BS EN 60398:2015

BSI Standards Publication

Installations for electroheating and electromagnetic processing — General performance test methods

National foreword

This British Standard is the UK implementation of EN 60398:2015. It is identical to IEC 60398:2015. It supersedes BS EN 60398:1999 and PD IEC/TS 62796:2013 which are withdrawn.

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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Installations for electroheating and electromagnetic processing - General performance test methods (IEC 60398:2015)

Installations pour traitement électrothermique et électromagnétique - Méthodes générales d'essai de fonctionnement
(IEC 60398:2015)

Industrielle Elektrowärmeanlagen - Allgemeine Prüfverfahren
(IEC 60398:2015)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of document 27/949/FDIS, future edition 3 of IEC 60398, prepared by IEC/TC 27 "Industrial electroheating and electromagnetic processing" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60398:2015.

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)	2016-02-14
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2018-05-14

This document supersedes EN 60398:1999.

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The text of the International Standard IEC 60398:2015 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	Harmonized as EN 60038.
IEC 60519 (Series)	NOTE	Harmonized as EN 60519 (Series).
ISO 638:2008	NOTE	Harmonized as EN ISO 638:2008.
ISO 2813:2014	NOTE	Harmonized as EN ISO 2813:2014.
ISO 8254 (Series)	NOTE	Harmonized as EN ISO 8254 (Series).
ISO 12100:2010	NOTE	Harmonized as EN ISO 12100:2010.
ISO/IEC Guide 51	NOTE	Harmonized as ISO/IEC Guide 51.

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 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60519-1	-	Safety in installations for electroheating and electromagnetic processing -- Part 1: General requirements	EN 60519-1	-
ISO 50001	-		EN ISO 50001	2011
ISO/IEC 13273-1	-	Energy efficiency and renewable energy sources - Common international terminology - Part 1: Energy efficiency	-	-
ISO/IEC Guide 99	-	International vocabulary of metrology - Basic and general concepts and associated terms (VIM)	-	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INSTALLATIONS FOR ELECTROHEATING AND ELECTROMAGNETIC PROCESSING – GENERAL PERFORMANCE TEST METHODS

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60398 has been prepared by IEC technical committee 27: Industrial electroheating and electromagnetic processing.

This third edition cancels and replaces the second edition of IEC 60398 published in 1999 and the first edition of IEC TS 62796 published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- the title and scope of the standard have been expanded to include installations and equipment for electromagnetic processing of materials;
- the requirements have been restructured;

- tests concerning safety have been moved to IEC 60519-1[1];
- new tests and clauses addressing energy efficiency considerations have been added;
- a new annex placing this standard in the context of energy efficiency assessment as developed by ISO and IEC has been added;
- new annexes addressing visual display of data, estimation of energy use and energy recoverability of fluids have been added.

The text of this standard is based on the following documents:

FDIS	Report on voting
27/949/FDIS	27/952/RVD

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

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

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

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

1 Fifth edition to be published.

INTRODUCTION

Designing equipment for electroheating (EH) or for electromagnetic processing of materials (EPM) is a complex task. The manufacturer of the installation or equipment usually needs to fulfil the following requirements, which come from different sources and are quite often in this order of priorities:

a) to enable the intended process and make the installation to work properly;
b) to be cost effective during design and manufacturing;
c) to ensure that the equipment is safe to use in the sense of providing freedom from unacceptable risk of physical injury or damage to the health of the operator (safety in the narrower sense of ISO 12100:2010);
d) to prove that the equipment is cost effective to operate and uses sufficiently small amounts of energy, material and other resources;
e) to ensure that the equipment is safe to use in the sense of providing freedom from unacceptable risk or physical injury or damage to the health of people, or damage to property or the environment (adding other safety aims to c) and in the much broader definition of safety according to ISO/IEC Guide 51).

It is usually part of the proprietary knowledge of the manufacturer or user of the equipment, to make it cost effective or enabling intended processes with a benefit. IEC 60519-1:— assists with achieving safety in the ISO 12100:2010 sense. The focus of this standard is on basic requirements for measuring instrumentation and test methods concerned with energy and resource efficiency, performance of the intended process and assessing cost of ownership for installations and equipment for EH and EPM.

INSTALLATIONS FOR ELECTROHEATING AND ELECTROMAGNETIC PROCESSING – GENERAL PERFORMANCE TEST METHODS

1 Scope

This International Standard specifies the basic test procedures, conditions and methods for establishing the main performance parameters and the main operational characteristics of industrial installations and equipment intended for electroheating (EH) or electromagnetic processing of materials (EPM).

Measurements and tests that are solely used for the verification of safety requirements of equipment for EH or for EPM are outside the scope of this standard and are covered by the IEC 60519 series.

This standard is applicable for the commissioning, verification of design improvements or for energy related tasks including benchmarking with respect to energy use or energy efficiency, establishing of an energy baseline, and labelling. Some concepts from this standard can directly be used as key performance indicators.

Detailed tests for specific types of EH or EPM equipment and installations are beyond the scope of this standard and are provided in particular test standards for EH or EPM equipment. This standard is intended as general reference for all future test standards applicable to particular EH or EPM equipment or installations.

This standard includes the concept and material presented in IEC TS 62796 on energy efficiency dealing with the electrical and processing parts of the equipment, as well as the overall performance.

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:—[2], *Safety in installations for electroheating and electromagnetic processing – Part 1: General Requirements*

ISO/IEC 13273-1[3], *Energy efficiency and renewable energy sources – Common international terminology – Part 1: Energy Efficiency*

ISO/IEC Guide 99, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

ISO 50001:2011, *Energy management systems – Requirements with guidance for use*

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2 Fifth edition to be published.

3 To be published.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60519-1, ISO/IEC 13273-1, ISO 50001, ISO/IEC Guide 99, as well as the following apply.

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

3.1 General

3.1.1
energy using system
physical item or organization with defined system boundaries, using energy

Note 1 to entry: An energy using system can be a plant, a process, part of a process, a building, a part of a building, a machine, equipment, a product, etc.

[SOURCE: ISO/IEC 13273-1:—, 3.1.11, modified – Original cross-references have been deleted.]

3.1.2
system boundary
physical or site limits and/or organizational limits as defined by the organization for a stated purpose

EXAMPLE A process; a group of processes; a site; an entire organization; multiple sites under the control of an organization.

Note 1 to entry: The stated purpose could be for a management system, or for the boundaries of an energy assessment or for the boundaries of a specific measurement and verification activity.

