BS EN 62693:2013

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Industrial electroheating installations — Test methods for infrared electroheating installations

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee PEL/27, Electroheating.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Industrial electroheating installations - Test methods for infrared electroheating installations (IEC 62693:2013)

Installations électrothermiques industrielles - Méthodes d'essais relatives aux installations électrothermiques par rayonnement infrarouge (CEI 62693:2013)

Industrielle Elektrowärmeanlagen - Prüfverfahren für Infrarot-Elektrowärmeanlagen (IEC 62693:2013)

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Foreword

The text of document 27/877/CDV, future edition 1 of IEC 62693, prepared by IEC/TC 27 "Industrial electroheating and electromagnetic processing" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62693:2013.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2014-04-23
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2016-07-23

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The text of the International Standard IEC 62693:2013 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60038	NOTE	Harmonised as EN 60038.
IEC 60398:1999	NOTE	Harmonised as EN 60398:1999.
IEC 60519-2:2006	NOTE	Harmonised as EN 60519-2:2006.
IEC 60825-1:2007	NOTE	Harmonised as EN 60825-1:2007.
IEC 61010-1:2010	NOTE	Harmonised as EN 61010-1:2010.
IEC 62471:2006	NOTE	Harmonised as EN 62471:2008 (modified).
ISO 638:2008	NOTE	Harmonised as EN ISO 638:2008.
ISO 2813:1994	NOTE	Harmonised as EN ISO 2813:1999.
ISO 8254-1:2009	NOTE	Harmonised as EN ISO 8254-1:2009.
ISO 8254-2:2003	NOTE	Harmonised as EN ISO 8254-2:2003.

Annex ZA
(normative)
Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60519-1 + corr. November	2010 2012	Safety in electroheating installations - Part 1: General requirements	EN 60519-1	2011
IEC 60519-12	2013	Safety in electroheating installations - Part 12: Particular requirements for infrared electroheating installations	EN 60519-12	2013

CONTENTS

INTRODUCTION

This standard on particular test methods for infrared electroheating installations is one of TC 27 standards that describe test methods for various types of electroheating installations.

Test methods for ovens under the scope of IEC 60397 [3][1] are also covered in this standard when infrared radiation is the intended heat transfer in such equipment – this is assumed to be valid above an actual or processing temperature of 700 °C, independently of the rated temperature of the oven.

This standard is solely concerned with tests for infrared equipment and installations. Tests that focus on the performance of infrared emitters will be covered by IEC 62798 [2] [11]. The rationale for this separation is that infrared installations are usually manufactured by other companies than infrared emitters. Still, infrared emitters are a very important and distinct part of infrared installations and a set of tests that allow for proper comparison of different infrared emitters will be valuable to manufacturers of infrared installations.

The major guiding principle in this standard is to define tests that can be performed with the usual test and measuring equipment available to most kinds of companies, large or small.

The tests focus on the performance and efficiency of installations, as these are of major interest for manufacturers and users of such installations. The tests are intended to enable a fair comparison of installations belonging to a given class. The standard includes considerations and tests concerned with energy efficiency, so that the tests can be used for assessment of energy use and for energetic optimisation of installations as well.

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1 Numbers in square brackets refer to the Bibliography.

2 Under consideration.

INDUSTRIAL ELECTROHEATING INSTALLATIONS – TEST METHODS FOR INFRARED ELECTROHEATING INSTALLATIONS

1 Scope and object

This International Standard specifies test procedures, conditions and methods according to which the main parameters and the main operational characteristics of industrial infrared electroheating installations are established.

A limitation of the scope is that the infrared emitters have a maximum spectral emission at longer wavelengths than 780 nm in air or vacuum, and are emitting wideband continuous spectra such as by thermal radiation or high pressure arcs.

In industrial infrared electroheating installations, infrared radiation is usually generated by infrared emitters and infrared radiation is significantly dominating over heat convection or heat conduction as means of energy transfer to the workload.

IEC 60519-1:2010 defines infrared as optical radiation within the frequency range between about 400 THz and 300 GHz. This corresponds to the wavelength range between 780 nm and 1 mm in vacuum. Industrial infrared heating usually uses infrared sources with rated temperatures between 500 °C and 3 000 °C; the emitted radiation from these sources dominates in the wavelength range between 780 nm and 10 μm.

Installations under the scope of this standard typically use the Joule effect for the conversion of electric energy inside one or several sources into infrared radiation emitted onto the workload. Such infrared emitters are especially

- thermal infrared emitters in the form of tubular, plate-like or otherwise shaped ceramics with a resistive element inside;
- infrared quartz glass tube or halogen lamp emitters with a hot filament as a source;
- non insulated elements made from molybdenum disilicide, silicon carbide or comparable materials;
- restive metallic heating elements made e.g. from nickel based alloys or iron-chromium-aluminium alloys;
- wide-spectrum arc lamps.

This standard is not applicable to

- infrared installations with lasers or light-emitting diodes (LEDs) as main sources – they are covered by IEC 62471:2006 [9], IEC 60825-1:2007 [6] and IEC/TR 60825-9:1999 [7];
- appliances for use by the general public;
- appliances for laboratory use – they are covered by IEC 61010-1:2010 [8];
- electroheating installations where resistance heated bare wires, tubes or bars are used as heating elements, and infrared radiation is not a dominant side effect of the intended use, covered by IEC 60519-2:2006 [5];
- infrared heating equipment with a nominal combined electrical power of the infrared emitters of less than 250 W;
- handheld infrared equipment.

