TECHNICAL SPECIFICATION

ISO/TS 5658-1

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2006-10-01

Reaction to fire tests — Spread of flame —

Part 1: **Guidance on flame spread**

Essais de réaction au feu — Propagation du feu —

Partie 1: Lignes directrices sur la propagation de la flamme

Reference number
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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 5658-1 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

This first edition of ISO/TS 5658-1 cancels and replaces ISO/TR 5658-1:1997, which has been technically revised.

ISO 5658 consists of the following parts, under the general title *Reaction to fire tests — Spread of flames*:

— *Part 1: Guidance on flame spread* (Technical Specification)

— *Part 2: Lateral spread on building and transport products in vertical configuration*

— *Part 4: Intermediate-scale test of vertical spread of flame with vertically oriented specimens*

Introduction

The rate and extent of flame spread are important properties to be characterized when evaluating the reaction to fire hazards of products that can be used in diverse applications such as in buildings, transport, furniture, electrical enclosures, etc. Historically, there have been many approaches taken to the measurement of flame spread and most of these have evolved with little fundamental justification. This Technical Specification describes different modes of flame spread and proposes some theoretical principles to assist with the relevant application of the data obtained from flame spread tests.

This guidance document is about flame spread and as such it fits within the scope of ISO/TC 92/SC 1. Flames are a major cause of fires being initiated (usually described as ignitability) and fire growth (usually physically observed as flames spreading from the initial seat of the fire where the ignition source was applied). Also, within the scope of ISO/TC 92/SC 1, it is generally assumed that fire growth applies up to the point of a developed fire after which the fire can spread (for example) from one compartment to another. This concept is usually covered by the scope of ISO/TC 92/SC 2 (fire containment).

Many flame-spread tests measure the rate and extent of the flame front as the flame moves over the surface of a large area, flat products such as linings on walls, ceilings and floors. Usually the orientation of the test specimen is related to the end-use application (for example, exposed face upwards for floor-coverings). This requirement for end-use relevance is satisfied by ISO 5658-2 and ISO 5658-4 when wall linings are evaluated.

Flame spread over construction and transport products is related to the fire scenario. ISO/TC 92/SC 1 have initially concentrated on the development of tests to simulate flame spread in rooms and along corridors. Other important scenarios where flame spread data are required are façades (both front and behind), shafts, stairs and roofs; much of the theoretical guidance given in this Technical Specification can be applied to these scenarios even though ISO test procedures might not be available as of the date of publication of this Technical Specification.

Flame spread can also occur over non-planar products (e.g. pipes) and within assemblies (e.g. along joints or inside air-gaps). Whilst this Technical Specification concentrates on the theory pertinent to flat products, some of the theory outlined can be applied to improve the understanding of these more complex situations.

The results of small-scale flame-spread tests (e.g. ISO 5658-2 [1] and ISO 9239-1 [2]) and large-scale tests (e.g. ISO 9705 [3]) can be used as components in a total hazard analysis of a specified fire scenario. The theoretical basis of these tests is explained so that relevant conclusions or derivations can be made from the test results.

Reaction to fire tests — Spread of flame —

Part 1: Guidance on flame spread

1 Scope

This Technical Specification provides guidance on flame spread tests. It describes the principles of flame spread and classifies different flame-spread mechanisms.

2 Principles of flame spread

Flame-spread tests are designed to quantify the flaming process outside of the zone heated by the ignition source (flaming, radiant or overheating) and as such, they help our understanding of how fire grows away from the initial seat of the fire. This concept is relevant to flame spread within the compartment or cavity where the fire originates (that is, the point/area of fire initiation/ignition). Flame-spread tests differ considerably in the conditions that are specified for characterization of the flame-spread process. These conditions include the following:

— intensity and area of thermal attack of ignition source;

— orientation of test specimen (for example, vertical, horizontal and inclined are normally defined);

— ventilation in the vicinity of the test specimen;

— mode of flame spread (see Table 1).

Flammability of surfaces is a major concern of many regulations. The primary room surfaces in buildings, for example, are any combustible linings used on the walls or ceilings, along with floor coverings. Similar flame-spread effects can also occur over the surfaces of transport vehicles (such as ships, trains, aircraft and buses). To understand the role of bench-scale tests in assessing this hazard, the dominant fire effects shall be placed in context.

The ceiling can show a very rapid fire spread and a high contribution to hazard. The least combustible materials should generally be positioned on the ceiling in order to minimize fire hazard. There is not universal agreement on this point and some studies [4] conclude the opposite. For almost any fire scenario, flame spread along the ceiling is wind-aided, which means that the air-flow and the flame spread are both in the same direction.

For common fire scenarios, flame spread on walls is upward (wind-aided) in the vicinity of the fire source. In other parts of the walls, the flame spread is downward (opposed-flow), since entrained air is moving upwards, opposite to the direction of flame motion. Much of the wall can, however, be directly ignited by submersion into the layer of hot gases forming below the ceiling. This ignition does not involve a flame-spread process at all, but ceiling flammability directly accelerates it.