[SOURCE: ISO/IEC 13273-1:—, 3.3.2, modified – "M&V" has been replaced by full term in Note 1 to entry.]

3.1.3
equipment category
group within a type of equipment, using the same principle for processing of the workload

Note 1 to entry: A category can be further divided with respect to the size or the capacity of equipment.

Note 2 to entry: An example of type is equipment for induction heating, and an example of category is such equipment for metal wire heating in a specified capacity interval, using medium frequency.

3.1.4
equipment 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.

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

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

3.1.6
processing range, <of EH or EPM installation>
range between an upper and a lower limit of set parameters between which the processed workload exhibits the intended workload quality

3.2 Energy efficiency

3.2.1
energy efficiency
ratio or other quantitative relationship between an output of performance, service, goods or energy, and an input of energy

EXAMPLE Conversion efficiency; energy required/energy used; output/input; theoretical energy used to operate/energy used to operate.

Note 1 to entry: Both input and output need to be clearly specified in quantity and quality, and be measurable.

[SOURCE: ISO 50001:2011, 3.8]

3.2.2
energy intensity
quotient describing the total amount of energy necessary to generate a unit of output, activity, economic value, or service

EXAMPLE Gigajoule per euro of GDP (gross domestic product); Gigajoule per unit of turnover.

[SOURCE: ISO/IEC 13273-1:—, 3.1.16 modified – Original cross references have been deleted.]

3.2.3
specific energy consumption
quotient describing the total amount of energy necessary to generate a unit of output, activity, or service

EXAMPLE Gigajoule (GJ) per tonne of steel, annual kilowatt hour (kWh) per square metre (m^2), litres (l) of fuel per kilometre (km), etc.

[SOURCE: ISO/IEC 13273-1:—, 3.1.17 modified – Original cross references have been deleted.]

3.2.4
heating efficiency, <of EH or EPM equipment>
ratio of the usable enthalpy increase in the workload to the electric energy supplied to it during a cycle of batch operation or stationary operation

3.3 States and parts

3.3.1
cold start-up
process by which the equipment is energised into hot standby operation from the cold state

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.

3.3.2
holding power
electric power consumed for keeping the workload in the processing chamber or zone 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: Holding power is not applicable for all EH or EPM equipment.

3.3.3
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.

3.3.4
shut-down operation
process by which the installation is de-energised safely into the cold state

3.3.5
port, <entrance or exit>
opening in the processing chamber or enclosure through which the workload moves

3.3.6
means of access
structural feature of the EH or EPM installation which can be opened or removed without the use of a tool to provide access to the installation

3.4 Workload

3.4.1
intended workload
normal workload
object intended to be processed as specified in the manufacturer's documentation

Note 1 to entry: The intended workload includes any container, holder or other device necessary for the processing and which is directly or indirectly subjected to the output power.

3.4.2
dummy workload
artificial workload with known thermal properties, designed for accurate enthalpy increase measurements by absorbing the available output power

3.4.3
performance test workload
artificial or partially artificial workload designed for discrimination of processing results

Note 1 to entry: Examples of such results are relative slag content, relative or absolute areas or volumes of unsatisfactorily processed material.

4 Basic provisions for testing and test conditions

4.1 Aim of testing

This standard provides tests concerning

– the outcome of the process,
– service performance or intended workload quality,
– energy use of the system,
– other resource use.

In all cases, the definition of the system boundaries is mandated and shall be documented.

The specific outcome of the process, the expected workload quality and the minimum service performance after processing are usually defined by the manufacturer and user.

NOTE Details can be beyond the scope of this standard or even particular test standards for EH or EPM equipment.

This standard determines all general tests necessary to assess the energy use of the system, which provide basic data for

a) determining energy intensity or specific energy use as agreed on by the manufacturer and user,
b) energy efficiency related services like comparing, labelling or classification (see Annex A),
c) determining energy performance indicators (see Annex A) or
d) tests related to energy management according to ISO 50001.

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

4.2 Communication of test results

Data generated during the measurements or tests defined in this standard can be used for many different purposes or services. Some of these services come with their own defined minimum requirements for the amount and depth of documentation and their requirements on communication.

This standard provides minimum requirements for documentation with each single test enabling use and reuse of data for different purposes. Only well-documented data is trustworthy and enables comparison in time or between different installations.

Annex B provides information on how data can be visualised.

4.3 Boundaries of the energy using system for testing

4.3.1 General considerations

The following basic rules apply:

– All energy uses being part of electric energy generation or transport to the installation are excluded.
– All energy uses being part of the installation or being necessary for the intended process of the installation are included.

The following energy uses of the intended process shall be considered:

a) Energy of compression or decompression of steam, air or any other gas shall be included in the calculations of used and lost energy.
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.
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 category not having this feature. Thermal energy used outside the process shall not be included in reporting (see Annex D).

4.3.2 Batch type installations

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

Normal operation includes a processing phase in the operation cycle and can also include one or more of the following sub-processes in this cycle:

– closing and opening of means of access;
– pressurising of the processing chamber;
– movement or transport of the workload, this includes for example rotation or wobbling movement during operation;
– holding the workload at a specified temperature for a specified time;
– introducing reactive or protective gases into the processing chamber, including deposition processes;
– free or forced cooling of the workload, for example, if cooling is necessary to avoid damage or boiling 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 a processing chamber or position; such equipment is a part of the installation and its energy use is included;
b) an exit port position where the workload is placed after normal operation for removal, or the equipment, which moves the workload out of a processing chamber or position; such equipment is a part of the installation and its energy use is included;
c) the energy use of all equipment in between, including for example all switchgear, pumps, and cooling means necessary for the processing.

NOTE In equipment utilising non-atmospheric pressure or other atmospheres than air, the boundary between the EH or EPM installation and any other installation is typically a valve; a load lock – consisting of two valves and used for the transfer of workload between different atmospheres – will usually be part of the EH or EPM installation.

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

4.3.3 Continuous type installations

Continuous type installations are characterised by a continuous or semi-continuous processing. The workload is conveyed through the processing region of the installation, which can be a processing chamber of the installation during normal operation. The processing occurs 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. Most installations go into standby operation when no workload is conveyed; this can be a hot standby for many thermal processes.

The normal operation includes a processing phase and can include one or more of the following sub-processes, which occur at different and typically 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 sub-processes shall be included only if it is necessary to cool or depressurise the workload in an integral part of the installation. The boundary of the installation is then 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 installation.

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.