The tests are intended to be used to enable a fair comparison of the performance of installations belonging to the same class.

Tests related to safety of the installations are defined in IEC 60519-12:2013. Tests related to the performance of infrared electroheating emitters are specified in IEC 62798:— [11].

Therefore, this standard is applicable to ovens and furnaces with resistive heating elements if they fall under the scope of this standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60519-1:2010, *Safety in electroheating installations – Part 1: General requirements*

IEC 60519-12:2013, *Safety in electroheating installations – Part 12: Particular Requirements for infrared electroheating installations*

3 Terms and definitions

For the purposes of this document, the terms and definitions of IEC 60519-12:2013 and the following apply.

NOTE General definitions are given in the International Electrotechnical Vocabulary, IEC 60050 [2]. Terms relating to industrial electroheating are defined in IEC 60050-841.

3.1 General

3.1.1
installation class
group within a type of installation, using the same principle for processing the workload and the size of this as well as the production capacity

3.1.2
production capacity
measure of the production rate capability of equipment in normal operation

EXAMPLE Flow, mass or volume.

Note 1 to entry: The capacity does not refer to the volume of the working space.

3.1.3
electroheating efficiency, <of an installation>
ratio of the usable enthalpy increase in the workload to the electric energy supplied to it at the location of the equipment, during a cycle of batch operation or stationary operation during a suitable time period for measurements

[SOURCE IEC 60050-841:2004, 841-22-70, modified – The term itself has been modified and details with respect to the kind of operation have been added.]

3.1.4
electric conversion efficiency
quotient between the available electric active power output for the transfer to the workload, and the electric input active power from the supply network, at power settings for normal operation

Note 1 to entry: The concept does not apply to conversion of electric energy to infrared radiation by heated elements.

3.1.5
intended workload quality
product quality
degree to which a set of inherent characteristics of a processed workload fulfils requirements

Note 1 to entry: All workload that does not attain the intended workload quality is regarded as scrap or undergoes rework to reach intended workload quality.

3.2 States and parts

3.2.1
cold start-up
process by which the equipment is energised into hot standby operation, from the cold state, including all other start-up operations which enable the equipment to operate as intended

Note 1 to entry: This mode of operation applies to cases where there is a significant energy consumption needed for obtaining a state of the equipment allowing the actual processing of the workload.

3.2.2
holding power
electric power consumption during which the workload is kept in the treatment chamber at a specified temperature

Note 1 to entry: The temperature is typically maintained during a time intended to equalize the workload temperature.

Note 2 to entry: This mode of operation is not applicable for certain types of electroheating equipment.

3.2.3
hot standby operation
mode of operation of the installation occurring immediately after normal operation

Note 1 to entry: This mode of operation of the installation is with its hot state remaining, without workload, and with the means of operation ready for prompt normal operation.

3.2.4
normal operation
range of output settings with the normal workload in allowable working conditions of the installation, as specified in the manufacturer's documentation

3.2.5
shut-down operation
process by which the installation is de-energised safely into the cold state

3.2.6
port
entrance or exit opening in the treatment chamber or enclosure through which the workload moves

3.2.7
means of access
all structural features of the infrared electroheating installation which can be opened or removed without the use of a tool to provide access to the interior of the installation

3.3 Workload

3.3.1
normal workload
object intended to be processed as specified in the manufacturer's documentation

Note 1 to entry: The workload is called "charge" in some electroheating contexts.

Note 2 to entry: The workload includes any container, holder or other device necessary for the processing and which is directly or indirectly subjected to the output power.

3.3.2
dummy workload
artificial workload with known thermal properties, designed for accurate enthalpy increase measurements by absorbing the available output power

3.3.3
infrared dummy workload
IDW
dummy workload intended to mimic the physical behaviour of the workload, especially its radiation absorption behaviour, allowing for the effective measurement of specific parameters of the process

Note 1 to entry: Example for a specific parameter is the homogeneity of processing of the surface of the workload.

Note 2 to entry: This note applies to the French language only.

4 Boundaries of the installation during tests

4.1 Energy considerations

It is necessary to define boundaries or limits of the installation with respect to equipment and energy uses included in or excluded from considerations during tests and calculations. The following definitions of boundaries are intended to enable fair comparisons for both batch and continuous type installations:

a) Energy of compression or decompression of steam, air or any other gas in the process chamber shall be included in the used and lost energy calculations of the installation.
b) Exo- or endothermic chemical energy involving any reactive gases in the processing of the workload shall be included.
c) Energy used for cooling action by any excess reactive and/or inert gases in the processing of the workload shall be included in the calculation of used and lost energy of the installation.
d) Energy used for cooling of the processed workload to ambient temperature or as preparation for further treatment as part of normal operation shall be included, but stated separately in the calculation of used and lost energy. If a part of this thermal energy is transferred back into the installation or process, this recycling of thermal energy shall be reported separately, to allow comparisons with other installations in the same class but without this feature. Thermal energy used outside the process shall not be included in reporting.

4.2 Batch type installations

Batch type installations are characterised by a discontinuous processing. If there are means of access, these are opened and a workload is placed inside the treatment chamber of the installation and then undergoes normal operation. The means of access are then reopened and the workload is removed from the treatment chamber and the installation either goes into hot standby operation with closed means of access, or the process is restarted with another workload.

