20,0 to 24,0 (60 % RH)	-	
United Kingdom	Guidance	13,0 to 30,0		-	
Finland	National Building Code	< 25,0 (< 28,0 [a])	< 25,0 (< 26,0 [a])	45 (21 °C)	
China	GB/T18883-2002	22,0 to 28,0	16,0 to 24,0	40 to 80	30 to 60
Singapore	Guidelines	22,5 to 25,5		< 70	
Australia	Guidelines	23,0 to 26,0	20,0 to 24,0	< 70	
New Zealand	Employment Regulation	19,0 to 24,0 [b] 16,0 to 21,0 [c]	18,0 to 22,0 [b] 16,0 to 19,0 [c]	40 to 70	
Japan	Ordinance on Health Standards in the Office	17,0 to 28,0		40 to 70	

[a] When the outside temperature is above 20 °C.

[b] Workplace mainly for desk work.

[c] Workplace with a lot of activity.

The data in Table 5 can be referred to as typical indoor conditions, but care should be taken as the actual conditions are not always within the ranges given because they are not strict regulations; in many cases they are simply guidelines. For example, Azuma et al. surveyed the rate of conformity to the guidelines in various types of buildings in Japan [12]. The results of the survey taken in 2008 are shown in Table 6. The conformity rate of temperature is high for offices and commercial spaces, such as department stores and general shops. However, conformity to the relative humidity guidelines is lower, and the measured humidity was out of the range in almost half of the survey sites.

Table 6 – Rate of conformity to the guidelines for temperature and humidity in Japan

Type	Rate of conformity to the guidelines in Japan (%)	
	Guidelines for temperature 17,0 °C to 28,0 °C	Guidelines for relative humidity 40 % RH to 70 % RH
Amusement	74 %	58 %
Department store	80 %	53 %
General shops	80 %	53 %
Office	84 %	50 %
School	65 %	50 %
Hotel	86 %	67 %

5.3 Light

5.3.1 Consumer homes

In consumer homes, the spectral distribution is very different from that of sunlight because the structure of the house protects from direct sunlight, and window glass filters out some parts of the sunlight. This is especially true in the reduction of the UV components of sunlight, which tend to degrade the materials and components of displays. Figure 2 shows some examples of the relative spectrum in consumer homes compared to that of direct sunlight. The intensity data has been normalized at 550 nm.

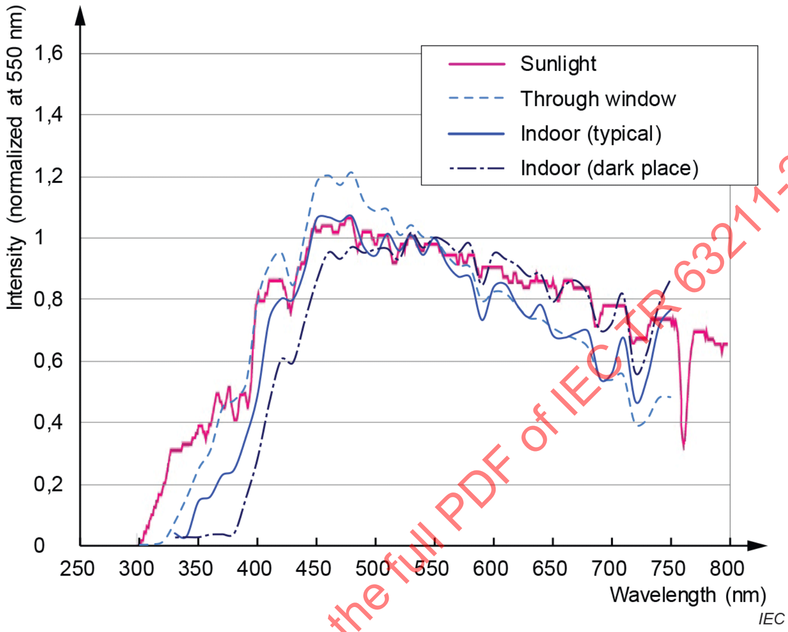
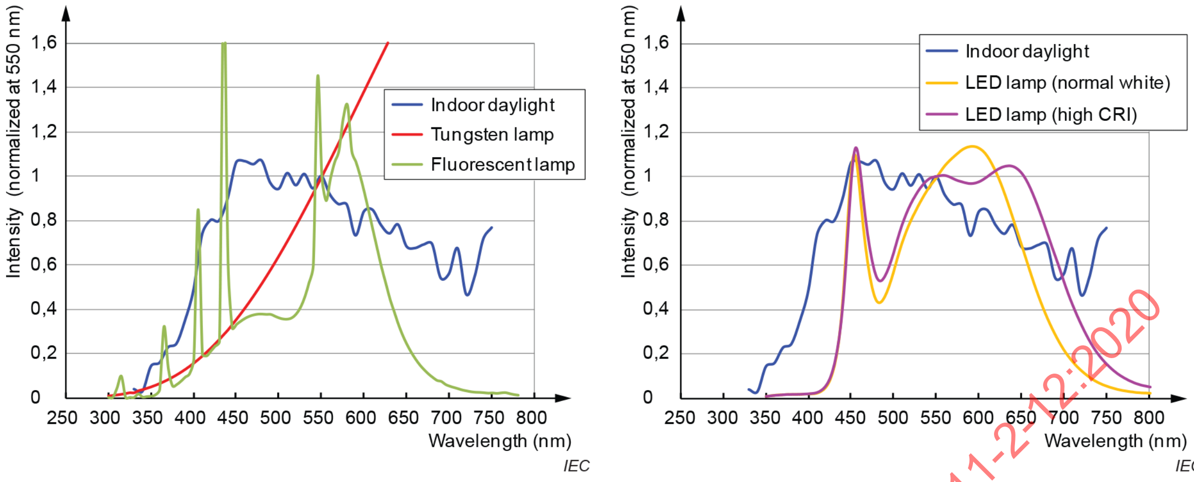


Figure 2 – Examples of relative spectrum distribution of daytime in consumer homes

In addition to sunlight entering through the window, various lighting is also used indoors. In the past tungsten lamps and fluorescent lamps were mainly used. In recent years many kinds of LED lamps have been developed and they are rapidly spreading in the world. Figure 3 shows the spectrum distribution of various lamps. Like the sunlight entering through the windows, these illumination lights contain few UV components.