Generally, flame spread on floors within a room is very limited until later stages of a fire. Flame spread on floors in corridors, however, can be of major concern. This flame spread is usually caused by a room fire impinging on the adjacent corridor and igniting the flooring. There is usually some prevailing air-flow direction within a corridor. Flame spread can then proceed either in the wind-aided direction, or as opposed flow. Commonly, flame spread in both directions can occur simultaneously on corridor flooring materials.

In principle, two different bench-scale test methods would be required to represent the two fundamentally different flame-spread processes of wind-aided spread and opposed-flow spread. The flame spread rates are not similar in these two processes. Wind-aided spread tends to be much more rapid, since a large amount of virgin combustible can be the flame tip, whereas in the opposite direction, the heating of the material is limited to a very small heating zone. Research studies have shown, however, that a test solely dedicated to examining wind-aided spread is not necessary [5].

Theory and experiments both reveal that wind-aided flame spread can often be directly predicted once the heat release rate and the ignitability behaviour of the specimen is established. These would be done in bench-scale by the use of the ISO 5660 method for heat release rate and either ISO 5660-1 [6] or ISO 5657 [7] for ignitability.

Flame spread for the opposed-flow configuration also requires information about the flame flux and the flame heating distance for that geometry [8]. In the context of ISO bench-scale test methods, this is the role for the tests described in this part of ISO 5658 and in ISO 5658-2. Thus, while there are two flame-spread modes of concern and while the wind-aided spread is often of dominant concern, there is a need only for two bench-scale flame-spread ISO tests (ISO 5658-2 and ISO 9239-1). These tests are devoted solely to the opposed-flow mode.

3 Characteristics of flame-spread modes

3.1 General

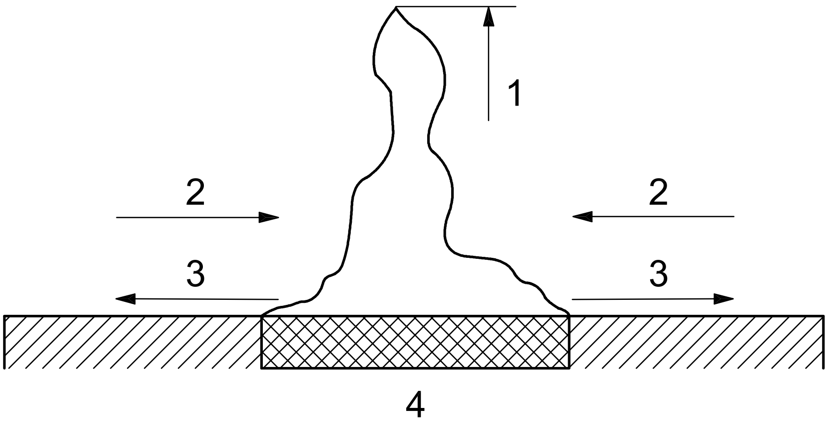
The characteristics of different flame-spread modes are described and summarized in Table 1. For each of the modes, the dominant heat-transfer mechanisms are identified. The various modes are distinguished by two criteria: orientation of the fuel surface and direction of the main flow of gases relative to that of flame spread. Only flat fuel surfaces are considered. It is assumed that the fuel slab is located in a normal gravity environment, i.e. special cases such as flame spread under microgravity conditions (spaceships) are not considered. The analysis is for thick fuels, or else thin fuels in combination with a backing board. Cases where burning can be on two sides simultaneously (e.g. upward flame spread over curtains) are not explicitly included as a specific flame-spread mode. In addition, discontinuous flame spread caused by separation of flaming parts from the pyrolyzing region of a fuel slab is not included in this clause. This effect can occur with some products in modes B.a, B.b, B.c and C.a. Flame spread from flaming droplets/particles is further described in Clause 9.

Table 1 — Modes of flame spread

Mode reference	Application	Type of flame spread
A.a	Flooring; Horizontal	Opposed-flow
A.b	Flooring; Horizontal	Opposed-flow
A.c	Flooring; Horizontal	Wind-aided
B.a	Walls; Vertical	Wind-aided
B.b	Walls; Vertical	Opposed-flow
B.c	Walls; Vertical	Opposed-flow
C.a	Ceilings; Horizontal	Wind-aided

3.2 Horizontal, facing upward

a) Mode A.a. Flame spread over a horizontal surface away from a burning area is illustrated in Figure 1. The burning area has the characteristics of a pool fire. The flow rate of air entrained into the flame is assumed to be reasonably uniform around the perimeter of the fire. Flame spread is against the direction of the entrained air flow and is, therefore, of the opposed-flow type. The heat transfer to the non-burning fuel is primarily flame radiation. Gas-phase conduction between the flame foot and the virgin fuel is the dominant mode of heat transfer; it occurs only locally, close to the pyrolysis front. If the flow rate of air entrainment is not uniform around the perimeter, the flame tilts in the direction of the dominant flow. As a result, the relationship of the far field flame radiation to the unburnt fuel is no longer symmetrical. Objects blocking the flow and ventilation openings providing fresh air can have a pronounced effect on the flow field close to the fire.