4.4 General requirements for testing

The relevant safety requirements and the manufacturer's instructions shall be observed during all tests, to ensure safety.

The characteristics and parameters defined in Clause 8 shall be tested in the hot state of an EH or EPM installation

– during commissioning,
– when the installation is ready for normal operation,
– at regular intervals as specified by the manufacturer,
– following maintenance or
– after modifications.

The operator responsible for performing the measurements or tests shall be sufficiently trained to make accurate tests and have sufficient time and resources at hand to perform measurements and tests as intended and indicated in this standard.

4.5 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.

4.6 Environmental conditions during tests

All tests shall be performed

– under standardised environmental conditions, at ambient temperature in the range between 5 °C and 40 °C, relative air humidity of less than 95 %, at less than 1 000 m altitude above the sea level, or
– at the place of use of the installation under the available and specified environmental conditions there.

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

a) temperature and humidity in the air inlet region to the processing chamber, if relevant;
b) temperature and humidity of cooling air drawn into the installation;
c) exhaust air temperature and humidity, if relevant for the energy balance calculations;
d) temperature of the workload when entering the installation;
e) moisture or solvent content of the workload when entering the installation, if applicable.

4.7 Supply voltage

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

NOTE The rated supply voltage range is specified by agreement between the manufacturer and user. A common range is a deviation not exceeding ± 10 % from nominal, as this is the range defined by IEC 60038.

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

5 Comparing equipment or installations

Benchmarking or labelling are services intending or allowing direct comparison between equipment. The same holds for the evaluation of different equipment categories for a specific process. The following differences between equipment can lead to differences in test results especially concerning specific energy use:

a) details of the process (e.g. processing frequency or mode of energy transfer to the workload),
b) type of process (batch or continuous),
c) equipment capacity especially in identical equipment category,
d) workload size or mass,
e) details of the equipment (e.g. size),
f) environment of the installation (e.g. average temperature and humidity, their fluctuations or height above sea level),
g) form of supply (from the electrical grid or on-site power generation) and secure delivery of electric energy (fluctuations of the input voltage, waveform) – 8.10 provides a test for the dependence of processing on supply voltage.

All relevant details as listed above or other applicable issues influencing comparison shall be part of any test documentation.

Comparison is useful when only some aspects are varied and others are kept constant. In case of comparison between equipment of a single category or between equipment categories, it is therefore recommended that identical workloads are used.

The manufacturer usually allows for some variation in workloads and settings so that comparative tests can be made with identical workloads, chosen within the manufacturers' specification limits for normal operation.

The specification of the workload used for the tests shall be part of the test report.

The heating of containers, holders or other devices in relation to that of the workload actually being processed can vary within an equipment category. If this is the case, the enthalpy increase of the workload including and excluding container, holder or other device necessary for the processing shall be separated during the test and adequately reported.

6 Measurements and workloads

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 depend 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 Frequency measurement

The frequency range of equipment covered by this standard is spanning from 0 Hz to the frequency of optical radiation (up to 30 PHz). As a general rule the accuracy of any frequency (or wavelength) measurement shall be sufficient to securely distinguish relevant differences. Refer to particular test standards for details. Measurement accuracy estimations shall be included in the test report.

6.4 Measurement of electric data

6.4.1 Supply voltage

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

6.4.2 Voltage, current, electrical power and resistance

The accuracy of equipment for voltage, current, power and resistance measurements in the mains frequency and lower range shall be of class 1.0, unless otherwise specified in a specific test. All equipment for energy measurements shall be of class 2.0 or better, unless otherwise specified in a specific test.

The measuring equipment for voltage and for a.c. current circuits shall be able to show true RMS independently of the waveform.

Equipment for resistance measurement shall use a four point probe, if applicable; the used probe type shall be part of the test report.

6.4.3 Measurement positions

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

a) at the supply inlet of the installation.
b) at the power outlet of the switchgear or the voltage or current sources connected to the processing equipment or feeding the converter to the processing frequency.
c) at the respective power outlet of the switchgear connected to any auxiliary equipment, if relevant.

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.

6.5 Temperature measurement

6.5.1 General

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

The relative measurement error for all temperature measurements in compliance with this standard shall not exceed 5 % stated in °C of the measured value, for temperatures above 20 °C. Measurement accuracy estimations shall be included in the test report.

NOTE The German VDI/VDE 3511 series of standards gives information on best practice for temperature measurement in industry.

6.5.2 Contact thermocouples

Contact thermocouples are simple to use and reliable and provide sufficiently accurate results

- if an intimate and non-detachable contact to a surface of an object is achieved, and
- the object having a sufficient high mass and good thermal conduction to the thermocouple is applied and checked.

They cannot, however normally be used in alternating magnetic, high frequency and microwave fields, so other methods such as with temperature sensitive paints and fiberoptic sensors shall then be used.

If temperatures are measured with thermocouples, they shall be fixed in a way

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

Fixing thermocouples can be done through

- polyimide based tape up to 400 °C;
- cement, or temperature resistant glue;
- metallic solder;
- heat bonding onto a thermoplastic material;
- placing the thermocouples in bored holes.

6.5.3 Thermographic methods

Pyrometers and infrared cameras, summarised as thermographic methods, may be used

- for all surfaces at elevated temperature,
- providing the emissivity of the surface is well known,
- and the surface is considered as Lambertian – i.e. following a cosine law of angular emissivity,
- and when the wavelength range is transmitted by any tube or window material protecting the source and being in the path of light between source and equipment.

The used value of the emissivity, the measurement wavelength and the presumed error of the emissivity shall be included in all measurement reports.

6.5.4 Colour change of paint or crayon marks

Specific paints or crayons (called thermo-paints) irreversibly change colour during heat-up. The colour change depends on the combination of maximum temperature and the time spent at the maximum temperature. A good practice for use is

- to dot one side of the workload with a thermo-paint;
- the dotted side of the workload is not exposed to intense optical radiation or other effects that can lead to overheating or decomposition of it.

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

6.6 Measurement of pressure, humidity or composition of fluids

The following data can affect tests specified in this standard:

– actual environmental pressure,
– actual environmental humidity,
– pressure, humidity or gas composition inside the processing equipment.

The kind of equipment used for the measurement depends on the temperature range and the accessibility.

Pressure, humidity or fluid composition shall be measured if a variation affects the test. The relative measurement error for these measurements shall be sufficiently small, to discriminate relevant influences. Measurement accuracy estimations shall be included in the test report.