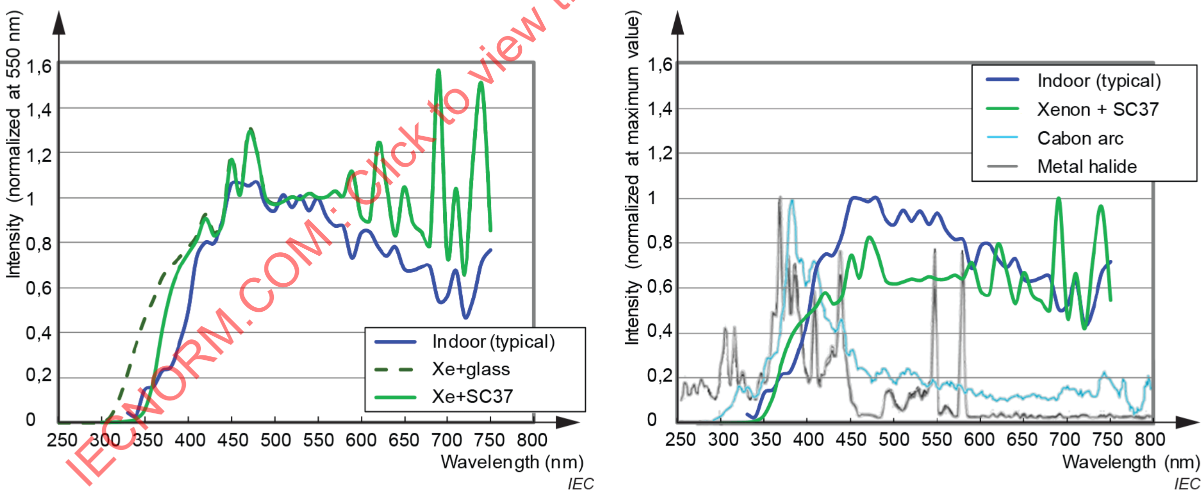
NOTE The Illuminating Engineering Society of North America (IESNA) supplies much information about various types of illumination indoors [13].



a) Tungsten lamp and fluorescent lamp **b) LED lamps**

Figure 3 – Examples of relative spectrum distribution of lamps in consumer homes

When the stability of a display to light is tested for usage in a consumer home, care should be taken over the spectral distribution, especially the UV component of the light source, which is shorter than 380 nm in wavelength. Excess UV components can sometimes cause degradation, which does not occur during normal usage, and so they are not appropriate even for accelerated tests. Figure 4 shows the spectral distribution of various light sources used in light stability testing. A xenon arc lamp with some types of UV filters is known to be appropriate for simulating indoor lighting conditions.



a) Xenon lamp with filter **b) Various lamps**

Figure 4 – Comparison of the relative spectrum distribution of various light sources used in light stability testing

Daytime light levels in seventy houses were measured in the United States, United Kingdom, Australia, Netherlands and Japan and are shown in the histogram in Figure 5 [14]. The average light level of the whole data set was around 160 lx, but the values varied widely, perhaps due to the various structures of houses around the world.

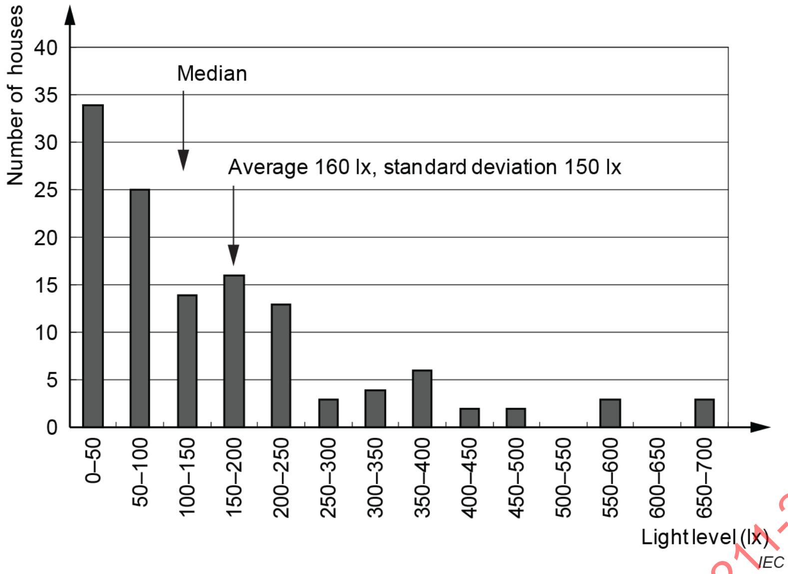


Figure 5 – Histogram of average daytime light levels in consumer homes around the world

5.3.2 Office and commercial buildings

The light level in offices and commercial buildings is higher than in consumer homes because it is necessary for business or commercial activities. ISO 8995-1 [15] and the related document, JIS Z 9110 [16], stipulate the appropriate light levels for various types of work, which can be referred to as typical conditions for considering the light stability of displays in actual usage. A summary of the conditions is shown in Table 7.

Table 7 – Summary of light levels in ISO 8995-1 [15] and JIS Z 9110 [16]

Type		Light level
Office	Workplace for reading, writing, typing	500 lx to 750 lx
	Common space	100 lx to 750 lx
Commercial building	Space for goods displayed	500 lx to 2 000 lx
	General space	300 lx to 500 lx

There exists a special case for the use of displays in commercial applications, where the displays themselves are set inside the building, but they are seen from the outside through a show window. In this case, the light level is much higher because of sunlight coming directly through the window. There is a similar situation for commercial prints in a show window. ISO TS 21139-1 [17] focuses on this kind of typical in-window condition in addition to the general indoor conditions for considering the light stability of commercial prints and gives useful reference information for the design of tests for electronic displays. The conditions in ISO TS 21139-1 [17] are listed in Table 8.

Table 8 – Typical conditions for commercial prints in ISO TS 21139-1 [17]

	General indoor display	In-window display
Light source	Indirect daylight through window glass or other general room illumination	Direct daylight through window glass
Light intensity	Duty cycle 12 h/24 h, 500 lx (150 lx to 1 000 lx)	Duty cycle 12 h/24 h, 3 000 lx (2 000 lx to 100 000 lx)
Spectral power distribution	Indirect daylight, LED, fluorescent, tungsten, halogen, metal-halide	Direct daylight through window glass

6 Outdoor

6.1 General

Outdoor conditions are extremely varied across the world. Latitude, altitude and distance from the ocean have an effect, and sometimes human activities such as agriculture and construction can cause a difference in climate. In addition, seasonal deviations are strong in some regions, so it is important to recognize regional variations in the places where a display is to be used.

6.2 Temperature and humidity

Temperature and humidity are two parts of climatic conditions and are typically categorized by the climatic divisions determined by Köppen [18][19]. There are five categories:

1) A: tropical zone;
2) B: arid zone;
3) C: temperate zone;
4) D: subarctic zone; and
5) E: frigid zone

The zones are defined mainly by temperature and the amount of rainfall. Climatic conditions in most cities in the world are categorised into the four zones from A to D. The climate of the frigid zone is so severe that there are few cities of high population in this category. The data of 48 cities from four climatic divisions was surveyed using long-term weather data. Table 9 shows the cities and the climatic divisions surveyed.

NOTE Long-term weather data for each region of the world is featured on the web page of "Weather Forecast & Reports": https://wunderground.com/.