Key

1 flame height

2 air flow

3 spread (mode A.a)

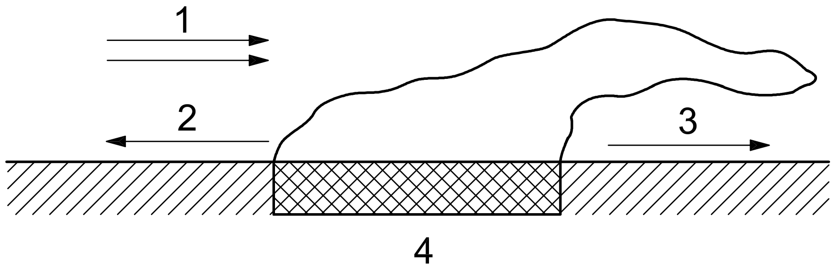
4 pyrolyzing region

NOTE See 3.2 a).

Figure 1 — Flame spread, mode A.a

b) Mode A.b is identical to A.a in 3.2 a), except that there is now a forced air flow that tilts the flame over in the direction of the flow. This is illustrated in Figure 2. On the upstream side of the pool fire, flames spread against the air flow. However, the view factor between the flame and the non-burning fuel on this side is now very small. Consequently, the far field flame radiation becomes negligible and the gas-phase conduction near the pyrolysis front is the only dominant method of heat transfer. In fact, significant flame heating is over only a very small region near the pyrolysis front (a few millimetres). Therefore, the spread rate is very slow and opposed-flow flame spread is commonly referred to as creeping spread.

c) Mode A.c is illustrated at the downstream side of the flame in Figure 2. Flames cover the fuel area between the pyrolysis front and the flame tip. The heat transfer to this area is primarily by flame radiation and convection. This is a typical example of wind-aided flame spread. There is still gas-phase heat conduction near the pyrolysis front, but this mechanism is rather insignificant. Due to the increased view factor, flame radiation in the region between the pyrolysis front and the flame tip is much greater than in mode A.a, at least when flames are luminous.



Key

1 air flow

2 spread (mode A.b)

3 spread (mode A.c)

4 pyrolyzing region

NOTE See 3.2 b) and 3.2 c).

Figure 2 — Flame-spread modes A.b and A.c

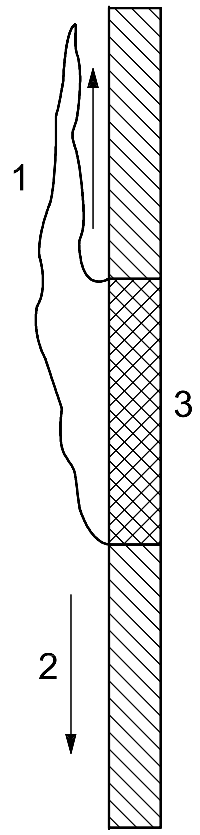
3.3 Vertical or inclined

a) Mode B.a. Perhaps the most important flame-spread mechanism is that of upward spread over vertical surfaces. This mode, B.a, is illustrated in Figure 3 and is very similar to that of mode A.c. The main difference is that flames cover part of the non-burning fuel ahead of the pyrolysis front due to buoyancy. Wind-aided spread is important because it is by far the fastest flame-spread mechanism. Consequently, many bench- and intermediate-scale tests used for regulatory purposes evaluate the wind-aided flame-spread potential of a material as a measure of its hazard in fire, for example the ASTM E84 Tunnel Test [9] and the DIN 4102 [10] test.

b) Mode B.b. Downward spread from a wall flame, is also shown in Figure 3. It is a form of opposed flow or creeping spread analogous to mode A.b.

c) Mode B.c. Lateral spread, is illustrated in Figure 4. Heat transfer to the non-burning fuel is primarily through gas-phase conduction near the pyrolysis front. Consequently, this mode is similar to that of A.b and B.b.

d) The important flame-spread mechanisms over an inclined plane are dependent upon the angle of inclination of a surface and the extent of the pyrolyzing region in relation to the width of the combustible surface. For surfaces inclined at angles in excess of around 30°, flame spread can be represented as illustrated in Figure 5. The flames from the burning fuel are in contact with the fuel surface ahead of the pyrolyzing region, producing substantial radiative and convective heat transfer to the fuel. The substantial flame lean is due to the fluid dynamics of the air entrainment process and results in a mode of flame spread similar to that of upward spread over vertical surfaces, as shown in Figure 3. This flame-spread process is evaluated in the NT Fire 007 test [11]. This effect is also described in 7.2.5 in relation to sloping corridors. For angles of inclination up to 30°, the modes of flame spread are represented by combinations of Figures 1 (mode A.a) and 2 (mode A.c).

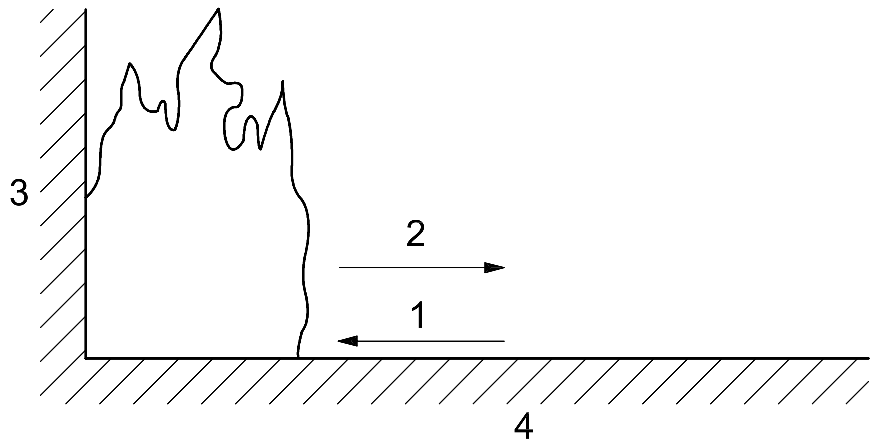


Key

1 upward spread (mode B.a) (wind-aided)
2 downward spread (mode B.b) (opposed flow)
3 pyrolyzing region

NOTE See 3.3 a) and 3.3 b).