6.7 Workload

6.7.1 General

With many processes, the end result is not directly related to an overall enthalpy increase of an actual workload. Depending on the intended process and the measured effect, different kinds of workloads are used:

– the intended workload,
– a dummy workload or
– a performance test workload.

The methodology for measuring enthalpy increase shall be clearly specified in the test report.

There are cases where the use of dummy workloads for enthalpy increase measurement are not meaningful or cannot be carried out. Examples are surface deposition, seam annealing and laser cutting processes, where the evenness of processing is more important than the overall enthalpy increase in the workload. Comparison within an equipment category can result in quite similar results using a dummy workload but in significant product quality differences in an intended workload. In these cases the intended workload can be the only realistic type of workload for comparative testing.

6.7.2 Enthalpy determination using a dummy workload

Dummy workloads may be used if the parties involved agree on this. They shall be designed to be simple and reliable to use and their use shall not introduce additional risks compared with the intended workload.

Dummy workload specifications and the methodology for measuring enthalpy increase shall be clearly specified in the test report.

The application of dummy workloads does typically not consider end product quality. Overall enthalpy increase is a relevant variable, but using normal workloads can cause problems with respect to reproducibility or enthalpy measurement accuracy.

Since the manufacturer does typically not specify the dummy workload or its use, safety precautions shall be observed by the party or parties carrying out the tests.

6.7.3 Use of a performance test workload

Since specifications of a performance test workload are typically not provided by the manufacturer, safety precautions shall be observed by the party or parties carrying out the tests.

Performance test workloads shall be used in cases where the result of the intended process is not simply an increase in enthalpy, but other effects. They can be used to investigate any significant performance differences between different equipment tested. Both performance test workloads and dummy workloads may be used, if deemed to be relevant.

The performance test workload specifications and test procedures as well as the parameters and criteria used for performance evaluation shall be stated in the test report.

6.7.4 Preparation of a performance test workload

The performance test workload shall either be a prepared piece of the intended workload, or it shall be prepared using the following considerations:

a) its surface shall mimic the intended surface properties of the workload;
b) especially if a coating is applied to the performance test workload that mimics the surface of the workload, the thermal contact between coating and the performance test workload shall be good over the complete surface;
c) it shall have a simple shape;
d) it shall be comparable in size, volume or weight to the intended workload as appropriate for the specific test;
e) it shall have a high thermal conductivity, if applicable.

If the performance test workload 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 performance test workload is expected, the temperature shall be measured at least on the exposed side and on the back side of it.

If the thickness of the performance test workload allows and its thermal conductivity is low, thermocouples or other suitable sensors can be placed inside to assess the temperature gradient inside.

7 Numerical modelling

In many cases, measurements are not possible due to lack of accessibility, being too complex, being too costly or measuring equipment not being available. In this case numerical calculations can be used instead. There exists a vast number of available methods depending on the actual problem to be tackled. Guidance on the use of specific methods is beyond the scope of this standard, but general minimum requirements for the performance of numerical tests can be given.

The accuracy of the calculation shall be comparable to achievable accuracy of measurements, if feasible. This defines the needed accuracy of the implemented geometrical setup and numerical effort like grid resolution or iterative cycles.

The use of calculated data instead of measurements shall be clearly stated. The documentation of the calculation shall include

a) the numerical method used;
b) the geometrical setup used;
c) all relevant modelling data;
d) a description of the models used relevant to the calculation;
e) the software and version used;
f) any set parameter of the software that influences the result;
g) a measure for accuracy of the result provided by the software, such as energy lost from the system or energy not ascertained in the system due to numerical effects;

h) the method used for verification of the accuracy of the used models and the calculation itself.

As a general rule, it shall be possible from the data stored, to implement the models again and to make the calculation again on another system or using different software.

8 Technical tests

8.1 Overview

The performance test methods can be grouped according to their focus:

– 8.2 through 8.7 provide basic information on energy consumption during different stages of the operation and life cycle;
– 8.8 and 8.9 provide more general information on the variation and amount of energy use;
– 8.10 and 8.11 concern the possible range of normal operation or intended processing and their dependence on actual supply voltage;
– 8.12 provides basic tests concerned with quality aspects of processed workloads.

The tests defined in 8.2 through 8.7 can be performed

– for the complete installation or for parts of an installation,
– the processing equipment only or
– the auxiliary equipment only.

In all cases the definition of the boundaries of the energy using system given in 4.3 applies and great care in using the boundaries shall be observed.

8.2 Energy consumption and time for cold start-up

The measurement of time and energy consumption of cold start-up of installations is carried out as follows:

a) The initial state is at ambient conditions as stated in 4.6.
b) The installation is operated without a workload, if applicable.
c) Any preheating of the processing 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.

In case the installation is intended to be heated up safely with workload only, this shall be applied.

8.3 Power consumption during hot standby operation

The hot standby power consumption measurements are carried out as follows:

a) The installation is operated without workload, if applicable.
b) Conditions of hot standby operation are maintained.
c) The power consumption is calculated from the total energy consumption measured over a sufficiently long time for averaging.

8.4 Power consumption during holding operation

In certain types of installations a holding feature is needed to equalise the workload temperature before or after the heating part of the processing.

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

The measurement of power consumption during holding operation with workload shall be carried out if the following applies:

a) holding is part of normal operation;
b) normal operation is with a preheated workload;
c) the temperature of the workload is kept constant, using particular control settings for this purpose.

The total energy consumption during holding and the holding time are measured over a sufficiently long time allowing for averaging.

8.5 Energy consumption and time for shut-down operation

The time and energy consumption measurement during the shut-down of installations with which this is needed and significant is carried out from hot standby as specified by the manufacturer. The shut-down period ends when the power supply to the installation can be safely disconnected.

8.6 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.

8.7 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 complete cycle; this may be measured and averaged over a defined number of cycles, which shall then include typical hot stand-by and holding periods. The number of cycles and variation of energy consumption shall be recorded in the measurement report.
b) The energy of a continuously operating installation during processing of a defined amount of workload, during which no stand-by or holding operations occur and where the installation has reached a stationary state.
c) The energy consumption of the installation over a complete production cycle – for example, during a workday, one week or a complete year.

8.8 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 period of overall use 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:

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

The internal electric conversion and switchgear parts of the installation are designed for accepting specified peak power consumption. It defines the rated power used in the design and dimensioning of the overall electric system and components 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/in a batch type installation;
– during other modes of operation.

