
Fire tests — Use of LED (light-emitting diode) as an alternative to white light for measuring smoke parameters

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Traditional white light bulbs including tungsten incandescent lamps, used until now for smoke density measurements in fire tests, are no longer available. Methods therefore need to be developed for their replacement with LED (light-emitting diode) light sources. This document is intended to provide guidance on replacing the light source in a smoke density measurement with an LED light source.

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Fire tests — Use of LED (light-emitting diode) as an alternative to white light for measuring smoke parameters

1 Scope

This document specifies methodologies for comparing the smoke density and the smoke production rate during fire tests measured by LED (light-emitting diode) with those measured by white light. These methodologies are intended for the identification of suitable LEDs which can be used as alternatives to white light sources.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

3.1

opacity of smoke

ratio of incident light intensity to transmitted light intensity through smoke, under specified conditions

3.2

optical density of smoke

measure of the attenuation of a light beam passing through smoke expressed as the logarithm to the base 10 of the opacity of smoke

3.3

transmittance

ratio of transmitted light intensity through smoke to incident light intensity, under specified conditions

3.4

smoke

visible part of fire effluent

3.5

smoke production

amount of smoke that is produced in a fire or fire test

3.6

smoke production rate

amount of smoke produced per unit of time in a fire or fire test

4 Symbols and units

For the purposes of this document, the symbols and units shown in [Table 1](#) apply.

Table 1 — Symbols and their designations and units

Symbol	Definition	Unit
D	degree of freedom	1
d	optical density	1
I_j	light transmission at time, t_j	1
I_{LED}	measurement of light transmission for LED	1
I_{WH}	measurement of light transmission for white light	1
N	normal distribution	1
n	sample size	-
S_{LED}	relative spectral distribution of a LED light	1
S_{Lamp}	relative spectral distribution of a white light	1
t_x	time at point x	s
t_{crit}	critical point (time)	s
V_d	variance	1
Δp	pressure difference on the measurement section	Pa
λ	wavelength	nm
σ	standard deviation	1

5 Principle

White light systems are currently used in several documents, for example, ISO 9239-1, ISO 9705-1, ISO 24473, IEC 61034-1, EN 13823 and EN 50399.

This document explains how the abovementioned standards can be amended based on the following comparisons in order to confirm that a given replacement light source is suitable:

- 1) comparison of light source spectra, as described in [Clause 8](#);
- 2) comparison of apparatus (ISO 9705-1, ISO 24473, ISO 9239-1 and EN 13823), as described in [Clause 9](#);

NOTE There are two different methods described in [Clause 9](#): method A (which is the preferred method) and method B.

- 3) comparison in an alternative experimental set-up specially designed for this purpose, as described in [Clause 11](#).

6 Overview of smoke measurement used in existing light extinction test methods

6.1 General

The white light smoke measurement system used in ISO 9239-1, ISO 9705-1 and ISO 24473, for example, consists of a light-emitting system and a receiver with a lens system in between. All parts are described in ISO 3182 and to some extent in each of the mentioned standards.

The light source is a gas-filled tungsten incandescent lamp. There are some small differences in colour temperature between the different apparatuses. A lens system is fitted to make a (nearly) parallel light beam with a diameter of 20 mm or 25 mm.

The detector has a spectral responsivity agreeing with the CIE photopic curve. It can be a silicon photo diode at least 7 mm² with a spectral filter set in front for adjusting the responsivity to fit the CIE photopic curve.

The receiver system is the same as prescribed in ISO 9239-1, for example.

6.2 Light-receiving system

All the light-receiving systems conform to ISO 3182, regardless of light source bulb in the light source system.

The light-receiving system shall consist of an achromatic system of lenses and a silicon photo-electric diode in front of which a spectral filter is located to accommodate the human eye luminosity function on viewing in daylight ([Figure A.1](#)).

6.3 Measuring device

The measuring device conforms to ISO 3182.

The measuring device is fitted with an amplifier that can be tuned to display the voltage of the photo-electric diode as a percentage of the initial value (transmission). The accuracy of the display is within $\pm 1,5$ % of the final value. There is a means for outputting the measured values for external recording.

In order to simplify evaluation of the measurements, the instrument may have a logarithmic output to allow the optical density to be recorded externally.

6.4 Neutral density filter comparison

The calibration procedure conforms to EN 50399.

The following steps are performed with the measuring equipment operating.

