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Foreword

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Background information

Section One—Cold and dry heat tests

Foreword for Japanese Industrial Standard

This Japanese Industrial Standard has been prepared based on the first edition issued in 1974 of "IEC 68-3-1, Environmental testing Part 3: Background information Section One: Cold and dry heat tests" and first supplement issued in 1978 without changing the technical contents.

1 Introduction

The performance of components and equipments is influenced and limited by their internal temperatures which depend on the external ambient conditions and on the heat generated within the device itself.

Whenever temperature gradients exist in the system formed by a device and its surroundings, a process of heat transfer will ensue.

The tests cover cold and dry heat testing, with both sudden and gradual change of the temperature, and of non heat-dissipating and heat-dissipating specimens (the latter with or without artificial cooling).

The use of test chambers with and without forced air circulation is covered as appropriate. A general block diagram of the total procedure is given in Appendix K.

1.1 *Reference ambient conditions*

Unfortunately, the actual ambient conditions in which the device will have to work are normally neither accurately known nor well defined, so that it is not possible to use them as a basis for design, specification or testing.

For these purposes, it is necessary to define conventional reference ambient conditions which may be specified taking into account Sub-clauses 1.2 and 1.3.

1.2 *Devices without heat-dissipation*

If the ambient temperature is uniform and constant and there is no generation of heat within the device, heat will flow from the ambient atmosphere into the device if the former is at a higher temperature, and from the device into the ambient atmosphere if the latter is at a lower temperature. This heat transfer will continue until the device has reached in all its parts the temperature of the surrounding atmosphere. From that moment on, the heat transfer ceases and will not start again unless the ambient temperature changes. In this case, the definition of a reference ambient temperature is simple, the only condition being that it shall be uniformly distributed and constant.

For the case when the device does not reach the temperature of the surrounding atmosphere, the definition of a reference temperature is more complicated and the conclusions in Sub-clause 1.3 apply.

1.3 *Devices with heat-dissipation*

If heat were generated within the device and there were no heat transfer to the ambient atmosphere, the temperature of the device would rise beyond any limit. It follows that if an ultimate steady temperature is reached, this implies that heat is flowing continuously from the device into the atmosphere whereby the device is always cooled, no matter what the ambient atmosphere is. Only if the ambient temperature rises, a further rise of temperature within the device may occur.

The reference ambient temperature for this case shall obviously be so defined that simple and well reproducible conditions for heat transfer are obtained. Because heat transfer is accomplished by means of three distinct mechanisms, convection, radiation and conduction, well-defined conditions for each of them shall be obtained separately but simultaneously.

If more than one specimen is subjected to one of the dry heat tests in the same chamber, it is necessary to ensure that all specimens are in the same ambient temperature and have identical mounting conditions. It has not, however, been found necessary to differentiate between testing of single specimens and multiple specimens when the cold test is being performed.

1.4 *Ambient temperature*

Users of components and equipments, particularly equipments, require to know the maximum and minimum values of ambient temperature between which the item will operate and these should be specific for the purpose of testing.

Certain difficulties arise here due to the fact that heat transfer is connected with temperature gradients and that therefore the temperature of the medium surrounding the device is necessarily varying in space. Consequently, the "ambient temperature" of the surrounding atmosphere shall be specially defined.

1.5 *Surface temperatures*

Considering on the other hand that the principal influence on the performance of the device is its own temperature, for the purposes of monitoring and adjusting test gear it may be convenient to refer to the temperatures at some significant points on the surface or even in the interior of the specimen.

2 **Reasons for the differing test procedures**

2.1 *Mechanisms of heat transfer*

2.1.1 *Convection*

2.1.1.1 Heat transfer through convection is a very important part of heat transfer from heat-dissipating specimens exposed to test chamber conditions.

The coefficient of heat transfer from the surface of the test specimen to the ambient air is affected by the velocity of the surrounding air. The heat transfer is more efficient the higher the air velocity. Therefore, with the same temperature of the ambient air, the surface temperature of the test specimen will be lower the higher the air velocity. This effect is illustrated in Figs. 3 and 4.

In addition to the influence on the surface temperature of the test specimen at any one location, the airflow will also effect the temperature distribution on the surface of the test specimen. This effect is illustrated in Fig. 5.

- 2.1.1.2 It is evident from Appendix B that there is no simple relationship between surface temperature and distribution for different air velocities and airflow directions. It is also obvious that if in conformance with actual conditions testing were to be defined with a particular value of air velocity and airflow direction, this would involve problems in the design of chambers.

The necessity for a well-defined, reproducible test condition where the test results can be easily compared with actual conditions leads to the use of "free air" conditions.