The time over which the peak power occurs is of importance for energy pricing by metering and other measures by the utility. Since this varies between utilities and industries, specifics have to be agreed upon for each equipment or plant.

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.

8.9 Equipment capacity

The equipment capacity or 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 started;
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, area per time, or length 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.

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

8.10 Performance dependence on supply voltage

The actual supply voltage or its variation can influence the performance of the installation. For example, Joule-effect heating means can operate directly or via fixed transformers on line voltage. 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 processing equipment with their applied working voltage depends on the category and specific technical details. This data may often be supplied by the manufacturer of the equipment. Thus the variation of power consumption with actual applied working voltage shall

– either be calculated using this data,

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

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

The actual supply voltage affects the results of all other tests and it shall be part of the test report, see 6.4.1.

8.11 Processing range of intended operation

The processing conditions inside an installation can vary and thus a variation of the workload quality over the surface or volume of the workload can ensue. 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 receives the lowest amount of energy 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 receives the highest amount of energy is showing signs of undergoing a destructive or an unwanted process – or the upper intended limit of power setting is reached. This is the upper limit.

The range of intended use defined by the manufacturer shall not be exceeded.

8.12 Properties of the processed workload surface

8.12.1 General

This 8.12 addresses mainly processes where the aim of the normal operation is to reach a specific state or specific properties of the surface of the workload. Testing the homogeneity of processing over the surface of the workload is typically a complex issue. Test methods vary with the specific property change which is the essential aim of the process performed in the installation.

One or more of the following parameters can be measured over surfaces of workloads and thus provide information on the quality or homogeneity of processing in the installation:

a) the temperature;
b) the residual content of a solvent on the workload, for an assessment of the evaporation of that solvent;
c) the obtained extent of crosslinking of a polymer or lacquer;
d) the amount of deposited substance or coating on the surface;
e) the mass loss of the surface;
f) the obtained extent of chemical reaction, which may include phase changes;
g) the surface gloss;
h) 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 analysis for each single position. 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.

A dummy workload specifically prepared for a test may be used (see 6.7.4).

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

8.12.2 Measurement sensor positions

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

a) measurement positions shall include a sample of positions with highest exposure to energy transfer 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.

8.12.3 Temperature homogeneity

The measurement method for homogeneity of the temperature of the workload during the process or at its end 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.

Using and especially fixing thermocouples on a (dummy) workload is defined in 6.5.2.

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

The temperature homogeneity of the workload in the transport direction depends on the ejection velocity, the workload 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:

a) any reflections from hot surfaces of the workload, as well as from other heating or lighting sources can cause extraneous signals;

b) even slight variations of the surface of the workload can cause strong variations in emissivity and thus cause signal errors;

c) surfaces having non-Lambertian scattering properties can cause incorrect variations of measured temperatures over the surface.

NOTE Basic concepts are given in ISO 10878.

A remote point temperature measuring system scanning over the complete width of the workload measures the temperature as the workload is transported. Some sources of error encountered with an infrared camera system are then avoided.

8.12.4 Homogeneity of evaporation of a solvent

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

NOTE ISO 638 or ISO 11093-3 provide standardised methods.

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

8.12.5 Homogeneity of gloss

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

NOTE 1 ISO 2813 provides standardised methods.

The spatial variation of gloss of paper can be measured.

NOTE 2 The ISO 8254 series provides standardised methods.

8.12.6 Other properties

For testing other workload properties like

– estimating the homogeneity of a chemical reaction or
– measuring the homogeneity of the deposition of a substance,

test methods may be agreed on between the manufacturer and user.

9 Efficiency of the installation

9.1 General

Many different energy performance indicators are conceivable, describing energy intensity or specific energy consumption of an installation or of equipment. The following 9.2 to 9.5 provide some basic indicators and can be used as guidance for the development of other indicators.

The theoretical minimum specific energy consumption of the workload undergoing the intended process is discussed in Annex C.

Very often the relevant energy intensity is not to be based on the electroheating efficiency or efficiency derived from the recoverable heat of the workload after the process. This is for example the case for intended processes like phase transitions, mixing, drying or hardening.

The recovery of otherwise lost energy is often beyond the boundaries as defined in 4.3; measures are beyond the scope of this standard, Annex D nonetheless provides some basic concepts.

9.2 Specific 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. This 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

a) energy consumption per piece, when the workload is countable, or
b) energy consumption per unit mass, or
c) energy consumption per unit area when the workload is a continuous sheet.

The calculation shall be made based on data from the applicable tests defined in 8.2 through 8.9. The reported value shall include the time base of the test.

9.3 Heating efficiency of EH or EPM equipment

The heating efficiency is calculated using the following formula:

$$\eta_{\text{inst}} = E_{\text{min}} / E_{\text{inst}} \quad (1)$$

where

η_{inst} is the heating efficiency;

E_{min} is the theoretical minimum specific energy consumption as defined in Annex C the minimum theoretically needed energy;

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

9.4 Supply power usage efficiency

The efficiency of power usage is defined as

$$\eta_{power} = \overline{P}_{nop} / P_{max} \qquad (2)$$

where

η_{power} is the efficiency of supply power usage;

$\overline{P}_{nop}$ is average supply power consumption during normal operation;

P_{max} is the peak supply power consumption (see 8.8).

Formula (2) allows for expressing the capability or processing latitude of the installation. It indicates the possibility for future changes to processing speed or throughput if necessary. It can also be interpreted as a measure of the design quality concerning especially the prediction of energy usage in the installation.

9.5 Energy transfer efficiency

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 C.

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 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 heating means, which can change in continuously operating installations during the processing;
– the absorption of radiation in 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 from the installation to the outside;
– windows, protective gratings, meshes, etc. hindering energy transfer to the workload;
– reflection or absorption of stray radiation by the installation.

Energy transfer efficiency therefore varies with test conditions and with the equipment.

The provisions on test conditions according to 4.5 shall apply. Particular care shall be taken to monitor the test conditions and reduce effects that can influence the outcome of the test.

Whereas different categories of installations are intended for many different processes, only some of these processes allow the exact measurement of energy transferred to 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 $c_p(T)$ are known;
b) the evaporation energy can be estimated, if temperature, evaporated mass, specific heat, and enthalpy of evaporation of the evaporating solvent 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 the intended workload or a dummy workload can give reasonably exact results. A clear discrepancy between workload and dummy workload with respect to any of the above listed makes the test irrelevant. Some examples for discrepancies are:

– A workload processed only from one side usually shows a temperature gradient inside the material. This temperature gradient depends on the thermal conductivity of the material 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 heating energy is absorbed also at some depth in the material, the combination of (usually exponentially decaying) penetration and thermal conductivity determines the temperature profile.
– Evaporation measurements are usually made by weighing the workload before and after processing. If some solvent remains in the workload after the intended process, evaporation will continue during cooling of the workload and prior to weighting.