- a) Place a light-blocking insert into the filter holder and adjust to 0.
- b) Remove the light-blocking insert and adjust the signal from the light receiver to 100 %.
- c) Start the time measurement and record the signal from the light receiver for a period of two minutes.
- d) Introduce one of the following filters and record the corresponding signal for at least one minute where the filters to be used are with optical density, d , 0,04 - 0,1 - 0,3 - 0,5 - 0,8 - 1,0 and 2,0.
- e) Repeat step d) for the other filters.
- f) Stop the data acquisition and calculate the mean transmission values for all filters.

Each d -value calculated from the mean transmission value [$d = -\lg(I)$] should be within ± 5 % or $\pm 0,01$ of the theoretical d -value of the filter, whichever is the greater.

7 LED light sources

LED sources that are considered as replacement candidates for the white light system should provide a continuous light spectra. The illumination reaching the detector side should be powerful enough to have a similar signal output as measured with the white light source (i.e. the strength of the light from the LED falling on the detector is similar to the white light). The light source shall be stable within $\pm 0,5$ % including temperature, for short- and long-term duration. The power source shall be adapted to ensure this.

8 Comparison of spectra from different light sources

Various LEDs exist with different colour and spectral distributions. Considering the purpose of light attenuation for smoke density measurement, it is necessary to understand the spectral distribution of

the tested LED. [Figure 1](#) shows an example of spectral distribution of an LED (white) compared with that of white light.

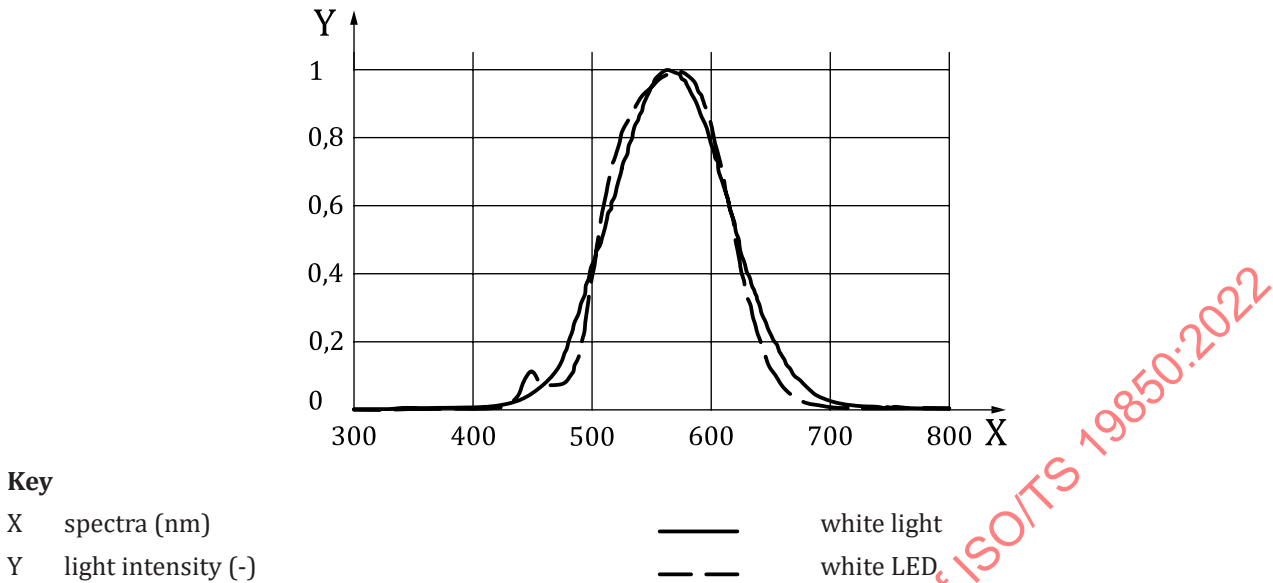


Figure 1 — Example of spectral distribution of white light and LED (white)

If the spectrum of the LED light is known as exemplified in [Figure 1](#) then the potential for the LED evaluated can be determined by comparing the spectra of the LED and the old white light system over the range of wavelengths (320 ~ 1 100 nm) to which the detector is sensitive. The comparison is conducted by multiplying the spectra with the sensitivity curve of the detector and then integrating over the wavelength range, as shown in [Formulae \(1\)](#) and [\(2\)](#):

$$\int_{320}^{1100} s_{LED} \times d\lambda \quad (1)$$

$$\int_{320}^{1100} s_{Lamp} \times d\lambda \quad (2)$$

The difference in the integral shall be less than 5 %, as expressed in [Formula \(3\)](#):

$$\left| \int_{320}^{1100} s_{LED} \times d\lambda - \int_{320}^{1100} s_{Lamp} \times d\lambda \right| / \int_{320}^{1100} s_{Lamp} \times d\lambda < 0,05 \quad (3)$$

For example, in case of [Figure 1](#), compared to the integral value of white light as standard, the integral value of white LED is 2,89 % less.