Normal operation always includes heating and can also include one or more of the following sub-processes:

- closing and opening of means of access;
- pressurising of the treatment chamber;
- transport of the workload – this includes for example wobbling movement during operation;

- holding the workload at a specified temperature for a specified time;
- introducing reactive or protective gases into the treatment chamber – including deposition processes;
- free or forced cooling of the workload – for example, if cooling is necessary to avoid damage by exposing the hot workload to ambient atmosphere.

The energy used to perform these sub-processes shall be included. The spatial boundary of the installation with respect to the process is defined by:

a) an entrance port position where the workload is placed prior to normal operation or the equipment which transports the workload into the treatment chamber; this equipment and its energy use is a part of the installation;
b) an exit port position where the workload is placed after normal operation for removal, or the equipment which moves the workload out of the treatment chamber; this equipment and its energy use is part of the installation;
c) all equipment in between, including for example all switchgear, pumps, cooling means necessary to operate the equipment.

NOTE In vacuum equipment, the boundary between the infrared installation and another installation is typically a valve.

The cycle of batch operation relevant for measurement shall begin after hot standby operation.

4.3 Continuous type installations

Continuous type installations are characterised by a continuous or semi-continuous processing. The workload is conveyed through the treatment chamber of the installation during normal operation. The steps of treatment occur at consecutive positions inside the installation as the workload is transported through it – for example in roll to roll operations or in sheet feed installations. This kind of installation usually goes into hot standby operation when no workload is conveyed.

The normal operation always includes heating and can include one or more of the following sub-processes which occur at separated spatial positions inside the installation:

- holding the workload at a specified temperature;
- introducing reactive or protective gases – including deposition processes;
- free or forced cooling of the workload – for example if cooling is necessary to avoid damage by exposing the hot workload to ambient atmosphere.

The energy used to perform these processes shall be included. The boundary of the installation is defined by

a) the entrance and exit ports;
b) all equipment in between, including for example all switchgear, pumps, cooling means necessary for operation of the equipment.

The energy consumption of transport or roll handling in stand-alone installations is included in the used energy. It shall be stated separately in the calculations.

5 Types of tests and general test conditions

5.1 General

No tests are defined for installations in the cold state. All such tests are safety related and are not covered by the scope of this standard. Relevant safety related tests are described in IEC 60519-1 and IEC 60519-12.

5.2 List of tests

The following tests shall be conducted in the hot state of the installation during commissioning or when the installation is ready for normal operation as well as at regular intervals as specified by the manufacturer, following maintenance or after modifications:

a) influence of supply voltage on the performance, refer to 7.1;
b) energy consumption during cold start-up operation and time needed, refer to 7.2;
c) power consumption during standby operation, refer to 7.3;
d) power consumption during holding operation, refer to 7.4;
e) energy consumption during shutting down operation and time needed, refer to 7.5;
f) energy consumption during regular maintenance operation, refer to 7.6;
g) energy consumption during normal operation, refer to 7.7;
h) energy consumption during a full operation cycle and peak power consumption, refer to 7.8;
i) production capacity, refer to 7.9;
j) efficiency of energy transfer to workload, refer to Annex A;
k) processing range of the installation to perform the intended operation, refer to 7.11;
l) homogeneity of workload processing, refer to Annex B;
m) infrared radiation distribution inside the installation, refer to Annex C.

Additional tests may be specified in the commissioning and operation manuals issued by the manufacturer or may be agreed between the manufacturer and user.

5.3 Test conditions

5.3.1 Operating conditions during tests

Operating conditions during tests shall be in the range of normal operation conditions and thus reflect the manufacturer's intended use of the installation while excluding extreme usage patterns, deliberate misuse or unauthorized modifications of the installation or its operating parameters.

5.3.2 Environmental conditions during tests

All tests shall be performed

a) under standardised environmental conditions, at ambient temperature in the range between 5 °C and 40 °C and air relative humidity of less than 95 %, or
b) at the point of use of the installation under the available and specified environmental conditions there.

The environmental conditions shall not exceed those defined for the intended purpose of the installation. All environmental conditions affecting measurement results shall be monitored during the tests and be part of the measurement report. This includes

- air temperature and humidity near the installation;
- temperature and humidity of cooling air drawn into the installation;
- exhaust air temperature;
- temperature of the workload when entering the installation;
- moisture content of the workload when entering the installation, if applicable.

5.3.3 Supply voltage

The supply voltage shall not exceed the limits defined for the intended purpose.

NOTE Limits of variation of line voltage are set in IEC 60038 [1].

The supply voltage to the installation shall be monitored during the tests.

All measurements of specific electrical values, such as power consumption or current shall include the data of the supply voltage.

5.4 Infrared dummy workload

The following aspects shall be considered when using an infrared dummy workload (IDW):

- in case of a planar workload, the IDW shall be planar;
- the IDW shall have the same size in batch processes or the same width in continuous processes as the intended workload, if effects covering the full usable size of the installation are to be tested;
- in case it is intended to process workloads with a complex shape, the IDWs shape shall include all relevant geometrical features of the normal workload;
- for the measurement of temperature homogeneity, the IDW shall have a comparable heat absorbing capacity, i.e. the factor of volume, density and heat capacity c_p;
- for the measurement of evaporation homogeneity, the IDW shall be made of the same material as the workload and be prepared with a comparable amount of evaporable substance;
- for the measurement of crosslinking homogeneity, the IDW shall be made of the same material as the workload.

6 Measurements

6.1 General

More than a single measurement is recommended for the tests defined in this standard. For time resolved measurements a data logger or multi-channel electronic data acquisition system shall be used, which automatically measures and stores the necessary data in a computer readable format.