Figure 3 — Flame-spread modes B.a and B.b

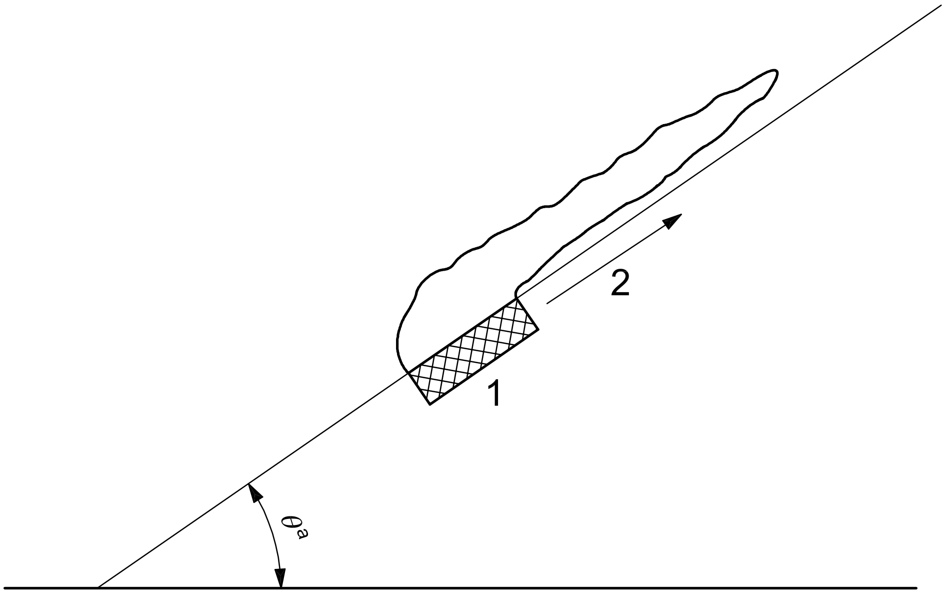


Key

1 air flow
2 lateral spread (mode B.c)
3 wall
4 floor

NOTE See 3.3 c).

Figure 4 — Flame-spread mode B.c



Key

1 pyrolyzing region

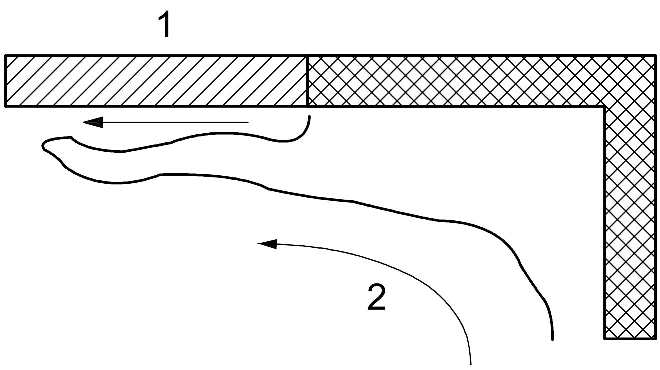
2 spread

[a] $\theta \geqslant 30°$.

Figure 5 — Flame spread up an inclined plane

3.4 Horizontal, facing downward

An example of ceiling spread, mode C.a, is shown in Figure 6. The mechanism for ceiling spread may be applied to the underside of wide ventilation ducts. Buoyancy and the main flow of gases result in a wind-aided type of spread similar to A.c and B.a.



Key

1 ceiling spread (mode C.a)

2 main flow of gases

NOTE See 3.4.

Figure 6 — Flame spread, mode C.a

4 History of surface spread of flame tests

Different spread of flame tests have been developed in several countries and for different applications.

Tables 2 and 3 provide parameters for ten commonly used spread of flame tests.

NOTE The difference between the tests concerns specimen size, specimen orientation (sometimes depending on the type of application for which a material is designed), heat and ignition source applied to the specimen, as well as criteria for acceptance.