Table 9 – Forty-eight cities from each climatic division

Climate	City	Country
A. Tropical (9 cities)		
Af	Singapore	Singapore
Af	Kuala Lumpur	Malaysia
Am	Manaus	Brazil
Am	Jakarta	Indonesia
Am	Cairns	Australia
As	Brasilia	Brazil
Aw	Kolkata	India
Aw	Mumbai	India
Aw	Bangkok	Thailand

Climate	City	Country
B. Arid (6 cities)		
BW	Dubai	UAE
BW	Riyadh	Saudi Arabia
BW	Abu Dhabi	UAE
BS	Ankara	Turkey
BS	Ulaanbaatar	Mongolia
BSk	Tehran	Iran

Climate	City	Country
C. Temperate (21 cities)		
Csa	Madrid	Spain
Csa	Rome	Italy
Cfa	Sao Paulo	Brazil
Cfa	Tokyo	Japan
Cfa	New York	USA
Cfa	Canberra	Australia
Cfa	Buenos Aires	Argentina
Cfb	Berlin	Germany
Cfb	London	UK
Cfb	Paris	Francs
Cfb	Amsterdam	Netherlands
Cfb	Bern	Switzerland
Cfb	Stockholm	Sweden
Cfb	Warsaw	Poland
Cfb	Brussels	Belgium
Cfb	Vienna	Austria
Cfb	Copenhagen	Denmark
Cfc	Reykjavik	Iceland
Cwa	New Delhi	India
Cwa	Seoul	Korea
Cwb	Mexico City	Mexico

Climate	City	Country
D. Subarctic (12 cities)		
Dwa	Beijing	China
Dwa	Harbin	China
D	Yakutsk	Russia
Dfa	Sapporo	Japan
Dfb	Moscow	Russia
Dfb	Ottawa	Canada
Dfb	Oslo	Norway
Dfb	Murmansk	Russia
Dfb	Karaganda	Kazakhstan
Dfb	Helsinki	Finland
Dfb	Asahikawa	Japan
Dfc	Anchorage	USA

NOTE Abbreviations such as Af, BW and Csa are Köppen climate symbols. Their description and defining criteria are stated in the reference documents [18][19].

Daily averaged data over one year was collected in each city. For example, data from New York in the US is shown in Figure 6.

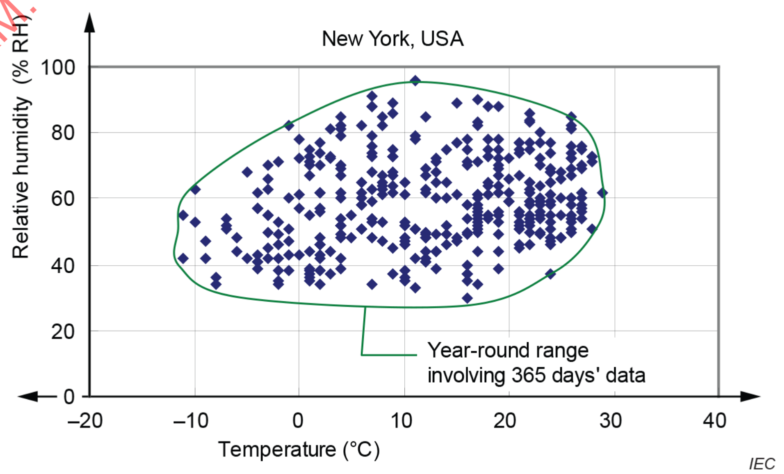
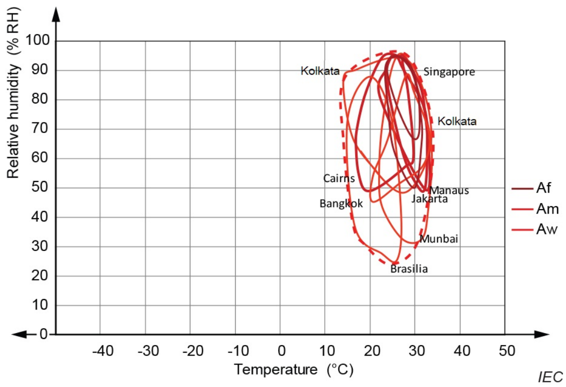
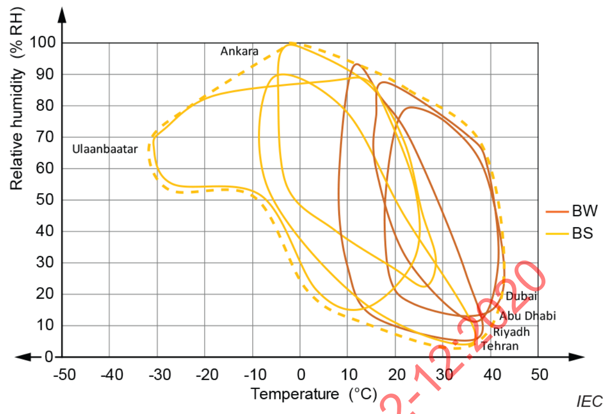


Figure 6 – Example of year-round data, New York (United States)

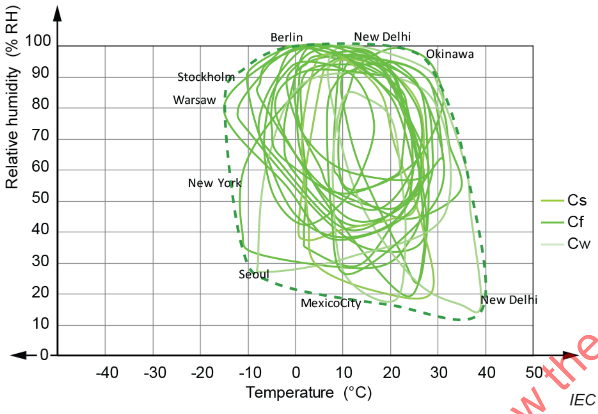
Data from the cities was gathered according to each climatic division. Figure 7 shows the maps of the four climatic divisions.



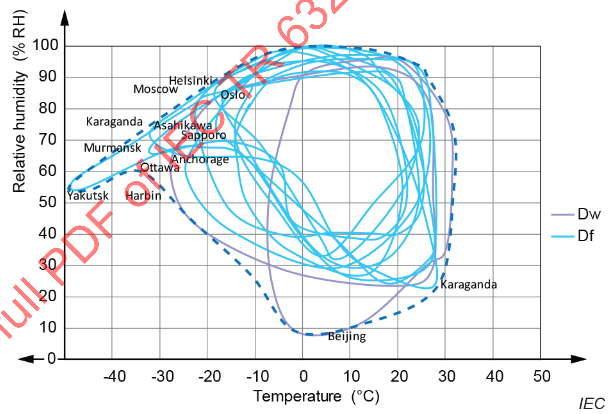
a) **Tropical zone**



b) **Arid zone**



c) **Temperate zone**



d) **Subarctic zone**

Figure 7 – Temperature versus humidity maps of four climatic divisions

The four maps of Figure 7 were combined into one, which is shown in Figure 8. It shows the worldwide deviation in temperature and relative humidity. In Table 10, the outer boundary of the worldwide data is listed.