6.2 Time resolution

The necessary time resolution of the measuring equipment and the data saving rate of the storage devices depends on the installation and the specific tests to be undertaken. The measurement and storage frequency shall be so high that all relevant signal variations are recorded.

6.3 Measurements of electric data

6.3.1 All equipment for voltage measurement shall be of class 2.0 or better. The measuring equipment for a.c. current shall be able to show true rms independently of the waveform.

6.3.2 All equipment for current measurement shall be of class 2.0 or better. The current measuring equipment for a.c. current shall be able to measure true rms independently of the waveform.

6.3.3 All equipment for energy consumption measurement shall be of class 2.0 or better. The measuring equipment shall be able to measure active and reactive energy independently of the waveform.

6.3.4 All equipment for power consumption measurement shall be of class 2.0 or better. The measuring equipment shall be able to measure active and reactive power independently of the waveform.

6.3.5 Measurements of all electric values, which are part of a test of energy or power use of the installation shall be performed at the power inlet to the installation.

6.3.6 Measurements of all electric values, which are part of a test of energy or power use of the infrared emitters of the installation, shall be performed at the power outlet of the switchgear connected to the emitters; transformers, capacitor circuits or comparable devices necessary to drive the emitter are part of the switchgear.

6.3.7 Measurements of all electric values, which are part of a test of energy or power use of auxiliary equipment, shall be performed at the respective power outlet of the switchgear connected to that equipment.

6.3.8 Specific access points may be installed during manufacturing of the installation. Measuring equipment may be part of the switchgear; its energy use is considered as part of the energy use of the switchgear.

6.4 Temperature measurement

The kind of equipment used for temperature measurement depends for example on the task, temperature range, available information on the surfaces being measured, and accessibility.

Contacting thermocouples are simple to use and reliable. They provide reliable and exact results if an intimate and non detachable contact to a surface of an object with high mass and good thermal conduction to the thermocouple is possible.

Pyrometers and infrared cameras summarised as thermographic methods may be used for all surfaces at elevated temperature, when the emissivity of the surface is well known and when the surface is considered as lambertian – i.e. following a cosine law of angular emissivity. The used value of emissivity, the measurement wavelength and the presumed error of emissivity shall be included in all measurement reports.

The relative measurement error for all temperature measurements in compliance with this standard shall not exceed 5 % of the temperature of the measured value stated in °C. Measurement accuracy shall be included in the measurement report.

NOTE The German VDI/VDE 3511 series [19 – 26] provides information on best practices for temperature measurement in industry.

7 Technical tests

7.1 Installation performance dependence on supply voltage

The actual supply voltage or its variation influences the performance of the infrared electroheating installation, if the infrared emitters operate on this directly or via fixed transformers. This effect can be even larger, if the actual supply voltage or the declared supply voltage differs from the rated supply voltage.

The variation of power consumption of individual infrared emitters with their applied working voltage depends on the type of emitter. This data may be supplied by the manufacturer of the emitter and the variation of power consumption with its actual working voltage

- shall either be calculated using this data,

- or may be measured by tracking the supply voltage of the installation and the power consumption of the installation or the emitters over a long period and at otherwise constant settings of the installation.

NOTE The future standard on infrared emitter tests [11] will consider the measurement of variation of power consumption depending on voltage.

Variation of power with the actual working voltage affects other parameters of the installation as well – for example wall temperature, processing time, heating up time.

The actual supply voltage can affect the results of all tests as well; it shall be part of the test report.

7.2 Energy consumption and time of cold start-up operation

The following applies for the measurement of cold start-up time and energy consumption for installations that by intent need to perform this operation prior to normal operation.

a) The installation shall be heated up from ambient conditions as stated in 5.3.2.
b) The installation is operated without a workload, if applicable.
c) Any preheating of the treatment chamber or zone to arrive at a state as close as reasonable to hot standby operation is carried out, if applicable.
d) The cold start-up total electric energy consumption and time are measured.

Cold start-up energy consumption can be measured for

- the complete infrared installation;
- the infrared emitters only;
- the auxiliary equipment only.

If the installation is intended to be heated up safely with workload only, this shall be considered.

7.3 Power consumption of hot standby operation

The following applies for the measurement of hot standby power consumption:

a) The installation is operated without workload, if applicable.
b) Conditions of hot standby operation are maintained.
c) The total energy consumption during hot standby and duration of hot standby are measured.

Hot standby power can be measured for

- the complete infrared installation;
- the infrared emitters only;
- the auxiliary equipment only.

7.4 Power consumption of holding operation

The holding feature of an installation is usually needed to achieve workload temperature equilibration after the process proper and does not exist in some types of installations.

NOTE The major difference between hot standby and holding is that the workload is present in the latter case and can emit radiation, or supply convective or conductive energy to its ambient. This is usually compensated by variation of the external energy supply to maintain the workload temperature.

The following applies for the measurement of the power consumption during temperature holding operation with workload:

a) The test is applicable if holding is part of normal operation.
b) The installation is operated with a heated up workload.
c) The temperature of the workload is kept constant, using particular control settings for this purpose.
d) The total energy consumption during holding and the holding time are measured.

Holding power can be measured for

- the complete infrared installation;
- the infrared emitters only;
- the auxiliary equipment only.

7.5 Shut-down operation energy consumption and time

The following applies for the measurement of energy consumption during shut-down operation, if applicable:

a) The installation is shut down as specified by the manufacturer.
b) The total energy consumption during shut-down and the shut-down time are measured.