Table 2 — National spread-of-flame tests based on radiant heat ignition models

Test	**Specimen orientation**	**Direction of flame spread**	**Specimen size** mm	**Heat flux at hot end of specimen** kW/m^2	**Pilot ignition source**	**Criteria**	**Principal countries of use**
ASTM E162 [63]	Inclined (face down)	Downward	150 × 460	30	Horizontal gas flame, applied to upper end	Flame spread, heat evolved, smoke	USA
ASTM E648 [62]	Horizontal (face up)	Horizontal	250 × 1 050	11	Horizontal gas flame, applied to the hot end	Critical flux for spread	USA, Germany
BS 476-7 [13]	Vertical	Lateral	885 × 265	33	Vertical gas flame, applied to the hot end	Extent and velocity of spread after 1,5 min and 10 min	GB, Belgium
NEN 3883 [64]	Vertical	Lateral	1 000 × 230	37	Vertical gas flame, applied to the hot end	Flame spread after 1,5 min and 10 min	Netherlands
UNI 9174 [65]	Vertical (wall position) Horizontal (floor position) Horizontal (ceiling position)	Lateral Horizontal Horizontal	800 × 155	30 12 16	Gas flame, applied to the hot end	Velocity and extent of spread Critical flux for spread of flame	Italy
NFP 92-506 [66]	Vertical	Lateral	400 × 95	30	Vertical gas flame, applied to the hot end	Extent of flame spread at 1 min and 10 min	France
IMO Resolution A 653 (16) [12] ASTM E1317-90 [67]	Vertical	Lateral	155 × 800	50	Vertical gas flame, applied to the hot end	Heat for sustained burning (Q_{sb}) Critical flux at extinguishment (CFE)	For ships in different countries USA

Table 3 — National spread-of-flame tests based on flame ignition models

Test	**Specimen orientation**	**Direction of flame spread**	**Specimen size** mm	**Heat flux at hot end of specimen** kW/m^2	**Pilot ignition source**	**Criteria**	**Principal countries of use**
DIN 4102 [10]	Vertical (four opposed specimens)	Vertical	190 × 1 000	30 + influence of opposite burning material	Gas flame at lower end of specimen (pilot and radiation)	Flame spread after 10 min	Germany
ASTM E84 05-01 [9]	Horizontal (face down)	Horizontal	510 × 7 320	35	Horizontal gas flame, applied to one end of specimen, with heat output of 5,3 MJ/min	Flame spread smoke	USA, Canada
NT Fire 002 [44]	Vertical	Vertical	800 × 300	35	Gas flame, applied to lower end of specimen	Ignitability Flame spread	Scandinavia Austria

5 Small-scale tests

5.1 Method given in ISO 5658-2

NOTE See Reference [1].

ISO 5658-2 applies to a surface spread of flame test where the test specimen is exposed to a heat flux of 50 kW/m^2. The test was developed by the International Maritime Organization (IMO) [12].

The purpose of the test method is to provide a method of classifying surface finish materials used on-board ships on the basis of their characteristics of surface flame spread.

The development concentrated on lateral flame spread over a vertical orientated specimen, because

a) an ISO spread-of-flame test utilized lateral flame spread;

b) reference was made to British Standard BS 476-7 [13];

c) heat-release measurement on the IMO test method is only possible with the specimen in a vertical position.

During the first stage of the round-robin test in IMO, some laboratories found it difficult to obtain a strictly specified heating condition because of the variety of the fuel (methane, propane, electric, etc.).

However, it was also found that if test results were described as multiplication of flame spread time at a place on the specimen and irradiance at this position, the results showed a good agreement among laboratories, even if there were some variance in the ability of laboratories to obtain identical heating gradients.

Due to the above reason, this parameter was introduced for classifying materials. The level of the classification on flame spread was developed in conjunction with BS 476-7.

“Heat for sustained burning (Q_{sb})” and “Critical irradiance at extinguishment (CFE)” are used in the IMO spread of flame test as parameters to describe degree of lateral flame spread on the surface of materials. The decision on the use of these parameters was a consequence of experimental studies on the test method and a consideration of the parameters of a similar test method (BS 476-7).

BS 476-7 specifies the heating condition of the specimen by incident heat flux. Then, flame spread distance at 1,5 min from the beginning of the test and maximum flame-spread distance within 10 min are used for categorizing the specimen in one of the four classes. During the discussion in IMO, it was assumed that incident heat flux along the lateral direction of the specimen is a more direct explanation of the heating condition than lateral distance, and that incident irradiance at the maximum flame-spread position (CFE) can be used instead of maximum flame-spread distance as a parameter that indicates the capability of the flame spread.

In IMO, it is assumed that flame spread at 1,5 min is an expression of the flame-spread speed and that multiplication of incident heat flux and time of flame spread to the position (Q_{sb}) can be used as a parameter of flame-spread speed. Some experimental studies have indicated that even if the heat flux condition is different, in some limited degree almost the same CFE and Q_{sb} could be obtained.

Results of some experimental studies and first round-robin tests on the test method have demonstrated that a logarithm plot of the flame-spread time to positions along the specimen against incident heat flux on these positions gives a unique linear line for the specimen, and the slope is nearly – 1 [14] (see Figure 7). This means that multiplication of incident heat flux and flame-spread time can be a unique value for a material.

Taking into account a comparison test of the results of BS 476-7 and the IMO spread-of-flame test [15],[16], pass/fail criteria for the IMO test were developed using CFE and Q_{sb}.

5.2 LIFT method

The LIFT procedure for determining ignition and lateral flame spread was standardized in the U.S.A. as ASTM E1321-90 [17] and has been used for some research and modelling purposes.

This fire-test response standard determines material properties related to piloted ignition of a vertically oriented specimen under a constant and uniform heat flux and to lateral flame spread on a vertical surface due to an externally applied radiant-heat flux.