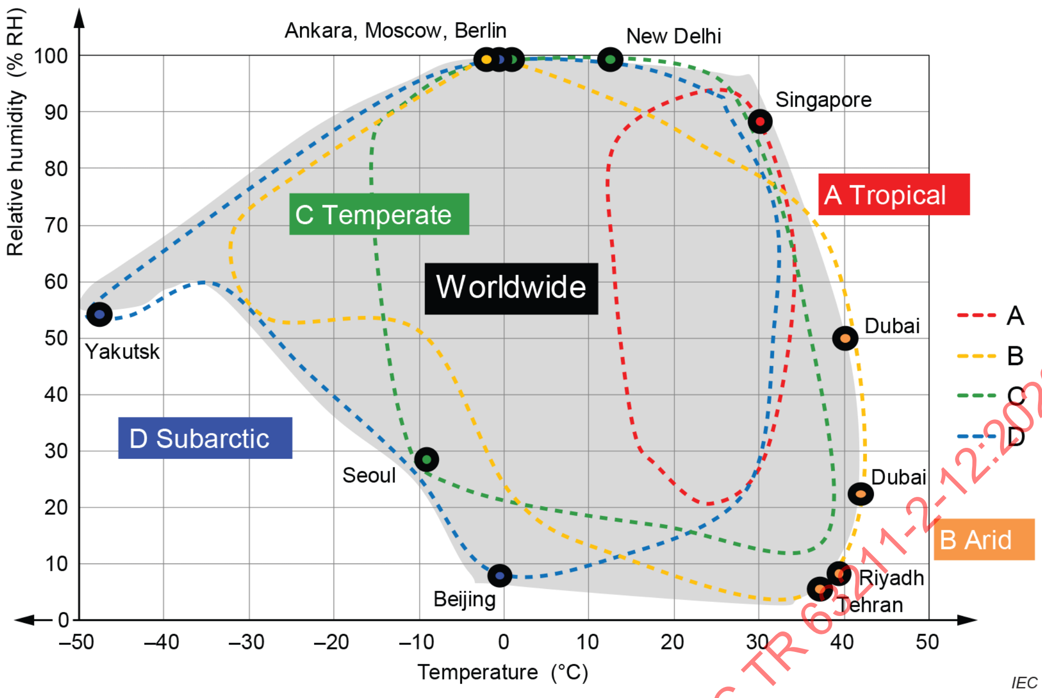


Figure 8 – Worldwide deviation of temperature and relative humidity

Table 10 – Boundary data of deviation around the world

Features		Examples of places			Data		
Temperature	**Relative humidity**	**Climatic division**	**City**	**Country**	**Temperature** (°C)	**Humidity** (%RH)	**Month**
High	High	Tropical	Singapore	Singapore	30	86	May
High	Low	Arid	Dubai	UAE	42	24	July
			Tehran	Iran	37	8	July
Moderate to low	Low	Subarctic	Beijing	China	-2	8	Feb.
Low	Moderate	Subarctic	Yakutsk	Russia	-47	57	Dec.
Low to moderate	Extremely high	Arid	Ankara	Turkey	-3	100	Jan.
		Subarctic	Moscow	Russia	1	100	Jan.
		Temperate	Berlin	Germany	2	100	Dec.
Moderate	Extremely high	Temperate	New Delhi	India	12	100	Jan.

6.3 Light

Radiation of sunlight is affected by both the position on the Earth and the climate. Radiation tends to be high in a low latitude area near the equator, while it tends to be lower in higher latitude areas. Radiation is also higher in sunny climates, like arid zones, while radiation is lower in cloudy, rainy or snowy climates, as in the other climatic divisions.

NOTE The World Meteorological Organization (WMO) of the United Nations is surveying the solar radiation data in many countries and provides the data at the following website of the World Radiation Data Centre (WRDC): http://wrdc.mgo.rssi.ru/wrdc_en_new.htm.

Table 11 shows the year-round average global radiation data from 21 countries. The most radiation is observed in Algeria and Chile, which are at lower latitude and have sunny climates, while the least radiation is observed in Iceland, which is at higher latitude and has a rainy or snowy climate.

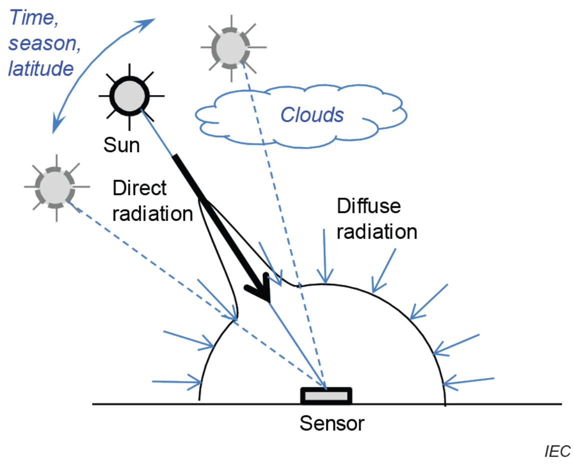
Table 11 – Year-round average data of global radiation from 21 countries

Region	Country	Year-round average (J/cm^2/day)	Maximum month (J/cm^2/day)	Minimum month (J/cm^2/day)
Africa	Algeria	2 310	2 768	1 555
South America	Chile	2 317	3 393	1 082
	Argentina (3)[a]	1 457	2 446	573
Oceania	Australia (5)	1 679	2 556	706
North America	United States (7)	1 596	2 575	634
Asia	Indonesia	1 450	1 613	1 172
	Japan (6)	1 442	2 192	743
	Philippines	1 432	1 765	1 055
	Korea	1 238	1 918	662
Europe	Greece	1 612	2 665	700
	Switzerland (4)	1 411	2 353	469
	Moldova	1 356	2 667	320
	Austria (3)	1 251	2 190	401
	Slovakia	1 197	2 190	374
	Germany	1 180	2 047	397
	Netherlands	1 026	1 988	177
	Latvia (3)	999	2 145	86
	Estonia	966	2 302	67
	Ireland	928	1 753	172
	UK (2)	919	1 693	140
	Iceland	751	1 751	14
Average		1 358		
Standard deviation		407		

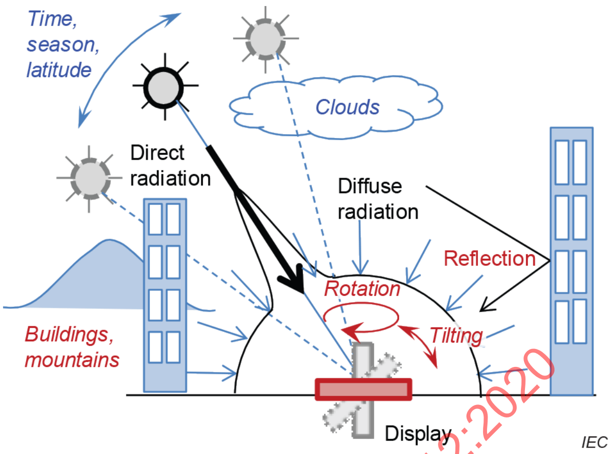
[a] The number in parentheses indicates the number of cities compiled and the data is averaged by country.