9 Method of measurement in each apparatus where the white light system is originally installed

9.1 General

In this clause, the method of comparing the transmission values of both the original white light and the new light source (LED) is described in relation to each standardized test method. As the smoke production rate and the smoke density are calculated based on the transmission values, the comparison procedures in this clause are primarily focused only on the light transmission.

There are two methods for installing the new light source (LED) to the duct: method A (the preferred method) and method B. In method A, both the new light source (LED) and the receiver are installed in the proximity of the original white light system. The advantage of this method of installing the new

light source (LED) is that it is possible to measure the transmission of two different light systems at the same time with the same smoke. On the other hand, the disadvantage is that it is necessary to make this new arrangement in the duct.

In method A the additional system should be placed a defined distance away from the original white light system. The distance shall be sufficient for avoiding any influence on the original white light system. A distance of one duct diameter is generally sufficient. This needs to be checked by turning on only one of the lights to see if it reaches the other detector. However, it is important to ensure that the additional system does not influence the flow profile or the measurements of the other parameters such as flow measurement and gas analysis. The additional system should also not be too close to bends in the duct or subject to other flow profile changes.

In method B, the original light source (white light) is replaced by the new light source (LED). The advantage of this method is that it is not necessary to make a new arrangement in the duct. On the other hand, the disadvantage is that it is impossible to measure the transmission of the two light systems at the same time. It is possible to remove this disadvantage by using repeatable test fire sources on each occasion. This means that the repeatability of smoke generation should be carefully considered in method B. Therefore, it is recommended to use method A wherever possible. If the situation does not always permit the additional installation of a new light source in the duct because of restrictions in the apparatus or laboratory environment, etc., then method B can be used as an alternative. In the case of ISO 9239-1, it is only possible to use method B.

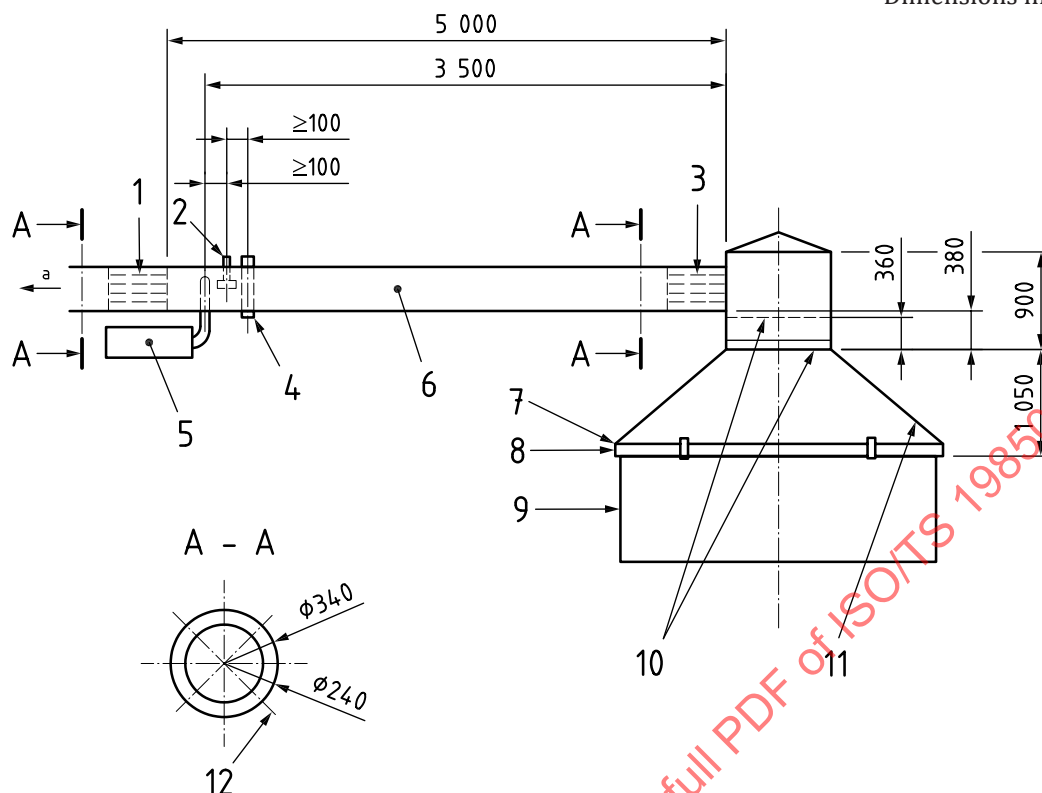
Information on suitable test fire sources is given in [Clause 10](#), and according to that information, three or more kinds of fire sources should be used for each test apparatus. For method A, two tests are performed with each fire source (six tests in total), while for method B, three tests are performed with each fire source and with each light source, resulting in eighteen tests in total.