Annex A
(informative)

Energy efficiency assessment

A.1 Use of this standard for energy efficiency assessment

This standard covers concepts and actions related to energy performance assessment:

a) the boundaries of the system as defined in 4.3;
b) key performance indicators identified and discussed in Clause 4;
c) data collection, measurement and tests defined in Clauses 5 to 8.

This standard does not cover improvement of energy usage or performance, dealt with in ISO 50001 and relating standards; neither does it provide any content concerned with classification or labelling of products as this is usually in the responsibility of local authorities. On the other hand, this standard assists its user to perform the full plan-do-check-act cycle (PDCA) as defined in A.2 or ISO 50001, as it provides the framework and applicable definitions and requirements allowing for assessment as well as a comparison with other installations.

Providing benchmark data or the classification of installations according to efficiency is beyond the scope of this general standard, but can be part of particular test standards.

A.2 Plan-Do-Check-Act cycle approach

The concept of energy performance includes energy use, energy efficiency and specific energy consumption of an installation or equipment. The full cycle for energy performance assessment and improvement of any installation or equipment involves the following steps:

a) definition of the system boundaries to be assessed;
b) definition of the relevant energy performance indicators and of the necessary data;
c) collection of the data, for example through tests or literature;
d) calculation of the energy performance of the system based on the energy performance indicators and by use of benchmark and other data. This step provides data for classification or labelling if intended;
e) identification and evaluation of opportunities for improvement of the system;
f) selection, then planning, then implementation of improvements;
g) restart of the cycle, if applicable, begins with step c).

Steps c) through f) define a Plan-Do-Check-Act (PDCA) loop; this is for example the method defined in ISO 50001.

A.3 Comparison, classification, labelling

The specific energy consumption is just one relevant factor when either comparing equipment, or when classification or labelling of equipment is intended. A specific amount of thermal energy transferred into the workload is quite often not a criterion or measure for the success of a specific process (i.e. reaching intended workload quality); often it is in providing a specific service measured through other physical values. Examples are:

– amount of a product of a specific quality, like a specific steel, its grain structure and composition as well as homogeneity;

– glossiness, stickiness, ultraviolet light resistivity, hardness or wear resistivity of a coating on wood, paper, metal wire or metal sheet;
– transition efficiency of a solar cell, inter alia characterised by homogeneity of processing, meeting of process schedule and small scale chemical composition;
– visual appeal and tastiness of a cheese melted on a pizza.

Thus it can be mandated to use the energy efficiency with respect to the quality of a process or the specific energy consumption (per amount of workload deemed well processed) as relevant and the final measures for energy for comparison.

Appropriate comparison, classification or labelling is possible when test methods and conditions, boundaries of the system and output of the process are comparable.

A.4 Comparison with ISO 13579-1

A.4.1 General

ISO 13579-1 specifies a general methodology for measuring energy balance and calculating the efficiency of the process involving industrial furnaces and associated processing equipment as designed by furnace manufacturers. It includes statements on measurement methods, provides formulas for calculation and minimum requirements for an energy balance evaluation report. The overall definition of energy efficiency in ISO 13579-1 has a much smaller scope than the definition used in ISO 50001 or in this standard as only the recoverable heat in the workload is considered as measure.

A.4.2 Considered energy generation

ISO 13579-1 includes the conversion of fossil fuels into thermal or electric energy in its calculations. The basic energy unit used for assessment of efficiency is the enthalpy of the different fuels involved. Whereas fuels burned in the installation can be accounted for easily by the user, information on the fuel mix and efficiency of power plants used for the generation of energy by the suppliers can be unavailable to the user of the standard. Data on the full amount of fuel or energy employed in generating electric energy can be highly contested (as with nuclear fuel when including fossil fuel consumption of mining and manufacturing) or not available to the user or both.

This standard considers the electric energy as drawn from the grid as the basic energy unit. Any decisions of the user of an installation on the use of sustainable sources of electric energy are outside the scope of this standard.

A.4.3 Comparing results

A direct comparison of any results becomes possible only, if

– the identical definition of energy efficiency limited to recoverable heat in the workload is used,
– the system boundaries are identical and
– the tests are performed in a comparable manner or identical test data is used.

The second requirement includes the necessity to restrict the system considered by use of ISO 13579-1 to the installation itself and exclude the generation of electric energy.

As ISO 13579-1 is quite vague on test conditions and output of the process, we recommend using this standard for guidance if comparability of data is intended or necessary.

Annex B
(informative)

Visual display of energy efficiency related information

B.1 General

This Annex B discusses the graphical display of energy efficiency related information, as quite often efficiency information given as a single number is not sufficient to start assessment of possible measures to increase energy use. ISO 13579-1 provides some further material.

Such information is usually generated during commissioning or even later during normal operation over long time frame.

B.2 Sankey diagram of power balance

A Sankey diagram of power usage and balance is a simple and very powerful way to display energy use, energy losses and to illustrate major sources of loss.

To make a power balance diagram useful, all energy input is considered:

– the electrical energy at the connection of the installation to the mains,
– all non-electrical energy as fuel enthalpy starting from a storage on the premises of the plant.