The sensors of observation devices are set horizontally for the measurement of global radiation. Measured radiation contains a direct radiation component from the sun and a diffuse radiation component from the whole unobstructed sky. The level of radiation is affected by the time of day, the season, latitude on the Earth and clouds in the sky, represented schematically in Figure 9a).

On the other hand, display devices are not usually set horizontally but can face various directions. Users usually put their mobile devices face-up on tables but they tend to hold their devices away from the sun when they watch the displayed contents. Digital signage displays are standing still but are usually set facing the direction of the target audience. These inclination (or tilting) and rotation angles of devices strongly affect the radiation amplitude. In addition, surrounding structures, such as buildings or mountains, also affect the level of radiation. If they shade the sunlight, radiation levels are decreased. In another case, reflected light from structures could increase the level of radiation. When assuming the solar radiation that a display receives, these additional factors need to be considered, as indicated in the schematic diagram in Figure 9b).



a) Measurement of global radiation



b) Display under sunlight

Figure 9 – Schematic diagram of solar radiation outdoors

In addition to radiation amplitude, spectrum distribution can vary according to the inclination (or tilting) and rotation angles of devices because there is a difference between direct radiation and diffuse radiation. The light of diffuse radiation has low radiation amplitude and contains a bigger portion of short wavelength and a smaller portion of long wavelength compared to that of direct radiation. ASTM G197-4 [20] describes the basis for assuming these spectral irradiance distributions.

7 Vehicles

7.1 General

In vehicles, the body structure divides the atmosphere into an inside and outside, just as in consumer homes. Cabins are usually kept comfortable by an air conditioner when passengers are in cars. However, conditions in vehicles tend to be affected by the outdoor conditions because the portion of windows is large, and the thermal insulation performance of the vehicle body tends to be poorer than in houses. In summer, especially when cars are parked in direct sunlight, the cabin becomes like a greenhouse, and the inside can experience an extreme rise in temperature. Displays that are used for an instrumental system like speedometers and a navigation system or are left in the cabin would be subjected to those severe conditions.

7.2 Temperature

As mentioned above, the inside temperature of a vehicle in summer is a special climatic condition. The temperature in a car was measured on a sunny summer day. The car was parked on a rooftop car park and left in the direct sunlight. Figure 10 shows the change in temperature over time. The temperature started to rise shortly after the initial measurement, and the dashboard temperature reached a maximum of 73 °C.

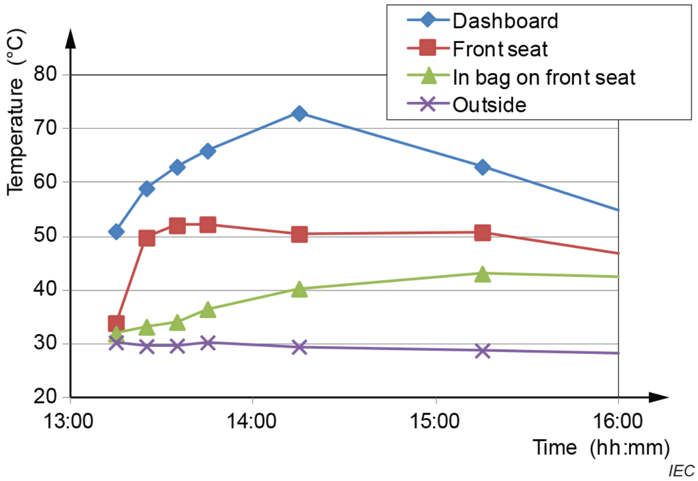


Figure 10 – Temperature trends in a car left in the sun in summer

The results from other similar surveys are listed in Table 12. The dashboard temperature reaches around 80 °C, more than 40 °C higher than the outside temperature. The displays for dashboard devices, like navigation systems, could be exposed to these elevated temperatures. The face of the seats reaches around 50 °C, more than 20 °C above the outside temperature. Displays of mobile devices could be exposed to these conditions if they are left in a vehicle.

Table 12 – Summary of temperature data in cars left in the sun

Survey	Place in Japan	Season	Outside temperature (°C)	Temperature in cars (Δxx = difference from outside)	
				On dashboard: D On rear parcel shelf: R (°C)	On front seat: F On rear seat: R (°C)
1	Kanagawa	Summer	30	D 73 (Δ43)	F 52 (Δ22)
2	Kanagawa	Early summer	32	R 72 (Δ40)	R 45 (Δ13)
3	Saitama	Summer	35	D 79 (Δ44)	
4	Saitama	Summer	35	D 74 (Δ39)	
Average				75 (Δ42)	47 (Δ18)

7.3 Light

Though the roofs of vehicles shade some parts from the sunlight, a large proportion of the sunlight can enter through the window glass that surrounds the cabin. An organization measured the intensity of light inside the cabin and compared it to the outside under summer sunlight [21]. The data is shown in Figure 11. Each data is indicated as a percentage of the irradiance inside the cabin to the outside, which has originally the unit of the power per unit area (W/m^2). Light intensity was high in the upper part of the cabin, and the measured value of the dashboard or rear parcel shelf is around 80 % of the outside light intensity. On the other hand, at lower parts of the cabin, the light intensity is smaller. For example, the value on the seat face is around 20 %.

NOTE The light intensity was measured in the summer around Tokyo, Japan. The value can vary depending on the measurement location in the world, season and time of day because the height of the sun varies with these factors.