- 2.1.1.3 "Free air conditions" means conditions within an infinite space where the movement of the air is effected only by the heat-dissipating specimen itself, and the energy radiated by the specimen is absorbed. It is not practical for testing purposes to try to reproduce free air conditions (see Clause 3).

It is shown in Appendix A that the use of free air conditions as a reference does not normally lead to expensive or impracticably large testing-chambers. Since free air conditions have certain technical advantages and are normally easier to comply with than specified forced air conditions, they are used as the preferred way of performing cold and dry heat tests on heat-dissipating specimens.

Due to reasons given in Clause 3, there are cases where difficulties in testing with no forced air circulation arise. Two alternative methods, where forced air circulation with low air velocity is allowed, have therefore been given. The first method applies to the cases where the size of the chamber is large enough to comply with the requirements in Appendix A, but where the heating or cooling of the chamber requires forced air circulation. The second method applies to the cases where the chamber is too small to comply with the requirements of Appendix A, or where the first method cannot be used for other reasons.

2.1.2 *Thermal radiation*

- 2.1.2.1 Appendix C shows that heat transfer by thermal radiation cannot be neglected when test chamber conditions for testing of heat-dissipating specimens are discussed. In the case of thermal black test specimens and thermal black chamber walls (emissivity coefficient approaching unity), nearly half of the heat transfer from the test specimen may be due to thermal radiation. Thus, if the heat-dissipating test specimen is subjected to a certain ambient temperature in a thermal white chamber and in a thermal black chamber, the surface temperature of the test specimen will be significantly different. The emissivity coefficient and the temperature of the chamber walls should therefore be limited by specification if *reproducible* test results are to be achieved.

- 2.1.2.2 If the test specimen is sheltered from the chamber walls by other specimens, heating or cooling elements, mounting devices, etc., which do not comply with the requirements for thermal colour and temperature of the chamber walls, the heat radiation between the test specimen and the chamber walls is affected. The percentage of the chamber walls which can be "seen" by a specific point on the test specimen determines the "*view factor*" of that point. The view factors of each point of the test specimen should not be unduly disturbed by devices which do not comply with the requirements on thermal colour and temperature of the chamber walls.

- 2.1.2.3 In an ideal “free air” condition, the heat transferred from the test specimen is completely absorbed by the surrounding air. This occurs as a result of free convection and complete absorption of the thermal radiation.

Most equipments and components will be operating in a surrounding which approximates more to thermal black than to thermal white.

It is furthermore easier to make the inside of a chamber approximately thermal black than to make it approximately thermal white. It is especially difficult to keep it thermal white for a long period due to ageing effects. In fact, most paints and materials (unpolished) approximate more to thermal black than to thermal white (see Appendix J).

If the temperature of the chamber walls varies within 3% of the specified test temperature in degrees Kelvin and the emissivity coefficient varies between 0.7 to 1, the resulting variation in surface temperature of the test specimen will normally be less than 3 K. Since the heat radiation is proportional to the difference between the fourth power of the surface temperature of the test specimen and the fourth power of the chamber wall temperature, the thermal radiation is less pronounced at low temperatures and therefore the requirements on thermal colour and temperature of the chamber walls are less stringent when low temperature testing is concerned.

- 2.1.2.4 The heat transfer due to thermal radiation is considerably dependent on the temperature of the chamber walls. This dependence is the main reason why testing with forced air circulation cannot be used without corrections in accordance with Appendix E when the difference between the surface temperature of the specimen and the temperature of the ambient air is significant.

2.1.3 *Thermal conduction*

- 2.1.3.1 Heat-dissipation by thermal conduction depends on the thermal characteristics of mounting and other connections.

- 2.1.3.2 Many heat-dissipating equipments and components are intended to be mounted on heat sinks or other well-conducting devices, with the result that a certain amount of heat is effectively dissipated through thermal conduction.

The relevant specification shall then define the thermal characteristics of the mounting and these should be reproduced when the test is made.

- 2.1.3.3 If an equipment or component can be mounted in more than one manner with different values of thermal conduction, the worst case should be covered. The worst case is different for differing applications as follows:

- a) Dry heat testing of heat-dissipating specimens. Since heat is transported in the direction from the test specimen to the mounting devices, the worst case is reached when this transfer is as small as possible, i.e. when the mounting has low thermal conductivity (thermally isolated).
- b) Dry heat testing of non heat-dissipating specimens. As long as thermal stability has not been reached, the heat is transferred from the chamber walls through the mounting devices to the test specimen. The worst case is then where the thermal conductivity of the mounting is high. The thermal capacity of the mounting should be low in order to avoid a considerable warm-up time of the mounting and accordingly a delay in the heat transfer from the chamber walls to the test specimen.
- c) Cold testing of heat-dissipating specimens and non heat-dissipating specimens. Since heat is transferred from the test specimen to the chamber walls through the mounting devices, the worst case (lowest temperature of the test specimen) is reached when this transfer is as effective as possible, i.e. when the thermal conductivity of the mounting is high.