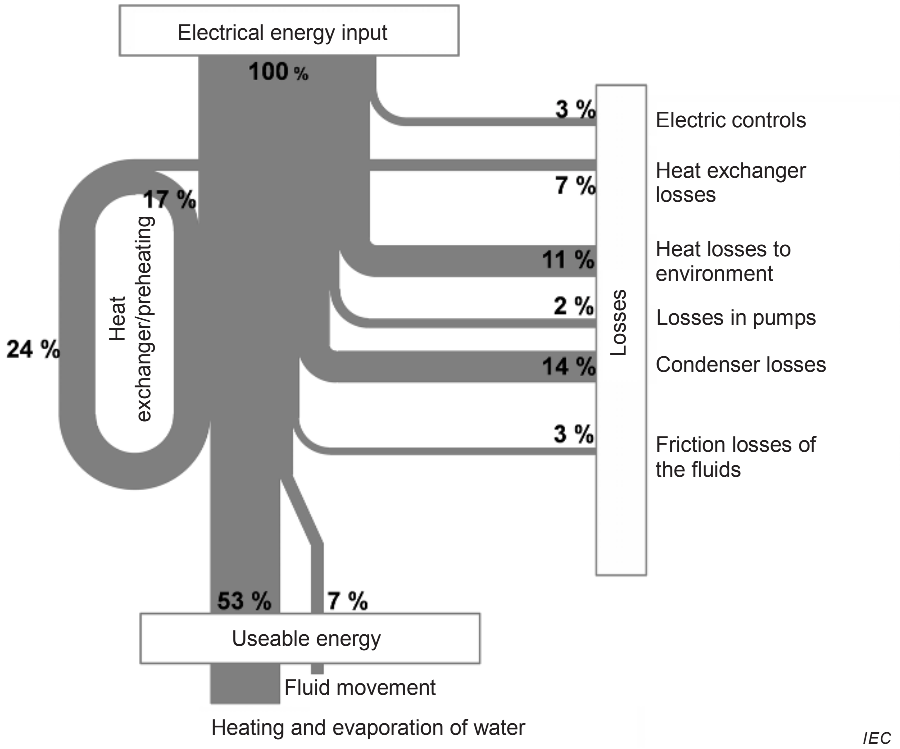
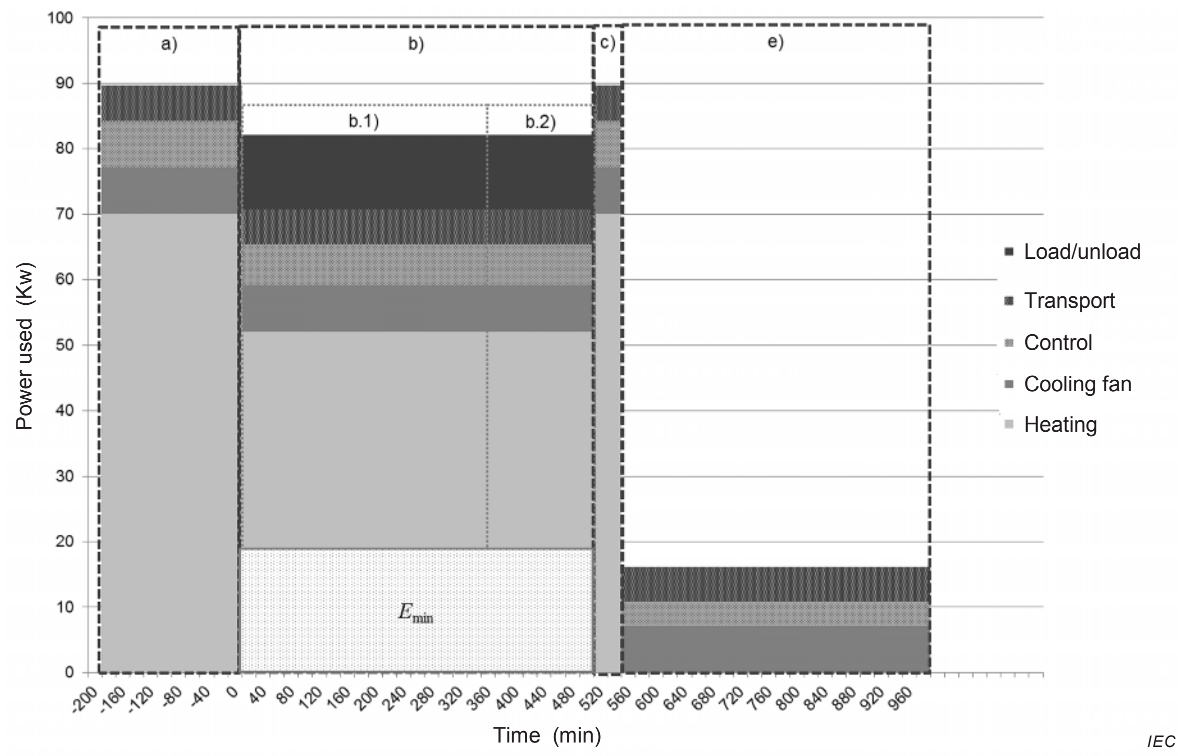


Figure B.1 – Example of a Sankey diagram

Figure B.1 provides an example for a drying process involving some recirculating fluid and a heat exchanger. The example is a drying process for foodstuff, where wet foodstuff is placed in circulating fluid, water is removed through heating, the dry foodstuff is removed through a cyclone and the water vapour is removed using a condenser.

B.3 Time resolved power usage diagram

If an installation is performing some different tasks for a process or energy use is not only dominated by the process itself, a Sankey diagram cannot reflect all relevant aspects. In this case a second approach, i.e. making use of a time resolved energy usage diagram is suggested; Figure B.2 provides an example.



Key

a) is time for start-up operation;

b) is normal operation with b.1) manufacturing intended workload quality and b.2) manufacturing either workload that needs to be reworked or scrap;

c) is time for cleaning operation;

d) maintenance activity, omitted in the figure;

e) is cooling down and shutting down operation and

E_{min} is the theoretical minimum specific energy consumption as defined in Annex C.

Figure B.2 – Example of a time-power diagram

The display of actual time resolved power usage data is definitively not creating maximum value. Instead, the following simplified presentation is recommended:

a) If available, average data for one cycle, if the installation cools down between cycles, one shift, if the installation is operating for some hours and cools down at the end of a workday, any other cycle that fits the operation pattern is used.

b) The different operations are displayed in a logical order on the time axis over the time they are performed on average: Start-up, holding, processing, cooling, shutting down and maintenance, to name some.

c) For each such operation the average energy use differentiated between relevant sub-systems is given in additive manner.

d) Processing time can further be differentiated between average time necessary for products in intended quality, for rework and for scrap.

e) The minimum energy use for the intended process can be indicated in the operation time.

A simple resistive heat treatment oven for continuous processing heating – here the application of a gold reflector on quartz tubes, is used as an example.

The oven needs 140 min for start-up operation; then the day's workload is processed on average over 500 min; of this time 40 min each day generate scrap and 100 min are spent for rework of parts which are reworkable after the first pass; a 40 min cleaning operation is necessary for burning off some residuals; cooling down safely needs many hours due to the refractories used as oven lining.

Figure B.2 displays the data as time resolved power usage diagram, the actual electrical energy efficiency and possible measures for improving energy efficiency become obvious from this.