9.2 Comparison between the original white light and the new LED in ISO 9705-1

9.2.1 General

In this example, both method A and method B could be applied. The exhaust system of ISO 9705-1 is shown in [Figure 2](#).

Dimensions in millimetres



Kev

A-A section of exhaust duct

- | | | | |
|---|-------------------------------|----|--|
| 1 | guide vanes | 8 | frame of steel profile (50 mm × 100 mm × 3,2 mm) |
| 2 | pitot tube | 9 | steel plates (1 000 mm × 3 000 mm) |
| 3 | guide vanes | 10 | steel plates (2 mm × 500 mm × 900 mm) |
| 4 | lamp, photocell system | 11 | hood (2 mm-thick steel plates) |
| 5 | gas analysis | 12 | four steel plates (395 mm × 400 mm) |
| 6 | exhaust duct (Ø 400 mm) | a | To exhaust gas cleaning. |
| 7 | opening (3 000 mm × 3 000 mm) | | |

Figure 2 — Exhaust system of ISO 9705-1

9.2.2 Method A

9.2.2.1 Installation of both the new light source (LED) and the receiver

Both the new light source (LED) and the receiver are installed in the proximity of the original white light system, which consists of the light source and the receiver. Both the new light source (LED) and the receiver should be located at a distance of one duct diameter from the position of original white light system. Both the LED and white light system need to be downstream of the gas analysis point.

9.2.2.2 Measurement of transmission of both the original white light and the new LED

The test fire source is burned under the hood for the ISO 9705-1 system, and transmission is measured for both the original white light system and the new LED system, at the same time (method A).

The position of the two light sources is exchanged, but the receivers are not moved, and the measurement is conducted again.

The comparison of the experimental results from the different light sources is conducted according to [Clause 12](#).

9.2.3 Method B

9.2.3.1 Measurement of transmission of the original white light

The test fire source is burned under the hood for the ISO 9705-1 system, and transmission of the original white light system is measured.

9.2.3.2 Replacing the original light source (white light) by the new light source (LED)

The original light source (white light) is replaced by the new light source (LED). The receiver remains in place.

9.2.3.3 Measurement of transmission of the new light source (LED)

The test fire source is burned under the hood for the ISO 9705-1 system, and transmission is measured with the new light source (LED).

The comparison of the experimental results from the different light sources is conducted according to [Clause 12](#).

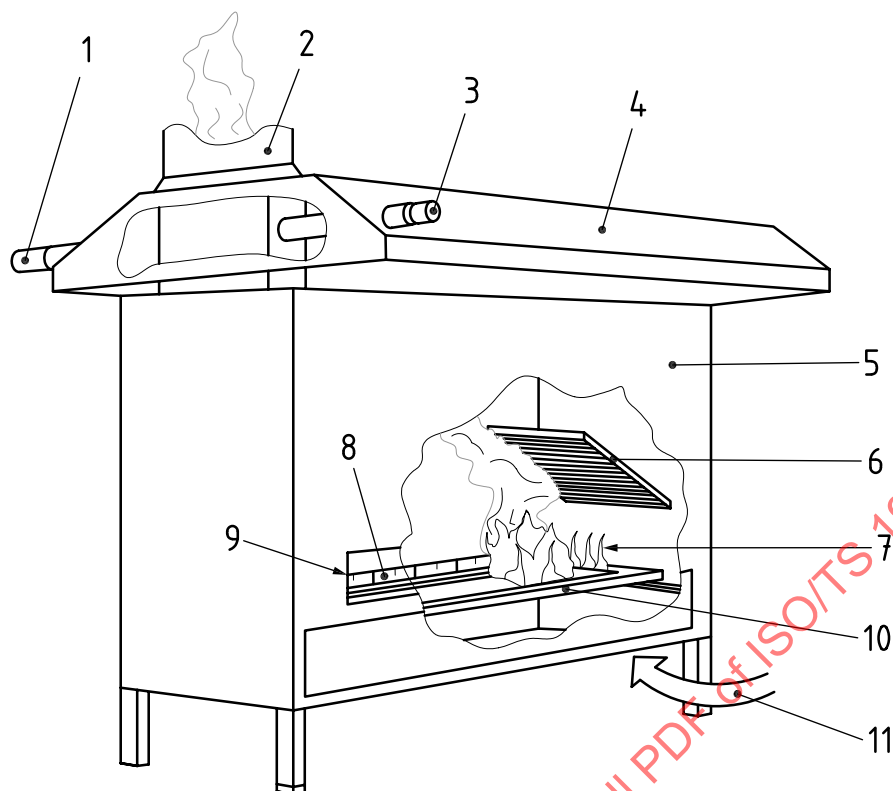
9.3 Comparison between the original white light and the new LED in ISO 24473

Regarding the measurement of smoke, ISO 24473 is technically almost identical to ISO 9705-1. Therefore, the same procedure as in [9.2](#) is applied here. Only the test fire source can be different, because the fire source is not fixed in ISO 24473. Information on the test fire source is found in [Clause 10](#).