2.1.4 *Forced air circulation*

- 2.1.4.1 Where the chamber is large enough to comply with the requirements in Appendix A, the heating and cooling of the chamber may necessitate forced air circulation.

In such cases, a check is made, at *laboratory temperature* inside the chamber, that the temperature at representative points on the surface of the test specimen is not unduly influenced by the air velocity used in the chamber. If the surface temperature at any point of the test specimen is not reduced by more than 5°C by the influence of the forced air circulation used in the chamber, testing is performed as in a chamber with no forced air circulation, and the cooling effect of the forced air circulation is neglected since it may be assumed to be reasonably small.

- 2.1.4.2 Where the chamber is too small to comply with the requirements of Appendix A, or where the reduction of surface temperature as measured in Sub-clause 2.1.4.1 exceeds 5 °C, an exploratory test should be made outside the test chamber.

The temperatures of a representative number of points on the surface of the test specimen are measured in the laboratory *outside the chamber* in order to give a basis for calculation of the surface temperatures at the specified test conditions. These measurements are carried out under those load conditions which are specified for the test temperature by the relevant specification.

For small temperature differences ΔT_1 between ambient temperature and surface temperature, this difference ΔT_1 can be assumed to be the same in different ambient temperatures as long as the differences ΔT_2 in ambient temperatures are small.

The error is within 3°C if $\Delta T_1 < 25^\circ\text{C}$ and $\Delta T_2 < 30^\circ\text{C}$.

The relationships between surface temperatures at different ambient temperatures are given in Appendix E. With Fig.9 in Appendix E, it is possible to calculate the surface temperature at any ambient temperature if the surface temperature at a certain ambient temperature is known. By using Fig. 9, it is possible to extend the range where the surface temperatures in specified test conditions can be calculated if they are known at laboratory temperature. Figure 9 in Appendix E can be used to at least $\Delta T_1 = 80^\circ\text{C}$ and $\Delta T_2 = 65^\circ\text{C}$.

Informative reference: ΔT_1 and ΔT_2 are shown in Appendix C.

- 2.1.4.3 The choice of representative points to be checked when the alternative first and second methods specified in JIS C 0020 (Tests A : Cold) Sub-clause 29.1.2 and JIS C 0021 (Tests B : Dry heat) Sub-clause 40.1.2 are used should be based on a detailed knowledge of test specimen (thermal distribution, thermally critical points, etc.).

Since such a choice is mainly a matter of skilled judgement, the preferred method where no forced air circulation is used is strongly recommended for type approval purposes because of its higher degree of reproducibility.

One exploratory test may cover the chamber performance for a long series of similar tests (e.g. similar components), whereas in other cases an assessment may need to be made prior to each test (e.g. for different equipment).

3 Test chambers

3.1 General

It is not practical for testing purposes to try to reproduce free air conditions, but it is however possible to simulate the effects of these conditions.

Even in very large chambers, the air circulation and temperature distribution around the test specimen will not be identical with actual free air conditions.

Nevertheless, it is established by experimental results and test experience that a reasonably large chamber with no forced air circulation will affect the temperature of the test specimen in approximately the same way as would free air conditions.

The requirements on size of chamber in relation to the size and heat dissipation of the test specimen, which are necessary for simulating the effects of free air conditions, are given in Appendix A.

The requirements presented are valid when the ambient temperature is monitored in the lower part of the testing chamber, where the air is not greatly affected by the heat convection from the test specimen.

However, in some cases difficulties in testing with no forced air circulation arise. In a number of existing chambers the heating or cooling of the chamber cannot be performed without forced air circulation, especially for testing of large specimens, or many components in the same chamber.

Table I shows the parameters of a test chamber that will have a considerable influence on the test results of a heat-dissipating specimen.

TABLE I

Transfer mechanism	Convection		Radiation	Conduction
	Free air	Forced air circulation		
Chamber parameters	Dimensions; air temperature	Air velocity; air temperature	Wall temperature; wall emission; view factor	Thermal characteristic of mounting

3.2 Methods of achieving the required conditions in the test chamber

3.2.1 Design of chambers for simulating the effect of free air condition

Heating and cooling elements should not be situated in the working space, as the controlling of the chamber temperature involves changes in the temperatures of these elements. Large fluctuations in the temperature of the chamber walls should be avoided in order to minimize radiation problems.

For the best results, all the walls of the chamber should be heated. Liquid circulation provides a convenient method of heating or cooling all walls without large fluctuations in wall temperature. The walls of the chamber should fulfil the emissivity requirements of the test.