The results of this test method provide a minimum surface flux and temperature necessary for ignition and for lateral spread, an effective material thermal inertia value, and a flame-heating parameter pertinent to lateral flame spread.

The results of this test method can be used to predict the time to ignition and the velocity of lateral flame spread on a vertical surface under a specified external flux. This analysis can be done using the equations in, for example, References [17], [18] that govern the ignition and flame-spread processes and which have been used to correlate the data.

The analysis may be used to rank material performance by some set of criteria [19] applied to the correlation, or the analysis may be employed in fire growth models to develop a more rational and complete hazard assessment for wall materials.

5.3 Method given in ISO 9239-1

NOTE 1 See Reference [2].

This project leading to the publication of ISO 9239-1:1997 was initiated by ISO/TC 38/SC 19, *Burning behaviour of textiles and textile products*, and had progressed to the development of a draft by 1988. In 1992, ISO/TC 92/SC 1 conducted a ballot for a new work item on flame spread over all types of floor coverings. This work item was well supported and the development of flame-spread tests for floor coverings (see References [52], [55], [58], [59], [60]), including both textiles and non-textiles and taking into account the latest improvement described in ASTM E648, was begun by ISO/TC 92/SC 1 in 1993. ISO 9239-1:1997 [20] was published in 1997. Subsequent to this publication, the European Commission decided that this method should be used to classify floorings in support of the Construction Products Directive. Further work was initiated according to the Vienna Agreement in CEN/TC 127 *Fire safety in buildings* in cooperation with ISO/TC 92/SC 1. The precision of the method was further examined by a European inter-laboratory trial involving 13 laboratories and 10 floorings. A revised second edition was published as ISO 9239-1:2002.

NOTE 2 A harmonized version, EN/ISO 9239-1:2000, was also published for regulatory use in Europe.

ISO 9239-1 provides a simple method by which the horizontal surface spread of flame on a horizontal specimen can be determined for comparative purposes. This method is particularly useful for research, development and quality control purposes.

ISO 9239-1 describes a test method for measuring the wind-opposed flame-spread behaviour (mode A.a) of horizontally mounted floor covering systems exposed to a radiant heat gradient in a test chamber when ignited with a pilot flame. The imposed radiant flux simulates the thermal radiation levels likely to impinge on the floor of a corridor whose upper surfaces are heated by flames or hot gases or both, during the early stages of a developing fire in an adjacent room or compartment under wind-opposed flame-spread conditions.

This test method is applicable to all types of floor coverings such as textile carpets, cork, wood, rubber and plastic coverings.

The test is intended for regulatory purposes, specifications or development and research.

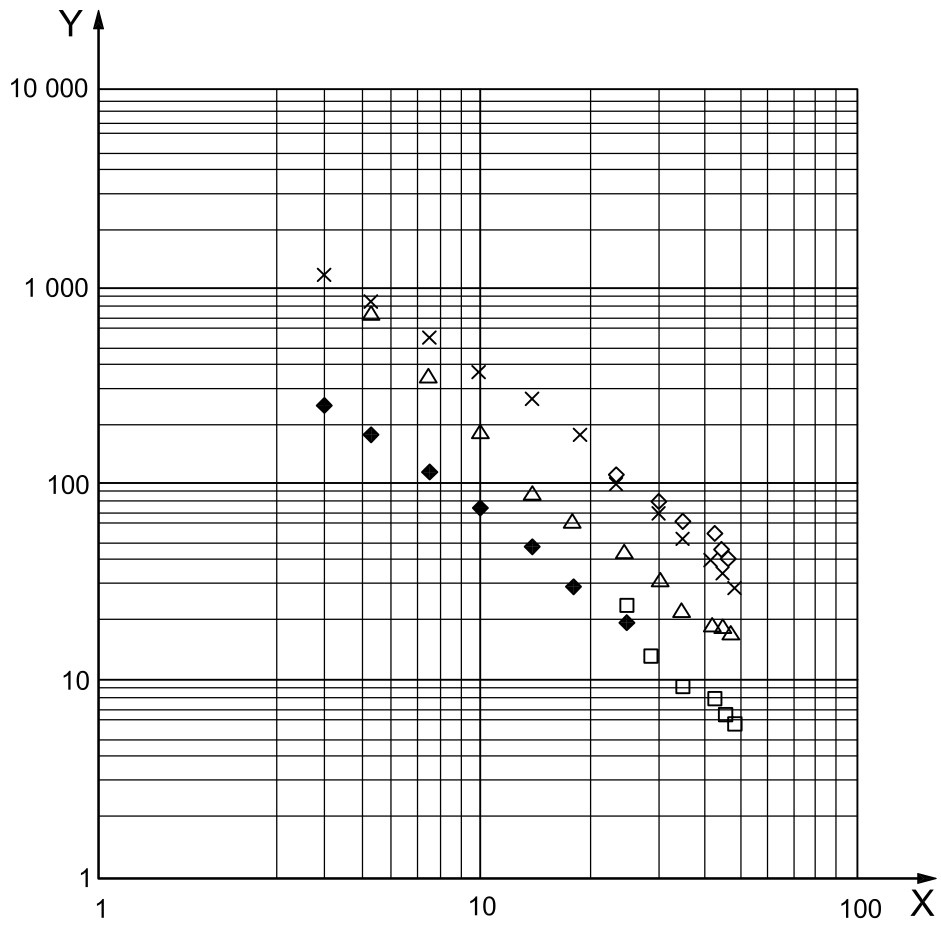
This test method consists of mounting conditioned specimens in a well-defined field of radiant heat flux from 11 kW/m^2 to 1 kW/m^2 and measuring the rate of spread of flame and the position of flame extinguishment.