9.4 Comparison between the original white light and the new LED in ISO 9239-1

9.4.1 General

In this example, there is only one method that can be applied: method B. The exhaust system of ISO 9239-1:2010 is shown in [Figure 3](#).



Key

- | | |
|---------------------------|---|
| 1 lamp | 7 pilot flames from line burner |
| 2 exhaust duct | 8 scale |
| 3 detector | 9 observation window |
| 4 exhaust hood | 10 specimen holder with specimen together on sliding platform |
| 5 test chamber | 11 air inlet all around specimen at bottom of chamber |
| 6 gas-fired radiant panel | |

Figure 3 — Exhaust system of ISO 9239-1:2010

9.4.2 Method B

9.4.2.1 Measurement of transmission of the original white light system

The test fire source is burned, and transmission of the original white light system is measured.

9.4.2.2 Replacing the original light source (white light) by the new light source (LED)

The original light source (white light) is replaced by the new light source (LED). The receiver remains in place.

9.4.2.3 Measurement of transmission of the new light source (LED)

The test fire source is burned, and transmission is measured with the new light source (LED).

The comparison of the experimental results from the different light sources is conducted according to [Clause 12](#).

9.5 Comparison between the original white light source and the new LED source in EN 13823

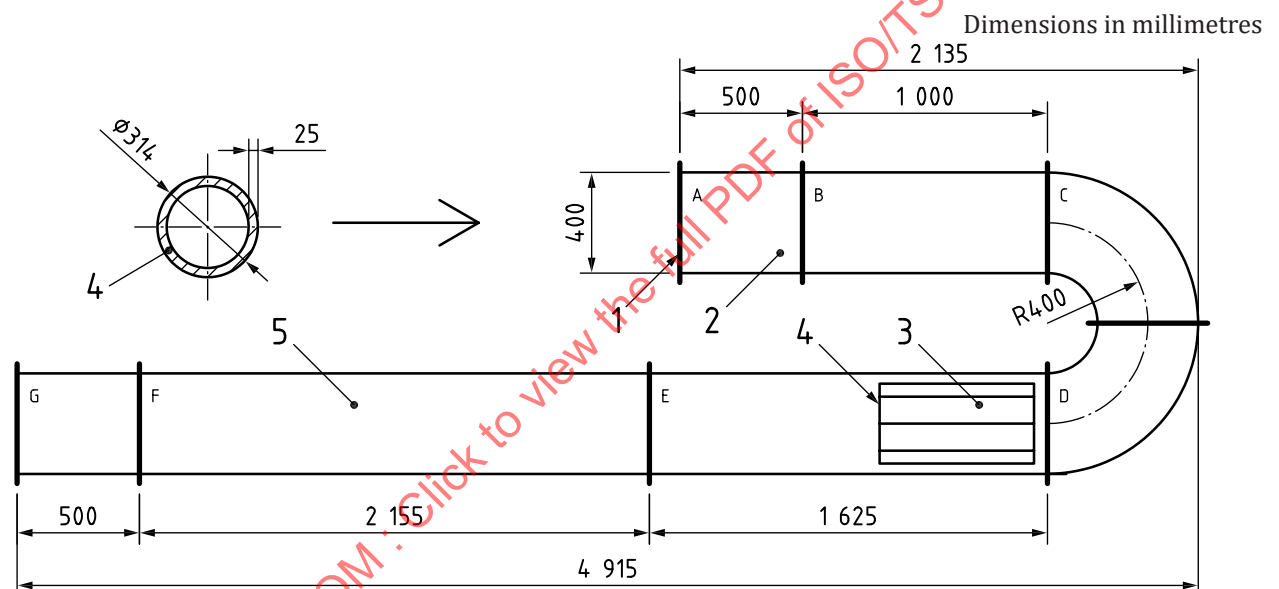
9.5.1 General

In this example, both method A and method B can be applied. The exhaust system of EN 13823 is shown in [Figure 4](#).