Annex C
(informative)

Estimating energy use

C.1 General

The energy used for a specific process depends on the energy necessary for the intended enthalpy increase in the workload; the minimum required power further depends on the defined processing time. The theoretical minimum specific energy consumption can usually be calculated (Clause C.2). It is a relevant concept for energy efficiency analysis, as it provides a theoretical limit for any improvements and is a benchmark for the actual specific energy consumption of the installation (9.2).

The actual power necessary for a process and thus the minimum installed power in an installation depend on the following factors:

– the minimum theoretical power necessary for the process;
– the holding power necessary to balance losses from the workload,
– the energy transfer efficiency to the workload
– the energy conversion efficiency of the installation and
– other losses inside the installation.

The limiting cases for power determination can be

– processes where the workload approaches the maximum processing enthalpy incrementally over some time – in this case the holding power, compensating losses, define the necessary power;
– processes where the necessary processing power well exceeds the holding power.

The first case is quite typical for drying processes, the latter for melting.

C.2 Minimum energy consumption

The theoretical minimum specific energy consumption (per unit mass or unit area of the workload undergoing the intended process) is defined by the increase of the enthalpy between incoming workload (in) and outgoing workload (out).

$$E_{\text{min}} = E_{\text{out}} - E_{\text{in}} = \dot{m} \cdot \left(c_{\text{p}}(T) \cdot \Delta T + p \cdot \Delta v + \Delta h_{\text{pc}} + r\right) \quad \text{(C.1)}$$

where

E_{min} is the theoretical minimum specific energy consumption;

E_{out} is the energy of the workload leaving the process;

E_{in} is the energy of the workload entering the process;

m is the mass of the workload (assuming no strong change of workload mass);

$c_{\text{p}}(T)$ is the specific heat of the workload;

ΔT is the temperature change from ambient to maximum process temperature;

p is the ambient pressure (assuming that the process starts and ends at ambient);

Δv is the change of the specific volume of the workload (relevant only for gases);

Δh_{pc} is the specific enthalpy of phase change (such as melting or evaporation of solvents) during the process;

r is the specific energy needed for intended chemical reactions to occur.

Formula (C.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.

The theoretical minimum specific energy consumption of the workload undergoing the intended process depends on the following:

a) the actual temperature of the workload prior to the process (this temperature depends on the actual environmental conditions of storage of the workload);
b) the state of the workload prior to the process;
c) the minimum necessary temperature of the workload necessary to perform the intended process;
d) the minimum requirement of phase changes and chemical reactions of the workload to perform the intended process.

Often, it is necessary to consider spatially resolved data or at least average over the workload, as any state undergoing change during process is understood as the 2D distribution on the surface of the workload and the 3D field inside the workload depending on the value.

NOTE For example, temperature is a 3D distribution, whereas water content of lacquer is a 2D distribution when considering large parts or 3D when considering micro-structures.

C.3 Holding power

Any workload loses energy when it is hotter than its environment. Thus independent from the power rating necessary to heat up the workload, any equipment should at least be able to balance all heat losses from the workload to the environment that occur, in particular at the maximum processing temperature. These losses are caused by

a) cooling by the atmosphere through free convection;
b) cooling by processing gases including air through forced convection ;
c) all radiation losses from the workload ;
d) heat conduction losses from the workload, e.g. to transport equipment.

Thus,

$$P_{hold} = P_{conv} + P_{rad} + P_{cond} \tag{C.2}$$

where

P_{hold} is the minimum required power to balance all holding losses;

P_{conv} are the free and forced convective losses;

P_{rad} are all radiative losses;

P_{cond} are all conductive losses.

Convective losses can be neglected in vacuum applications.

C.4 Transfer losses and transfer efficiency

The efficiency of energy transfer to the workload is independent from the earlier considerations. It is governed by

a) conversion losses of energy from one form of energy to another,
b) transfer losses of energy from one device to the next,
c) transfer losses from geometric effects like fields not matching the geometry of the workload or radiation exposing not only the workload,
d) electromagnetic energy not absorbed but reflected or transmitted by the workload or absorbed during transfer from the source to the workload by other parts of the installation.

Typical examples are

– losses during frequency or voltage conversion, in transformers or in condensators,
– losses in the conversion of electric power to Joule heat,
– radiation or fields absorbed by the installation (walls, structural parts, windows, guards or screens, i.e. never reaching the workload),
– radiation or fields reflected or transmitted by the workload, absorbed by the installation and not recycled for heating use,
– magnetic energy not absorbed by the workload.

C.5 Examples

C.5.1 Tempering of TCO on glass substrate

In this case only, the thin transparent conductive oxide (TCO) layer undergoes heating up to tempering temperature at about 600 °C. Heating of the glass substrate is not a mandatory part of the process and is excluded from the calculation of the minimum energy.

C.5.2 Drying and hardening of lacquer

In this case, solvents are removed from the lacquer and then hardening starts. So heating of the complete layer of lacquer up to hardening temperature and diffusion and evaporation energy of solvent are minimum requirements.

Thus the minimum energy can be calculated either neglecting the workload or by including it.

Annex D
(informative)

Energy recoverability

In general, the media by which thermal energy waste or release from the equipment occurs and can be recovered are fluids. They can have a high energy content well prepared for recovery. Energy recoverability of such fluids is defined by four factors:

a) the specific heat capacity of the fluid which has extracted the energy;
b) the mass flow rate of this fluid;
c) the temperature of this fluid immediately after extraction and the difference to ambient temperature;
d) the temporal structure or availability of the energy.

The first factor is a measure of the simplicity of transport of energy and of prospective heat losses in the transport from the location of generation to that of recovery.

The second factor is a measure of the speed of heat transfer and the prospective usefulness of the thermal energy, as such.

The third factor is a measure of the prospective usefulness in a heat engine or for other purposes.

The fourth factor is related to the practical usefulness of the available recovered energy and any need for energy storage. The continuity and fluctuations of the output of the recoverable energy, continuous or batch processing are of particular importance.

The heat capacity per volume of the fluid is calculated from tabulated physical and thermal property specifications of the actual fluid.

NOTE NIST-JANAF tables, VDI Heat Atlas, as well as ISO 13579-1 give information on sources for heat capacity and other thermal data.

Calculations of thermal recovery are made if the manufacturer provides optional energy recovery means with the equipment and the introduction of such measures is assessed. The relevant measurements or evaluations are made with and without the recovery means. Any extra power consumption of these means is included.

A numerical estimate for heat recovery potential provides the thermal exergy of the fluid.

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