Shut-down power consumption can be measured for

- the complete infrared installation;
- the infrared emitters only – if applicable;
- the auxiliary equipment only.

7.6 Energy consumption during a regular maintenance operation

The following applies for the measurement of maintenance energy consumption and time, if applicable:

a) Maintenance of the installation is performed as specified by the manufacturer.
b) The total energy consumption during the maintenance operation and time for maintenance are measured.

Maintenance power consumption can be measured for

- the complete infrared installation;
- the infrared emitters only;
- the auxiliary equipment only;
- the specific maintenance equipment only.

7.7 Energy consumption during normal operation

All measurements of the electric energy consumption shall reflect specific consumption by defined parts of the installation during a defined time period or a specified operation. The following shall be reported, if applicable:

a) The energy consumption of a batch type installation during one cycle; this may be measured and averaged over a defined number of cycles. The number of cycles and variation of energy consumption shall be recorded in the test report.
b) The energy of a continuously operating installation during processing of a defined amount of workload.
c) The energy consumption of the installation over a complete production cycle – for example, during a workday, one week or a complete year.

Normal operation energy consumption can be measured for

- the complete infrared installation;
- the infrared emitters only;
- the auxiliary equipment only.

7.8 Cumulative energy consumption and peak power consumption

The measurement of time resolved power consumption of the installation enables the calculation of the cumulative energy consumption for a complete operation of the installation and the measurement of peak power consumption. The test shall be made by monitoring the time resolved power consumption of the complete installation over:

a) one cycle, if the installation cools down between cycles;
b) one shift, if the installation is operating for some hours, but cools down at the end of a workday;
c) or over the complete heating up period and one hour of operation if the installation is operating continuously.

The internal electric conversion and switchgear of the installation are designed for accepting specified peak power consumption. It defines the rated power used for the designing and dimensioning of the electric power supply of the installation. The actual peak power consumption shall be measured over a typical full process cycle from heating up to cooling down.

Peak power consumption of the installation can be reached during one of the following stages:

- preheating of continuous processing installation;
- heating up of a batch type installation;
- or during other modes of operation.

NOTE A process phase resolved mapping of power consumed is the base for smart control or energy efficient control of the installation. It allows the reduction of peaks or moving processing intervals with high energy consumption to periods with low consumption of the plant or periods with low electric power or energy costs.

7.9 Net production capacity

The net production capacity is a measure of output efficiency of the installation in view of the intended workload quality. Only those parts of the workload having the intended workload quality after undergoing the intended process are evaluated.

The amount of workload shall be counted or measured:

a) when being placed into the installation and being of sufficient quality not to be rejected at that stage, checked for quality just before the processing is to begin;
b) when leaving the installation and being of intended workload quality, checked for quality just after the processing is finished.

The amount of workload shall be

- counted, when countable;
- stated as unit mass per time, when not countable, or
- stated as unit area per time, when being in sheet form.

The net production rate considering only processed workload of intended quality shall be stated for a single batch process or for a defined time period. It is defined as amount of workload of intended quality divided by all workload processed.

Scrap rate is defined as amount workload not of intended quality divided by all workload processed.

7.10 Efficiency of energy transfer to the workload

The estimation of the efficiency of energy transfer to the workload is typically a complex task. Test methods concerning the efficiency of transfer from the installation to the workload are given in Annex A of this standard.

7.11 Processing range of intended operation

The processing range of an installation for a specific process is defined as the range between an upper and a lower limit of set parameters between which the processed workload exhibits intended quality. The processing conditions can still vary inside the installation and thus over the surface of the workload.

The processing range can be measured using the following approach:

a) The installation is operated with workload and the power setting is increased until the complete workload is well processed – i.e. the part of the workload which gets the lowest amount of infrared radiation during processing is undergoing the necessary process. This is the lower limit.

b) The installation is operated with workload and the power setting is further increased until the workload shows first signs of overheating – for example, the part of the workload which gets the highest amount of infrared radiation is showing signs of undergoing a destructive process. This is the upper limit.

7.12 Homogeneity of the processed workload

Testing the homogeneity of the processing over the surface of the workload is typically a complex issue. Test methods vary with the specific quantity or quality being the essential aim of the process performed in the installation. Specifications are given in Annex B.

7.13 Infrared radiation distribution in the heating chamber

Tests of the infrared radiation distribution inside the operating installation can be necessary for estimation of the infrared electric conversion efficiency (8.2) or for tracking the source of inhomogeneous processing of the workload. Test methods concerning the distribution of infrared radiation inside the installation are given in Annex C.

8 Efficiency of the installation

8.1 General

The results from the tests given in Clause 7 allow calculation of relevant efficiency values of the installation.

The minimum theoretically needed energy per piece, unit mass or unit area of the workload undergoing the intended process is

$$E_{\text{min}} = m \cdot c_{\text{p}}(T) \cdot \Delta T + E_{\text{eva}} + R \qquad (1)$$

where

m	is the mass of the workload;
$c_{\text{p}}(T)$	is the specific heat of the workload;
ΔT	is the temperature change from ambient to maximum process temperature;
E_{eva}	is the energy needed for evaporation of solvents during the process for a mass of m of the workload;

R is the energy needed for intended chemical reactions to occur for a mass m of the workload.

Additional processes may be considered. Formula (1) is for calculating the minimum energy needed to perform the intended process, when no energy is lost and no energy is reused or recycled in the installation.