9.5.2 Method A

9.5.2.1 Installation of both the new light source (LED) and the receiver

Both the new light source (LED) and the receiver are installed in the proximity of the original white light system, which consists of the light source and the receiver. Both the new light source (LED) and the receiver should be located in the measuring section, location 5 according to [Figure 4](#), and at least 1 duct-diameter away from the original white light system.



Key

- | | |
|------------------------------------|---|
| 1 connection to collector and hood | 4 reduction ring (stainless steel/ $\varnothing 314$ /thickness 2 mm) |
| 2 temperature measurement | 5 measurement section (Δp , temperature, smoke, sample) |
| 3 guide vanes | |

Figure 4 — Exhaust system of EN 13823:2010

9.5.2.2 Measurement of transmission of both the original white light and the new LED

The test fire source is burned, and transmission is measured for both the original white light system and the new LED system, at the same time.

The position of the two light sources is exchanged, but the receivers are not moved, and the measurement is conducted again.

The comparison of the experimental results from the different light sources is conducted according to [Clause 12](#).

9.5.3 Method B

9.5.3.1 Measurement of transmission of the original white light system

The test fire source is burned, and transmission of the original white light system is measured.

9.5.3.2 Replacing the original light source (white light) by the new light source (LED)

The original light source (white light) is replaced by the new light source (LED). The receiver remains in place.

9.5.3.3 Measurement of transmission of the new light source (LED)

The test fire source is burned, and transmission is measured with the new light source (LED).

The comparison of the experimental results from the different light sources is conducted according to [Clause 12](#).

9.6 Comparison between the original white light source and the new LED source in IEC 61034-1

9.6.1 General

In this example, only method B shall be followed. The reason for this is that the white light system in IEC 61034-1 is not collimated. It is a diverging beam and is set to a diameter of 1,5 m at a 3 m distance. Therefore, if method A is taken, the required distance between the two light systems would result in different smoke conditions at the two systems. For this reason, method A is not suitable.

The exhaust system of IEC 61034-1 is shown in [Figure 5](#). Example results are given in [Annex A](#).