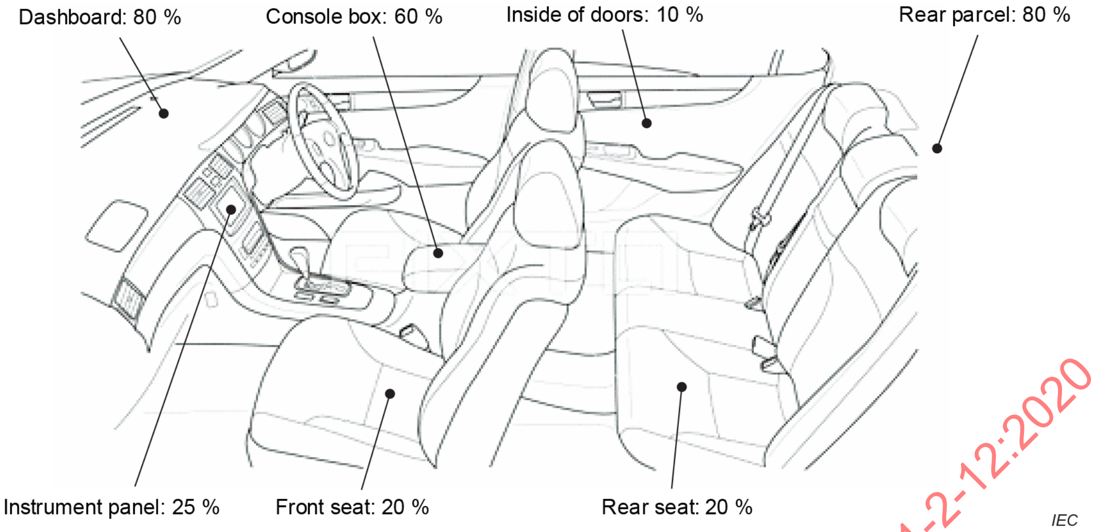


Figure 11 – Light intensity inside a car cabin as a percentage of the outside light intensity

In addition to intensity, the light spectrum also needs to be considered. Figure 12 shows the spectral transmittance examples of glass used in automobile front windows. The UV components are effectively absorbed by all four types of glass. When the light stability of devices or components is tested, the spectral range of the light source should be taken into account for the same reason as in the consumer home, as mentioned in 5.3.

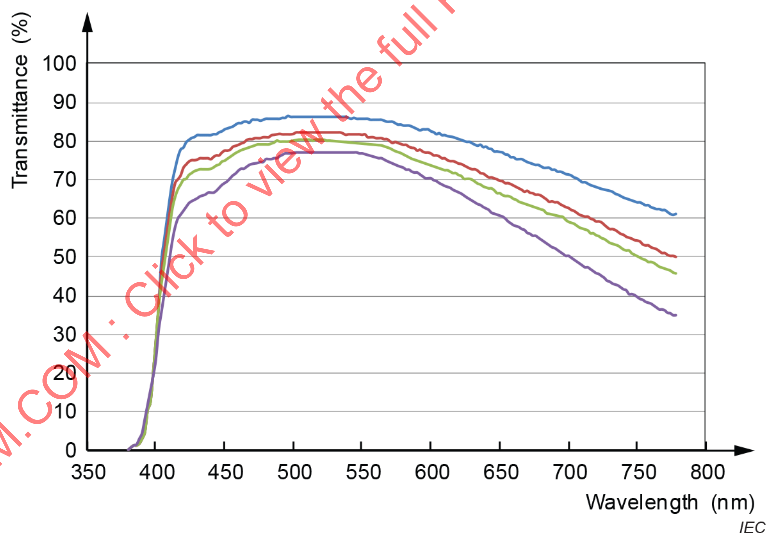


Figure 12 – Spectral transmittance examples of automobile windows

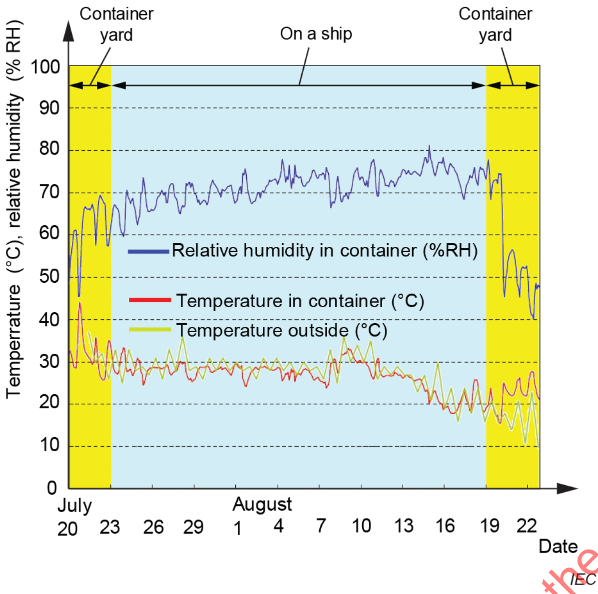
8 Transportation and storage

8.1 General

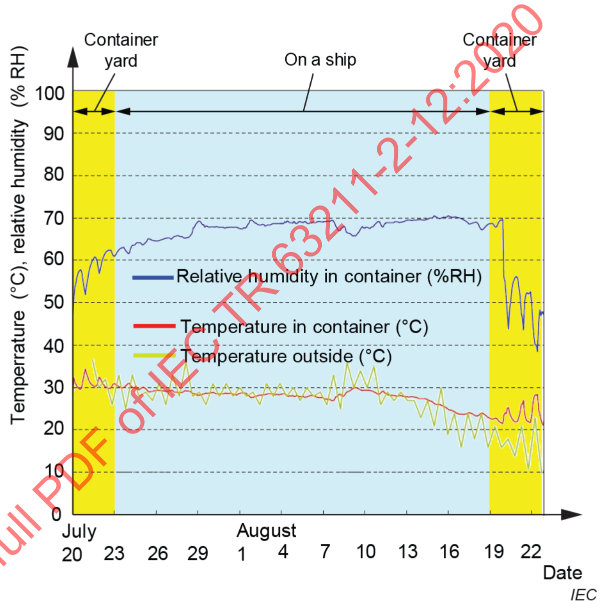
Display devices are produced in several countries and distributed to every part of the world. Marine transportation using containers plays a major role, and transportation by road and rail is also used for relatively short distances. In addition, devices can be stored for some time between transportation until they reach their final destination. Generally, display devices are packed with some materials, like a sealed bag and/or cardboard boxes. The packaging materials can shade the devices from sunlight but the temperature and humidity can be affected by conditions experienced during transportation. In addition to marine and land transportation, air shipment is also used, especially when a short time delivery is required.

8.2 Temperature and humidity

Trends in temperature and humidity during marine transportation from Japan to some countries in Europe, North America and South America were surveyed. Two typical cases, a dry container and a reefer container, are shown in Figure 13. The temperature in a dry container varies considerably over the day-night cycle, especially when a container is stocked in a container yard. The relative humidity also changes in a similar way. On the other hand, the temperature is stable when it is on a ship in the ocean even if it passes the equator. Likewise, the relative humidity is also stable in a container on a ship and is a little higher than when in a container yard. In a reefer container the overall trends are similar to that of a dry container but the short-term deviations are less pronounced.



a) **Dry container**



b) **Reefer container**

Figure 13 – Temperature and humidity trends of marine transportation

The data from the marine transportation surveys is listed in Table 13. In dry containers, the temperature tends to rise, especially when stored at a container yard, where it reaches around 40 °C to 50 °C in some cases. In most cases, storage at a container yard is temporary and can only last several days, but this is an element that should be taken into consideration. On the other hand, the temperature in reefer containers is kept relatively stable throughout transportation. However, even in reefer containers, the temperature rises while in storage at container yards, and the maximum temperature was measured at this point.