8.2 Infrared electric conversion efficiency

8.2.1 General

Infrared electric conversion efficiency is the efficiency of the conversion of electric power into infrared radiation inside the installation. It is a significant feature of industrial infrared electroheating installations, as it should be the dominating means of energy transfer. The infrared conversion efficiency is defined as

$$\eta_{\text{conv}} = \frac{E_{\text{irr}}}{E_{\text{inst}}} \tag{2}$$

where

η_{conv} is the electric-to-infrared conversion efficiency;

E_{irr} is the radiation energy irradiated onto the workload;

E_{inst} is the energy consumption of the installation.

This efficiency may either be stated for energy consumption of the complete installation or of the infrared emitters only.

A first step is the definition and calculation of the electric-to-infrared conversion ability

$$\eta_{\text{con-ab}} = \frac{\sum_i \eta_{i,\text{conv}} \cdot E_i}{\sum_i E_i} \tag{3}$$

where

$\eta_{\text{con-ab}}$ is the electric-to-infrared conversion ability of the installation;

$\eta_{i,\text{conv}}$ is the electric-to-infrared conversion efficiency of the *i*-th emitter;

E_i is the energy consumption under test conditions of the *i*-th emitter.

NOTE A test method for measuring the conversion efficiency of a single emitter will be given in future IEC 62798 [11].

This value does not describe the conversion efficiency, but the amount of infrared radiation generated by the infrared emitters inside the equipment under the assumption that all infrared emitters operate under single emitter test conditions, which can dramatically differ from operation conditions inside the installation. The electrical conversion efficiency of the equipment differs from the electrical conversion ability due to

- the difference in operating conditions of the single emitters at test condition for measuring the single emitter electrical conversion efficiency and the actual measurement conditions in the installation;
- re-absorption of radiation between the emitters;
- absorption of radiation by gases or fumes inside the equipment;

- absorption of radiation inside the equipment;
- loss of radiation from the equipment through openings;
- reflection of radiation from the workload;
- emission of radiation from other surfaces inside the equipment,

to name the most important effects. Thus the conversion efficiency can be larger or smaller than the conversion ability but tends to be smaller.

8.2.2 Calculation

The infrared conversion efficiency can be estimated from the data generated by a measurement as described in Annex C, if not only variation of irradiation is measured, but the irradiation itself is traced and effects otherwise caused by the workload are included in the measurement. Such measurements are usually beyond the ability of industry.

The electroheating efficiency as defined in 8.3 or in Annex A is usually applied (more accessible and with a smaller error margin).

8.3 Electroheating efficiency

The electroheating efficiency is calculated using

$$\eta_{\text{inst}} = E_{\text{min}} / E_{\text{inst}} \tag{4}$$

The efficiency shall be stated

- for the complete installation;
- for the infrared emitters only.

8.4 Power usage efficiency

The efficiency of power usage is defined as

$$\eta_{\text{power}} = \overline{P}_{\text{nop}} / P_{\text{max}} \tag{5}$$

where

η_{power}	is the efficiency of power usage;
$\overline{P}_{\text{nop}}$	is average power consumption during normal operation;
P_{max}	is the peak power consumption (see 7.6).

This is a measure for the capability or processing latitude of the installation. It indicates the possibilities for future process changes. It can also be interpreted as a measure of the design quality concerning especially the prediction of energy usage by the installation.

8.5 Energy consumption of the workload

The energy consumed for processing the workload per amount of workload is calculated using the energy consumption of the installation including start-up, holding, hot standby and shut-down energy consumption. It is the average total energy consumption of the installation divided by the amount of workload of intended quality made during time of measurement. It is

- energy consumption per piece, when the workload is countable, or
- energy consumption per unit mass, or

- energy consumption per unit area when the workload is a continuous sheet.

The calculation shall be made based on data from the test defined in 7.8. The reported value shall include the time base of the test.

Annex A
(normative)

Energy transfer efficiency

A.1 General

Efficiency of energy transfer from the installation to the workload is defined as

$$\eta_{\text{ete}} = \frac{m \cdot c_{\text{p}}(T) \cdot \Delta T + E_{\text{eva}} + R}{E_{\text{proc}}} \tag{A.1}$$

where

E_{proc} is the electric energy used by the installation for the process.

The measurement of temperature rise of the workload and the energy consumption by the installation shall be made according to Clauses 6 and 7.

The efficiency of energy transfer from the installation to the workload during processing is influenced by various particular features of the installation and the workload, such as the following:

- the emission spectrum of the emitter, depending on voltage and thus its operating conditions;
- the wavelength dependent absorption of the workload, which can change during the processing;
- the surface structure and the angular absorptivity of the workload, which can change during the processing;
- the relative orientation between workload and infrared emitter, which can change in continuously operating installations during the processing;
- the absorption by the atmosphere between emitter and workload, which can change during the processing due to evaporation of solvents;
- the convective transport of heat inside the installation and out of the installation – this includes intentional cooling of parts of the installation;
- losses through heat conduction from the workload or the heating chamber to the outside;
- windows, protective gratings, meshes, etc. between the emitter and workload;
- reflection or absorption of stray radiation by the installation.

Energy transfer efficiency therefore varies with test conditions and with the equipment, as considered by E_{proc} in Formula (6).

The provisions on test conditions according to 5.3 shall apply. Particular care shall be taken to monitor the test conditions and reduce effects that can influence the outcome of the test but are not kept constant or are not monitored.