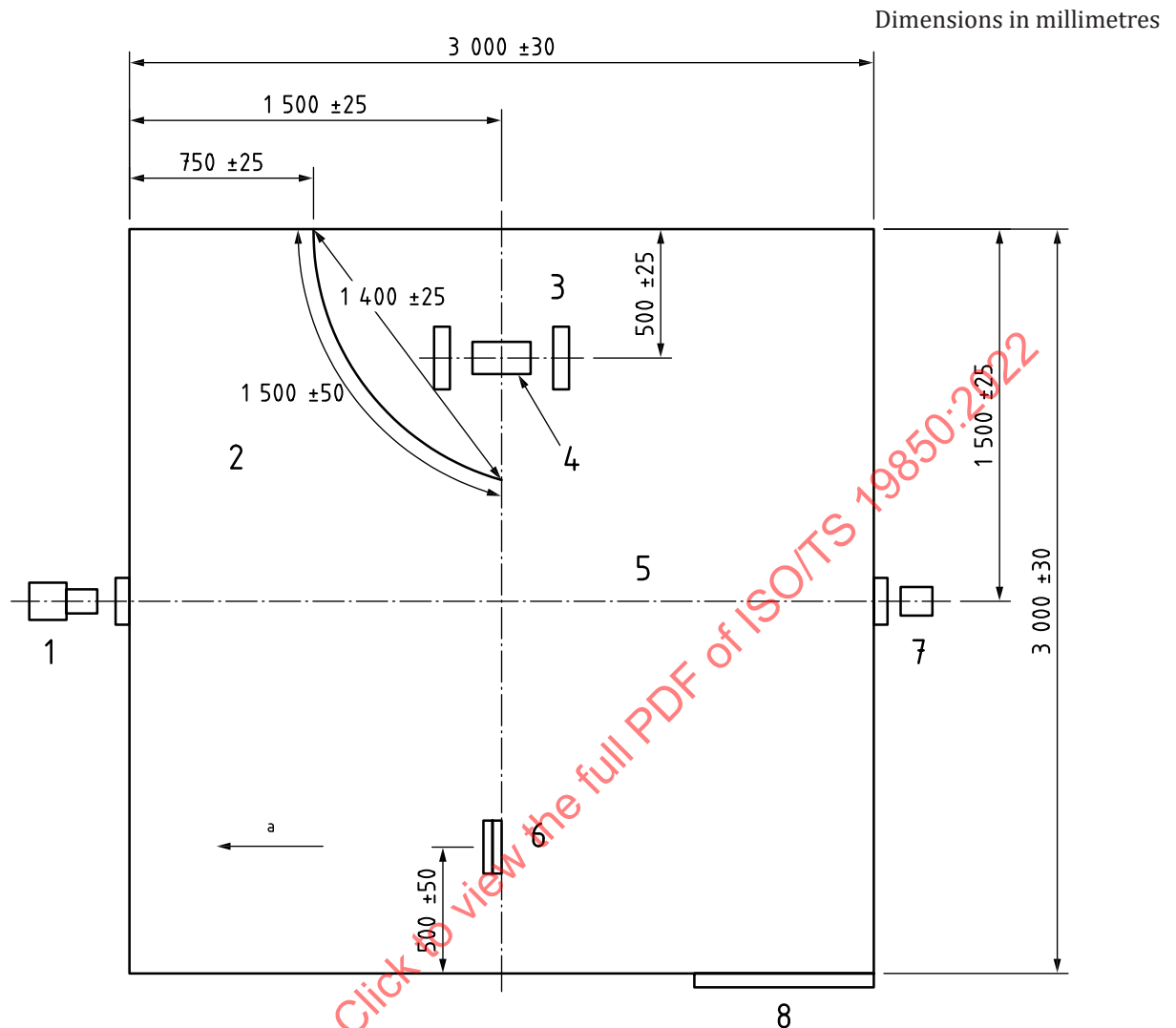


Figure 5 — Exhaust system of IEC 61034-1:2005

9.6.2 Method B

9.6.2.1 Measurement of transmission of the original white light system

The test fire source is burned, and transmission of the original white light system is measured.

9.6.2.2 Replacing the original light source (white light) by the new light source (LED)

The original light source (white light) is replaced by the new light source (LED). The receiver remains in place.

9.6.2.3 Measurement of transmission of the new light source (LED)

The test fire source is burned, and transmission using the new light source (LED) is measured.

The comparison of the experimental results from the different light sources is conducted according to [Clause 12](#).

10 Test fire sources

10.1 General

In order to make a proper comparison on measuring the smoke production rates between the different light systems, three or more kinds of fire sources should be used. The smoke generation rates should cover low, moderate and high smoke rates to cover the range expected during tests. The selection of the smoke production rates should consider the acceptance criteria where these are used in regulatory approvals.

In the case of method B, the tests need to be repeated at least three times for each of the fire sources and light source systems resulting in at least eighteen tests in total for two light sources.

For method B, the repeatability of the fire source is important, and the repeatability needs to be sufficiently good so that the evaluation criteria in [Clause 12](#) can be met.

In the following subclauses, the standards will be divided into four categories, and test fire sources will be introduced accordingly.

10.2 For standard tests in which a burner is used

In standards where a burner is used, one option can be to use this as a low fire source. However, it is important that the smoke production rate is high enough as could be expected in a test. In general, gas burners give too little smoke unless they are fed with gases such as acetylene, for example. Other options include liquid pools, as used for yearly calibration in EN 13823, for example.

Furthermore, in order to produce smoke with higher smoke production rates, simple combustible specimens can be installed in the test rig (such as wooden boards, PMMA boards, etc.) based on the experience of laboratory staff, using the same burners as prescribed in the original test standard. Three or more kinds of fire sources should be used for proper comparison between the different light systems.

10.3 For standard tests in which radiant heat is used

In those standards in which radiant heat sources are used, such as ISO 9239-1 (the radiant panel is used with pilot ignition), it is necessary to consider the specimens for generating the smoke. Simple combustible specimens (such as wooden boards, PMMA boards, etc.) could be one option, but also, other specimens can be chosen based on the experience of laboratory staff. In addition, other fire sources can be used that are not dependent on the radiating panel being used. Three or more kinds of fire sources should be used for proper comparison between the different light systems.

10.4 For standard tests in which liquid fuel is used

In those standards in which liquid fuel is used, such as IEC 61034-1, etc., it is one option to use liquid fuel as a test fire source. In order to produce the smoke with minimum smoke production rate, the procedure prescribed in the original standards even without specific test specimens installed in the test rig is followed.

Furthermore, in order to produce smoke with larger smoke production rates, simple combustible specimens can be installed in the test rig, such as cables, wooden boards, PMMA boards, etc. This should be based on the experience of laboratory staff, using the same liquids as prescribed in the original test

standard. Alternatively, in order to generate more smoke., the amount of the same liquid fuel could be increased without the presence of specimens, or different liquids could be burned

Three or more kinds of fire sources should be used for proper comparison between the different light systems.