Table 13 – Survey results of marine transportation

Survey	Container type	Position on ship	From		To		Transport by land[a]	Duration	Over 30 °C (days)[b]			Max temp.	
			Country	Date	Country	Date		(days)	(1)	(2)	(3)	(°C)	place
A	Dry	on deck	JPN	Jul. 21	NLD	Aug. 23		34	5	1	3	59℃	Yard
A	Dry	on deck	JPN	Jul. 21	NLD	Aug. 23		34	6	2	1	44℃	Yard
A	Dry	under deck	JPN	Jul. 21	NLD	Aug. 23		34	3	0	2	46℃	Yard
A	Dry	under deck	JPN	Jul. 21	NLD	Aug. 23		34	2	3	0	39℃	Yard
B	Dry	on deck	JPN	Sep.23	NLD	Oct. 17		25	3	0	0	33℃	Yard
C	Dry	on deck	JPN	Jun. 3	NLD	Jun. 26		24	10	0	0	32 ℃	Ship
D	Dry	under deck	JPN	Aug. 28	NLD	Sep. 21		25	11	0	0	34 ℃	Yard
F	Dry	under deck	JPN	Sep. 15	UK	Oct. 16		32	5	0	0	33 ℃	Yard
H	Dry	-	JPN	Aug. 22	USA	Sep. 7	Yes	17	3	0	1	41 ℃	Yard
H	Dry	on deck	JPN	Aug. 22	USA	Sep. 4	Yes	14	3	3	1	41 ℃	Yard
J	Dry	-	JPN	Aug. 20	USA	Sep. 26		38	12	11	1	42 ℃	-
A	Reefer	on deck	JPN	Jul. 21	NLD	Aug. 23		34	5	0	0	33 ℃	Yard
A	Reefer	on deck	JPN	Jul. 21	NLD	Aug. 23		34	5	0	0	33 ℃	Yard
A	Reefer	under deck	JPN	Jul. 21	NLD	Aug. 23		34	9	0	0	33 ℃	Yard
A	Reefer	under deck	JPN	Jul. 21	NLD	Aug. 23		34	9	0	0	33 ℃	Yard
E	Reefer	on deck	JPN	Feb. 21	NLD	Mar. 16		24	0	0	0	< 30 ℃	Ship
G	Reefer	-	JPN	Jul. 30	BRA	Sep. 24		57	0	0	0	< 30 ℃	Yard
H	Reefer	-	JPN	Aug. 22	USA	Sep. 7	Yes	17	0	0	0	< 30 ℃	Yard
H	Reefer	-	JPN	Aug. 22	USA	Sep. 4	Yes	14	10	0	0	34 ℃	Yard
I	Reefer	-	JPN	Aug. 23	USA	Sep. 4	Yes	13	0	0	0	< 30 ℃	Yard
J	Reefer	-	JPN	Aug. 20	USA	Sep. 26		38	10	0	0	34 ℃	-

NOTE JPN: Japan, NLD: Netherlands, UK: United Kingdom, BRA: Brazil.

[a] If "Yes", it contains track or rail transportation in the country of destination.

[b] Number of days when maximum temperature (T_{max}) was above 30 °C: (1) 30 °C ≤ T_{max} < 35 °C, (2) 35 °C ≤ T_{max} < 40 °C, (3) 40 °C ≤ T_{max}.

For transportation by land, cargo cabins, dry containers and reefer containers on trucks or freight trains are used. The duration of transportation by land is relatively short, but the temperature tends to be more changeable than during marine transportation, as seen from the survey data listed in Table 14. Daytime sunshine causes the temperature to rise, and it can reach around 40 °C to 50 °C.

Table 14 – Results of survey of transportation by land

Survey	Form of transportation	From City	From Date	To City	To Date	Duration (days)	Condition over 30 °C[b] (1)	(2)	(3)	Max. temp.
K	Cargo cabin of truck	Odawara	Jul. 16	Fukuoka	Jul.19	4 days	6 h	4 h	1 h	41 °C
L	Cargo cabin of truck	Odawara	Jul. 30	Fukuoka	Aug. 2	4 days	10 h	8 h	2 h	46 °C
M	Cargo cabin of truck	Odawara	Aug. 6	Fukuoka	Aug. 9	4 days	21 h	0	0	33 °C
N[a]	Dry container on road	Fujinomiya	Sep. 3	Fukuoka	Sep. 9	11 days	5 days	0	0	33 °C
	Dry container on ship			Okinawa	Sep.13					

[a] N: 1) land transportation from Fujinomiya to Fukuoka, 2) marine transportation from Fukuoka to Okinawa.

[b] The time when the temperature (T) was above 30 °C: (1) 30 °C ≤ T < 35 °C, (2) 35 °C ≤ T < 40 °C, (3) 40 °C ≤ T

Surveys O and P in Table 15 show cases when cargo was left in a truck that remained parked for some time in the summer. Because of the daytime sunshine, the temperature rose and reached around 40 °C to 50 °C at the maximum.

Table 15 – Cargo left in a parked vehicle or stored in a warehouse

Survey	Left or stored in	Package	From Date	To Date	Duration (h)	Condition over 30 °C[a] (1)	(2)	(3)	Max. temp.
O	Cargo cabin of truck	Cardboard box	Jun. 15 morning	Jun.15 evening	12 h	2 h	2 h	4 h	44°C
P	Cargo cabin of truck	Cardboard box	Aug. 4	Aug. 10	7 days	18 h	13 h	22 h	50°C
Q	Warehouse without air-conditioner	Cardboard box	Sep. 7	Jan. 27	142 days	0	0	0	33°C

[a] The time when the temperature (T) was above 30 °C: (1) 30 °C ≤ T < 35 °C, (2) 35 °C ≤ T < 40 °C, (3) 40 °C ≤ T

As mentioned above, air shipment is also used, especially when a short time delivery is required. Though the temperature outside an aircraft falls to around -50 °C during flight, the air in the cargo rooms is conditioned to maintain the temperature and the air pressure. The conditions in some examples of aircraft models are shown in Table 16. The temperature is usually controlled to keep the value above 0 °C.