A.2 Rationales for the measurement method

Whereas different infrared installations are intended for many different processes, only some of these processes allow the exact measurement of energy transferred into a workload. Many process parameters are hard to capture during processing:

a) heat energy stored in the workload can be calculated from the temperature rise of the workload, if its mass and the specific heat $c_{\mathrm{p}}(T)$ are known;

b) the evaporation energy can be estimated, if temperature, evaporated mass, specific heat $c_{\mathrm{p}}(T)$, and enthalpy of evaporation of the evaporating solvent ΔH_{eva} are known;

c) the energy needed for chemical reactions can be estimated if the mass of workload undergoing a chemical reaction is known, as well as the energy needed for the reaction.

Tests employing an IDW give reasonably exact results, if the IDW mimics the relevant physical properties of the workload to be processed and the parameters set for the installation mimic the relevant aspects of the process. A clear discrepancy between workload and IDW with respect to any of the above listed makes the test irrelevant. Some examples for discrepancies are:

- A workload heated only from one side shows a temperature gradient inside the material. This temperature gradient depends on the thermal conductivity of the material k and the surfaces where energy is absorbed in the material.
- If energy is absorbed only at the surface, thermal conduction determines the temperature dependency depending on depth inside the material. If radiation is absorbed also at some depth in the material, the combination of exponentially decaying penetration and thermal conductivity determines the temperature profile.
- Evaporation measurements are usually made by weighing the IDW before and after processing. If some solvent remains in the IDW after the intended process, evaporation will continue during cooling of the IDW.

A.3 Use of a test installation instead of a production installation

Measurements performed in an installation used for production have limitations, since:

- if the design of the installation has been finished, performing tests at this late stage states the ability of the installation, but does not provide necessary input for the design process;
- completed installations can usually not be changed in performance or layout;
- completed installations can usually not be used for any tests after commissioning – for example, due to safety issues.

However, experience and data can be used for the design of the next generation of this kind of installation.

Therefore the use of a test installation preliminary to starting the design of new installations is encouraged instead of making trials on a non-fitting old installation, if some requirements are met. To allow for meaningful tests and to meet the requirements of this standard a test installation shall offer

a) necessary means to mimic the process under consideration – for example, a conveyor belt of sufficient speed, installation of sufficient power;
b) a sufficient variation of different types of infrared emitters – varying independently in spectral output, infrared radiation power available, their geometrical form;
c) means to vary the conditions of the process space – for example, air flow, or thermal insulation;
d) sufficient switchgear to drive the test installation at necessary power and to vary the power of the infrared emitters sufficiently.

Test equipment that consists of a single emitter type, operating in one specific spectral range and offers one single technical solution for tests, is of less value to the user and insufficient for tests.

A.4 Preparation of the dummy workload

A.4.1 General

The IDW shall either be a prepared piece of the intended workload, or it shall be prepared using the following considerations, as far as possible:

- it shall have an identical surface material as the workload;
- it shall have an identical surface structure as the workload;
- if only a coating is applied to a IDW that mimics the surface of the workload, the thermal contact between coating and IDW shall be good over the complete surface;
- it shall be planar or of another simple shape;
- it shall be comparable in size to the intended workload;
- it shall have a high thermal conductivity, if applicable.

A.4.2 Preparations for temperature measurements

If the IDW is made of a material with high thermal conductivity, a single sensing point on the front or back side is sufficient.

If a temperature gradient inside the IDW is expected, the temperature shall be measured on the exposed side and on the back side of it.

If the thickness of the IDW allows and its thermal conductivity is low, thermocouples can be placed inside to assess the temperature gradient inside.

If temperatures are measured with thermocouples, they shall be fixed:

a) so that they have a low thermal resistivity contact to the IDW throughout the measurement time;
b) so that they do not influence the irradiation or the convection inside the installation;
c) on the irradiated side of the IDW only if a pyrometric measurement is not feasible.

Fixture of thermocouples may be done by:

- polyimide based tape;
- cement, or temperature resistant glue;
- metallic solder;
- heat bonding onto a thermoplastic material;
- placing the thermocouples in bored holes.

A.5 Tests for optimisation of the process

The goal of the test is:

- to characterise a specific installation to be used for a defined process, or
- to seek the optimum process parameters for a specific installation, or
- to prepare the design of a new installation by investigating relevant parameters – for example those listed in A.1.

To ensure that the test is relevant, the following applies:

a) All environmental parameters shall be documented throughout the measurement process – they are ambient temperature and humidity.

b) All settings of the test installation shall be documented.

c) If settings are varied during the measurements, a data logger shall be used for documentation.

d) The documentation of the test shall include the intended settings as well as the measured real values – for example of voltage, current or power.

e) Temperature measurement of the workload or dummy workload shall be documented using a data logger with sufficient time resolution for all measurement points.

f) All other changes of the installation during the test as well as other observations in connection with the test shall be documented.

A.6 Supporting calculations

For preparation of tests or for limiting the number of tests, numerical calculations may be used. Annex CC of IEC 60519-12:2013 states minimum requirements for good practice.

Annex B
(normative)

Homogeneity of the workload

B.1 General

One or more of the following parameters can be measured over the surface of the workload or the infrared dummy workload (IDW), to get to a description of the homogeneity of processing in the installation:

- the temperature;
- the residual content of a solvent on the workload, for an assessment of the evaporation of that solvent;
- the obtained extent of crosslinking of a polymer or lacquer;
- the amount of deposited substance or coating on the surface;
- the mass loss of the surface;
- the obtained extent of chemical reaction, which may include phase changes;
- the surface gloss;
- any other surface related parameters.