10.5 For the standard tests in which the fire source is not prescribed

In those standards in which the fire source is not prescribed, such as ISO 24473, etc., it is necessary to first consider the fire source for the purpose of generating enough smoke for comparison based on the different light systems. A gas burner without a combustible specimen, a gas burner with a combustible specimen, some liquid fuel placed in a steel tray or a wooden crib could be used as a fire source. Three or more kinds of fire sources should be used for proper comparison between the different light systems. One option is that a selection of different liquid fuels burning in the same sized tray could be used as the fire source.

11 Alternative method

11.1 General

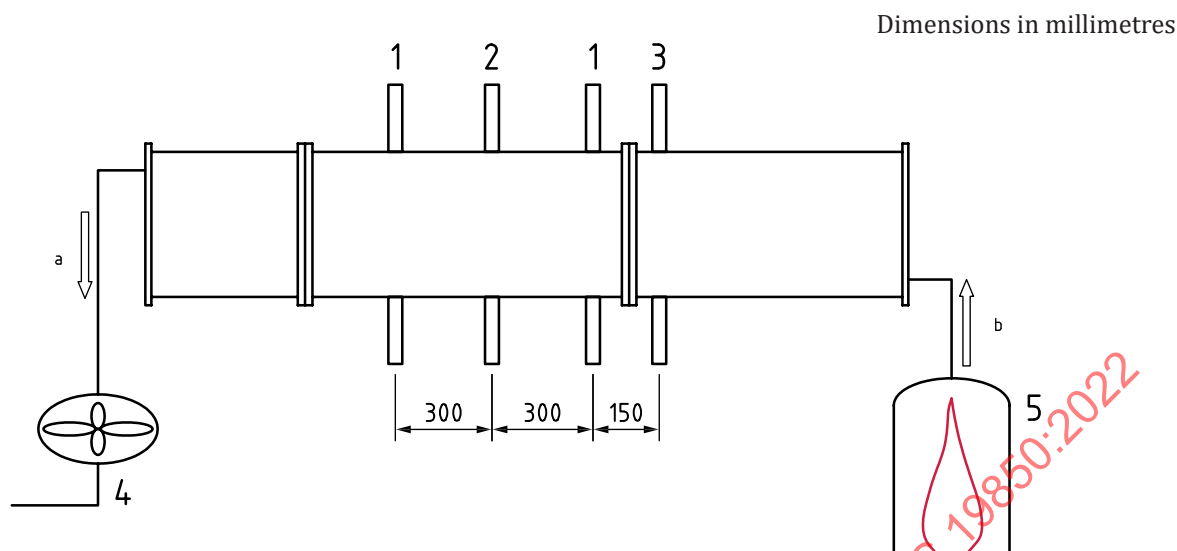
This clause describes an alternative method, in which smoke is generated by a smoke generator and flows into a duct of 400 mm diameter by accelerating an exhaust fan. Two different procedures are available, the static and dynamic method.

In the case of the static method, the fan is stopped after the duct is filled with smoke, and smoke density is measured by two or more light-measuring systems. These use the same light receivers but differ in light sources. White light shall be included as one of the light sources, as the smoke densities measured by a tested LED or other new light sources will be compared with those measured by white light. Then, by accelerating and stopping the exhaust fan again, ambient air will flow into the duct in order to decrease the smoke density. Smoke density will then be re-measured. This procedure shall be repeated for measuring smoke density at different (decreasing) levels of densities. After completion, the results of smoke measurement shall be compared to find whether a candidate light source is an acceptable alternative to white light as the replacement light source for smoke measurement.

For the case of dynamic measurement, instead of the fan being stopped, the smoke shall continue to flow inside the duct, and the smoke production rate measured by the LED light source is compared with the value measured by the white light source.

11.2 Overview of apparatus

The apparatus (see [Figure 6](#)) consists of a smoke generator, flexible hose, exhaust fan, duct, light source systems, light receiving systems, power supply unit and measuring device.

**Key**

- | | | | |
|---|---------------------------------------|---|---|
| 1 | white light | 5 | smoke generator |
| 2 | LED | a | Smoke incoming through flexible hose to duct. |
| 3 | laser | b | Smoke outgoing through flexible hose from duct. |
| 4 | exhaust fan, approximately 0,35 l/min | | |

Figure 6 — Duct apparatus for alternative method**11.3 Smoke generator**

The smoke generator (see [Figure 7](#)) consists of a fire source inside a plastic bag. For light, white smoke, the fire source can be a smoke canister or incense sticks. For dark smoke, ABS (acrylonitrile butadiene styrene) boards, or black PMMA boards can be used as the fire source.

Alternative smoke generators can be used, as long as they can generate and input enough smoke to the duct continuously. Furthermore, particular attention should be paid in order to avoid ignition of the plastic bag. An adequate means of extinguishing the specimen should be provided.



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Figure 7 — Example of smoke generator