Table 16 – Examples of the temperature in air cargo compartments

Aircraft	Compartment (cargo room)	Temperature at high altitude	Remarks
Boeing 767 -300/300L/300ER	Front and rear	From 4 °C to 10 °C	
	Bulk	From 4 °C to 10 °C	Normal mode
	Bulk	From 18 °C to 24 °C	Vent mode
Boeing 777 -300/300ER	Front	From 4 °C to 10 °C	
	Rear and bulk	From 4 °C to 10 °C	Normal mode
	Rear and bulk	From 18 °C to 24 °C	High mode
Boeing 787 -8	Front	From 13 °C to 21 °C	
	Rear	From 3 °C to 18 °C	
	Bulk	From 8 °C to 21 °C	
Embraer 170 Embraer 190	Front	About 25 °C	
	Rear	(No data)	
NOTE Data from the website of Japan Airlines: http://www.jal.co.jp/en/jalcargo/support/aircraft/			

Singh et al. surveyed the temperature, humidity and air pressure trends during air shipment [22]. The surveys were performed on domestic transportation in the USA and on international transportation. All air shipments were scheduled to be a round trip to the respective destinations originating from San Luis Obispo, California, USA. Because the data was collected from door to door, it also contains land transportation and any temporary storage. The data is shown in Table 17. The minimum temperature was 8,0 °C, and the minimum air pressure was 78,6 kPa, equivalent to an altitude of 1 950 m, while standard atmospheric pressure at sea level is 101,3 kPa. The effect of low pressure should also be a concern during air shipment.

Table 17 – Temperature, humidity and air pressure during air shipment

Destination		Number of data	Temperature (°C)			Humidity (% RH)			Air pressure (kPa)		
			Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.
Domestic in USA	Atlantic City, NJ	3	23,1	31,9	16,9	56,9	81,5	33,1	100,0	101,4	78,6
	Clemson, SC	3	23,4	35,3	15,8	56,9	83,1	35,4	98,6	102,7	80,0
	East Lansing, MI	3	22,1	35,6	16,6	52,7	74,0	25,0	98,4	101,4	80,0
	Gainesville, FL	3	23,5	36,6	14,6	53,6	80,8	33,4	100,7	102,0	78,6
	Washington DC	3	22,7	28,9	18,0	57,0	78,5	32,3	100,7	103,4	80,0
International	Melbourne, Australia	3	21,0	36,9	8,0	48,7	92,7	21,9	98,6	102,0	79,3
	Rio de Janeiro, Brazil	3	23,9	35,4	13,9	61,2	84,0	24,8	100,0	102,7	78,6
	Beijing, China	3	25,1	38,4	15,8	58,0	80,0	31,7	98,6	102,7	80,0
	Berlin, Germany	3	23,9	45,6	13,1	55,4	78,3	22,4	99,1	102,0	80,7

Annex A
(informative)

Test conditions in standards dealing with electronic displays

A.1 IEC standards on electronic displays related to environmental tests

Several standards on electronic displays related to environmental tests have been published by IEC/TC110. Existing standards are listed in Table A.1. Each standard focuses on displays of a specific technology and involves some special test methods or conditions, although many parts are common for multiple display technologies. The test conditions especially related to temperature and humidity are shown in Table A.1 to Table A.7. It is recommended to select the conditions according to the specific use profiles mentioned above.

Table A.1 – IEC standards for electronic displays related to environmental tests

IEC document (scope)	Title	Status and date of publication
61747-10-2 [2] (LCD)	Liquid crystal display devices – Part 10-2: Environmental, endurance and mechanical test methods – Environmental and endurance	Edition 1.0 2014-09-03
61988-4-1 [3] (PDP)	Plasma display panels – Part 4-1: Environmental testing methods – Climatic and mechanical	Edition 1.0 2015-03-25
62341-5 [4] (OLED)	Organic light emitting diode (OLED) displays – Part 5: Environmental testing methods	Edition 1.0 2009-11-20
62679-4-2 [5] (EPD)	Electronic paper displays – Part 4-2: Environmental test methods	Edition 1.0 2016-08-29
62715-6-2 [6] (FDD)	Flexible display devices – Part 6-2: Environmental testing methods	Edition 1.0 2017-05-24
62908-13-10 [7] (TID)	Touch and interactive displays – Part 13-10: Reliability test methods of touch displays – Environmental durability test methods	Edition 1.0 2016-11-25

A.2 High-temperature testing

The methods of high-temperature testing for storage and operation are stipulated in each standard. Basically, they refer to IEC 60068-2-2 [1] for the test procedure. Testing conditions for each standard are listed in Table A.2 for storage and Table A.3 for operation. Some differences exist, but most conditions are common.

Table A.2 – Testing conditions for storage at high temperature

IEC No. (scope)	Specified conditions		Example conditions
61747-10-2 [2] (LCD) 62341-5 [4] (OLED) 62679-4-2 [5] (EPD) 62715-6-2 [6] (FDD) 62908-13-10 [7] (TID)	Temperature (°C)	100, 95, 90, 85, 80, 75, 70, 65, 60, 55, 50, 45, 40, 35, 30	LCD 80 °C, 240 h 60 °C, 240 h 60 °C, 500 h FDD 55 °C, 30 % RH, 168 h TID 80 °C, 500 h
	Duration (h)	2, 16, 24, 48, 72, 96, 120, 192, 240, 300, 500, 1 000	
61988-4-1 [3] (PDP)	Temperature (°C)	80, 70, 60	
	Duration (h)	24, 48, 72, 96, 120, 240, 500	

Table A.3 – Testing conditions for operation at high temperature

IEC No. (scope)	Specified conditions		Example conditions
62341-5 [4] (OLED)	Temperature (°C)	80, 75, 70, 65, 60, 55, 50, 45, 40, 35, 30	
	Duration (h)	2, 4, 8, 12, 24, 48, 72, 96	
62715-6-2 [6] (FDD) 62908-13-10 [7] (TID)	Temperature (°C)	80, 75, 70, 65, 60, 55, 50, 45, 40, 35, 30	FDD 55 °C, 30 % RH, 168 h TID 80 °C, 240 h
	Duration (h)	2, 16, 24, 72, 96, 120, 192, 240	

A.3 Low-temperature testing

The methods of low-temperature testing for storage and operation are stipulated in each standard. Basically, they refer to IEC 60068-2-1 [23] for the test procedure. Testing conditions for each standard are listed in Table A.4 for storage and Table A.5 for operation. Some differences exist, but most conditions are common.

Table A.4 – Testing conditions for storage at low temperature

IEC No. (scope)	Specified conditions		Example conditions
61747-10-2 [2] (LCD) 62341-5 [4] (OLED) 62679-4-2 [5] (EPD) 62715-6-2 [6] (FDD) 62908-13-10 [7] (TID)	Temperature (°C)	-50, -45, -40, -35, -30, -25, -20, -15, -10, 0	LCD -20 °C, 240 h -20 °C, 500 h -30 °C, 240 h TID -25 °C, 500 h
	Duration (h)	2, 16, 24, 48, 72, 96, 120, 192, 240, 300, 500, 1 000	
61988-4-1 [3] (PDP)	Temperature (°C)	-40, -30, -20, -10, -5, 0	
	Duration (h)	24, 48, 72, 96, 120, 240	