A test specimen (1 050 mm long by 230 mm wide) is placed in a horizontal position below a gas-fired radiant panel inclined at 30° and a pilot flame is applied to the hotter end of the specimen.

Following ignition, any flame front that develops is noted and a record is made of the progression of the flame front horizontally along the length of the specimen in terms of the time it takes to travel to various distances.

The results are expressed in terms of flame-spread distance versus time and their derived radiant fluxes at X minutes (HF-X) as well as the critical heat flux at extinguishment (CHF). Since the average heat for sustained burning (Q_{sb}) is not required by European regulations, this parameter, which was included in ISO 9239-1:1997, was deleted from the revised second edition ISO 9239-1:2002.

The test may be terminated after 30 min since burning behaviour may not be significant for fire hazard assessment purposes after this point in time.



Key

X incident heat flux, expressed in kW/m^2

Y flame-spread time, expressed in seconds

× hard-wood fibre board

◆ soft-wood fibreboard

◇ melamine-formaldehyde laminate

△ acrylic carpet

□ wool carpet

Figure 7 — Relationship between heat flux and flame-spread time in ISO 5658-2 and IMO tests

5.4 Method given in ISO 9239-2

NOTE See Reference [21].

ISO 9239-2 [21] was developed in recognition that more severe fire conditions on floorings than those represented by ISO 9239-1 are found in post-flashover scenarios [22]. The fire model for ISO 9239-1 is for wind-opposed flame-spread behaviour (mode A.a). Research conducted after the introduction of ISO 9239-1:2002 shows that heat fluxes higher than 11 kW/m^2 can be imposed on floorings inside compartments containing a fully developed fire (that is, post-flashover situations) [23], [24], [25]. In addition, wind-aided conditions (mode A.c) can occur in corridors, on sloping floors and up stairs. Under these mode-A.c wind-aided conditions with developed fires, heat fluxes onto the floor of 25 kW/m^2 are recorded.

The apparatus for ISO 9239-2 is essentially similar to that for ISO 9239-1:2002. Apart from the increase in gas supply to the radiant panel that is required to obtain 25 kW/m^2 at the hot end of the test specimen, the only other change is to modify the air flow over the test specimen. In ISO 9239-2, the specimen holder has been redesigned so that the air enters the test chamber at the hotter end of the exposed specimen. The air velocity in the exhaust stack in ISO 9239-2 is 2,5 m/s, which is the same as in ISO 9239-1:2002.

The precision of ISO 9239-2 has been determined in a round-robin in which seven laboratories participated. The results of this round-robin confirm that the variability obtained in ISO 9239-2 is similar to that obtained in ISO 9239-1:2002. In the analysis of the CHF parameter, coefficients of variation of 6 % to 18 % (repeatability) and 10 % to 30 % (reproducibility) were found for most flooring.

6 Intermediate-scale tests

6.1 Corner tests

A full-scale corner test is a widely recognized configuration for conducting large-scale fire test evaluations for demonstrating the flame-spread potential and the material damage characteristics of insulated walls and ceilings. A corner provides a critical surface geometry for evaluating the fire behaviour of material surfaces since it results in a combined heat flux from the conductive, convective and radiative response of any material burning in the corner. Large-scale corner tests are, however, expensive to conduct. A scaled-down screening test that exhibits good reproducibility and good correlation is therefore useful for predicting the results of full-scale corner testing. A variety of small corner tests have been judged to meet these criteria and the EN 13823 single-burning item (SBI) test [26] is now used in Europe for regulatory purposes. The SBI test offers the possibility to measure lateral flame spread but in practice lateral flame spread rarely travels further than 0,6 m on the long wing due to the lack of a ceiling and high ventilation through the test specimen assembly.

Corner tests are particularly useful for measuring wind-aided flame spread on the tops of the walls and over the ceiling (mode C.a). They are also able to show opposed-flow flame spread (mode B.c) laterally and downwards over the walls for more flammable linings.

6.2 Method given in ISO 5658-4

NOTE See Reference [27].

ISO 5658-4 specifies an intermediate-scale method of test for measuring the vertical spread of flame over a 1,5 m × 1,0 m specimen of a product orientated in the vertical position. A measure of lateral spread can also be obtained. The test provides data suitable for comparing the performance of materials, composites or assemblies that are used as the exposed surfaces of walls or other vertically orientated products in construction and transport applications. Some products with profiled surfaces can also be tested with a modified procedure representative of the end-use conditions of the product.

The modes of flame spread measurable in this method are:

— vertical upward: mode B.a;

— vertical downward mode B.b;

— lateral mode B.c.