Where a chamber relies on air circulation for maintenance of the test temperature, it may be possible to place the test specimen inside a box which is then placed in a chamber. The volume of the box should fulfil the dimensional requirements of the test and the walls should meet the emissivity coefficient requirements.

3.2.2 *Design of chambers with forced air circulation*

A chamber with an airflow is intended for use with specimens which make the use of a free air chamber impracticable either by virtue of their large size or high dissipation. All the requirements for free air chambers thus apply except for those relating to dimensions.

The airflow should be large enough to ensure that the specimen is not overheated, yet should not be so large that excessive cooling of the specimen can occur. The effects of airflow are given in more detail in Appendix B. In practice, an airflow of 0.5 m/s has been found to represent a fair compromise, although facility to vary the rate of flow is a useful advantage.

The airflow should be as uniform as possible. The airflow should be directed vertically upward to minimize the variation from that which would occur due to convection above. If the fan causes a pressure build-up in an antechamber, from which the air is allowed to escape through a filter (e.g. fibre-glass mat) a uniform airflow results.

This antechamber may also contain the heaters which control the chamber temperature. Alternatively, the heaters and filter may be combined by the use of woven mesh heaters.

3.2.3 *Emissivity coefficient of walls*

The walls of the chamber should be thermal black if free air conditions in infinite space are to be simulated. The Table IV of Appendix J indicates that an emissivity coefficient of 0.70 may easily be achieved.

Most matt paints are perfectly satisfactory for the treatment of chamber walls operating at moderate temperatures.

3.2.4 *Thermal characteristics of mounting devices*

Reference should be made in Sub-clause 2.1.3 and Appendix D where some characteristics for wire terminations are given.

Reference should also be made to Appendix F which gives thermal conductivities of various materials. In cases where conduction by a mounting and/or terminations, such as lead wires, becomes important, it is essential that a constant length of such wire terminations is used for all tests.

4 **Measurements**

4.1 *Temperature*

Measurements of temperature at various points on or in a specimen are necessary for the purposes of tests involving heat-dissipating specimens in conditions other than "free air"

Recommendations are given in Appendix G.

4.2 *Air velocity*

A knowledge of the velocity of the air in the test chamber, while not essential for specification of the tests, is nevertheless most useful, e.g. to ensure uniformity of conditions within the chamber in the case of testing multiple specimens in the same chamber with forced air circulation.

Recommendations are given in Appendix H.

4.3 *Emissivity coefficient*

Since the transfer of heat by radiation is important in the case of testing of heat-dissipating specimens, the emissivity coefficient of the walls of the chamber shall be measured and periodically checked.

Recommendations for such measurements are given in Appendix J.

5. Precautions on tests

5.1 Overstress

Certain equipment is used or stored under high or low temperature conditions only for periods shorter than the time for achieving temperature stability. A test of such equipment, according to Tests A : Cold and B : Dry heat where the duration of the test is counted from the time at which the specimen has reached temperature stability, may then overstress the equipment.

When such an overstress must be avoided, the procedures defined in the cold and dry heat tests may be used with the deviations and precautions given in Sub-clause 5.2 below.

Examples where this may be the case are certain aircraft and missile equipment.

Although equipment with large thermal time constants compared to diurnal temperature fluctuations are normally tested according to the cold and dry heat tests under temperature stability conditions, there are cases where a close simulation of the actual environment is desired. In such cases, a test without temperature stability of the specimen may be used.

Testing for a period shorter than the time for achieving temperature stability may be relevant also for the cases where a high or low temperature in a large equipment (e.g. power supply transformers and motors with high thermal time constant) is wanted to be obtained in a short time. In such cases, the test ambient temperature is chosen higher or lower than the ambient temperature which is expected in conditions where the equipment is to be used.

5.2 Testing precautions

5.2.1 General

In order to achieve reproducibility, the temperature test must be so designed that the hottest (coldest) temperature attained in a certain point of the specimen will be the same independent of the testing laboratory. For the design of a test with a short test duration compared to the time needed for the specimen to attain temperature stability, the following precautions must be taken into account.

5.2.2 Velocity of the air surrounding the test specimen

The efficiency of the heat exchange between the test chamber air and the test specimen depends on the air velocity.

A close simulation of air velocities connected with high (low) temperatures in the actual environment is desirable. Due to limited knowledge of the actual environment as well as difficulties in providing defined air velocities (including degree of turbulence, etc.) in testing chambers, such simulation is normally not feasible. Therefore, a "worst case" must normally be used for testing to cover all possibilities.

In the case of testing *non heat-dissipating specimens*, a higher air velocity results in a higher (for cold testing, lower) specimen temperature. It is therefore recommended to use a high air velocity in the test chamber for this test.

Informative reference:

The air velocity is preferably not less than 2 m/s measured in the empty working space.