The measurements of these parameters involve quite different equipment and measurement methods. Some measurements can best be made using 2D methods, such as an infrared camera, others need complex pointwise analysis. The simplest available measurement methods are preferred, if possible and if a simple connection between effects is known – for example, if a chemical reaction depends strongly on temperature, a 2D measurement of temperature homogeneity is sufficient.

An IDW specifically prepared for the test may be used, see Annex A.

In normal operation, the intent is that the complete usable surface (or volume) of the workload reaches a certain value of at least one of these parameters without some parts of the workload being overheated or otherwise suffering a destructive process.

B.2 Measurement sensor positions

If a 2D or scanning device is not available for the measurements, but only point methods are possible, the following applies:

a) measurement positions shall include a sample of positions with highest exposure to the infrared emitters and of positions of lowest exposure during operation;
b) in batch type installations and for sheet-like materials this shall include the centre of the sheet and the corners of it;
c) in continuous type installations and for sheet-like materials this shall include the centre of the sheet and the edges of the sheet.

B.3 Temperature homogeneity

B.3.1 General

The measurement method for homogeneity of the temperature of the workload during the process or at the end of the process depends inter alia on the accessibility, the surface of the workload, the type of process and various temperatures. The following measurement methods are examples of best practice, but are by no means exhaustive.

NOTE The German series of standards VDE/VDI 3511 [19 – 26] contains information on best practice for most aspects of temperature measurements.

B.3.2 Thermocouples

A number of thermocouples can be fixed on the workload or the IDW.

All thermocouples shall be fixed by the same means and on the same side of the workload. Methods for fixing of thermocouples are given in A.4.2.

All thermocouples shall be of comparable length, same material and preferably of a single type from the same supplier.

The measured signal shall be recorded by a data logger or a pen recorder.

B.3.3 Infrared camera

The temperature of the surface of the workload or IDW can be measured using an infrared camera directly after the workload exits the treatment chamber.

The temperature homogeneity of the workload or IDW in the transport direction depends on the ejection velocity, the workload or IDW itself and environmental factors. These effects shall be estimated and included in the data interpretation and the report.

The following effects shall be considered, when using the measured data:

- any reflections from hot surfaces of the workload or IDW, as well as from other heating or lighting sources can cause extraneous signals;
- even slight variations of the surface of the workload or IDW can cause strong variations in emissivity and thus cause signal errors;
- surfaces having non-Lambertian scattering properties can cause incorrect variations of measured temperatures over the surface.

NOTE Basic concepts are given in ISO 10878 [17][3].

B.3.4 Temperature scanning

A remote point temperature measuring system scanning over the complete width of the workload measures the temperature over a line on the workload, as the workload moves. Some sources of error encountered with an infrared camera system are then avoided.

B.3.5 Temperature indication by colour change of paint or crayon marks

These materials (commonly called thermo-paint) irreversibly change colour during heat-up. The colour change depends on the combination of maximum temperature and to some degree on the time spent at maximum temperature. A good practice for use is:

- to dot one side of an IDW with a thermo-paint;
- the dotted side of the IDW is not facing the infrared emitters;
- the side of the IDW facing the infrared emitters is identical to the intended workload.

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[3] To be published.

It is usually necessary to calibrate the colours of the temperature sensitive colour indicating paint to process parameters used for the tests.

B.4 Other tests

B.4.1 Homogeneity of evaporation of a solvent

The spatial distribution of evaporation of water from paper or printed matter can be measured.

NOTE ISO 638 [12] or ISO 11093-3 [18] provide standardised methods.

Other tests may be agreed on between the manufacturer and user.

B.4.2 Homogeneity of the chemical reaction

Tests may be agreed on between the manufacturer and user.

B.4.3 Homogeneity of the deposited substance

Tests may be agreed on between the manufacturer and user.

B.4.4 Homogeneity of gloss

The spatial variation of gloss on paint or varnishes can be measured.

NOTE 1 ISO 2813 [13] provides standardised methods.

The spatial variation of gloss of paper can be measured.

NOTE 2 The ISO 8254 series [14 – 16] provides standardised methods.

Annex C
(informative)

Measurement of radiation distribution inside the installation

C.1 General

The methods as outlined in IEC 60519-12 are well suited to characterise the radiation inside an infrared electroheating installation during all stages of operation.

Major problems to be considered are:

- most or all of the measuring equipment needs more physical space than is available inside many installations;
- all common measuring equipment is not made for hot environments and is not able to survive long exposure to ambient temperatures above 50 °C;
- the measurement methods in IEC 60519-12:2013 are for point measurement only. To use them for the measurement of spatially resolved data a scanning operation is necessary for characterising the radiation or irradiation inside any installation;
- spectral scanning additionally needs time, so the measurement time can easily extend over days;
- the workload influences the radiation field inside the installation;
- the test equipment influences the radiation field inside the installation;
- spatial positions where radiation measurements are of most value are on the surface of the workload.

C.2 Calculating the radiation information

Annex CC of IEC 60519-12:2013 gives minimum requirements on ray tracing calculation of radiation for infrared electroheating installations and can be used for this purpose as well.

Verifications may be made by simpler experiments in only some parts of the installation.

C.3 Irradiation

A measurement of spectrally integrated irradiance can be made using the measurement device outlined in Annex FF of IEC 60519-12:2013, being placed inside a water cooled housing.

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