Upward flame spread is not limited to surfaces that are vertical. It is recognized that an enhanced form of upward, wind-aided flame spread can also occur on surfaces at an angle greater than 20° from the horizontal without any external ventilation. This type of flame spread can occur in both planar sloping surfaces and stepped surfaces such as stairs. Flame spread in these situations can become very rapid and can cause serious problems in escape routes such as stairs and escalators. When assessing stepped or sloping surface materials, it can be more appropriate to use a vertical flame spread test rather than a test in which the specimen is horizontal.

ISO 5658-4 is applicable to the measurement and description of the properties of materials, products, composites or assemblies in response to radiative heat in the presence of non-impinging pilot flames under controlled laboratory conditions. The heat source can be considered to represent one burning item such as a wastepaper bin or an upholstered chair within an enclosure, and this scenario is generally considered to apply during the early developing stage of a fire (see ISO/TR 11696-1 [28] and ISO/TR 11696-2 [29]).

The test method consists of exposing conditioned vertically orientated specimens to a single well-defined field of radiant heat flux, which is typically up to 35 kW/m^2 to 45 kW/m^2 near the base of the specimen. Measurements are made of the time of ignition, of the vertical spread of flame and, where appropriate, of observations of other fire-spread effects, such as flaming droplets/particles and lateral spread.

A test specimen is placed in a vertical position adjacent to a gas-fired radiant panel that exposes the lower part to a defined field of radiant heat flux. A non-impinging line pilot burner is positioned above the radiated area of the specimen to ignite volatile gases issuing from the surface.

Following ignition, any flame front that develops is noted and a record is made of the progression of the flame front vertically over the height of the specimen in terms of the time it takes to travel various distances. The results are expressed in terms of ignition time and flame-spread distance versus time.

Mass loss, heat release and smoke data can also be measured if required. For these measurements, the apparatus should be positioned underneath a calibrated hood/duct facility; for example, see ISO 9705 [3].

A number of flame-spread characteristics may also optionally be derived from the measurements taken in ISO 5658-4. Average flame-spread rates (both vertically and laterally) can be calculated based on flame-spread distances measured from the X-O and Y-O reference lines drawn on the test specimens.

The precision of ISO 5658-4 has been determined in a large inter-laboratory trial involving 11 laboratories and 16 products. Flame-spread results were recorded using specific software that allowed flame spread to be measured into 100 mm by 100 mm zones drawn as a grid over the whole test specimen. The area of flame spread gave coefficients of variation of 0 % to 36 % (repeatability) and 0 % to 61 % (reproducibility), which compare favourably with values found in other inter-laboratory trials on other reaction-to-fire parameters.

6.3 Method given in ISO/TR 14696:1999

NOTE See Reference [30].

In ISO/TR 14696:1999 [61], Annex F, it is stated, “The ICAL is used to determine many of the parameters or values needed in computer fire models”. Flame spread is not included in the examples described since no references were available at the time of the publication of ISO/TR 14696. However, the ASTM E-1623 ICAL standard indicates in the scope that “this test method is suitable for determining the flame spread constant but does not provide the testing and calculating procedures due to insufficient testing and research”.

Since the preparation of both the ISO and ASTM ICAL documents, a significant amount of flame-spread work has been performed using the ICAL, some of which has been published [31].

The ICAL is a test method designed to measure fire parameters on a 1,0 m by 1,0 m specimen in a vertical orientation. The specimen is exposed to a uniform and constant heat flux from a gas fired radiant panel. The heat flux can be as high as 60 kW/m^2 and is regulated by changing the distance between the radiant panel and the specimen. The capability of the ICAL to expose a 1,0 m by 1,0 m specimen to a uniform and constant external heat flux was found convenient also for a quantitative investigation of lateral and downward flame spread.

The flame spread is initiated in the test by placing a line burner along a vertical or the top edge of a specimen. Flame-spread velocities are easy to measure in the ICAL because of the large specimen size. The specimens can be grid-marked and the transit times can be measured visually, either directly or based on video records.

A technique was developed [31] to determine the flame-spread parameters in the ICAL by measuring flame-spread velocities and equilibrium surface temperature at two different irradiances and then calculating the pyrolysis temperature, T_p, and the flame spread parameter, A. The flame-spread velocity, V_s, can then be calculated at any surface temperature (T_s) using the correlation in Equation (1):

$$V_s = A(T_p - T_s)^{-2} \tag{1}$$

This correlation assumes that A and T_p are independent of surface temperature. This assumption can be checked for a category of materials by conducting the flame-spread test at three or more fluxes. In fact, the temperature dependence of these parameters can be determined with these additional tests for use in CFD fire models.

7 Large-scale tests

7.1 Room corner test (ISO 9705)

NOTE See Reference [3].

ISO 9705 describes a full-scale room fire-test method to evaluate the performance of lining materials in a room/corner scenario. Further details of this method are now published in ISO 9705-2 [32]. The test room has a height and width of 2,44 m, and a depth of 3,66 m. There is an open doorway 0,76 m wide by 2,03 m high in the front wall. All walls (except the front wall) and/or ceiling are lined with the test material. A gas-burner ignition source is placed in one of the rear corners of the compartment. The main measurements are the time to flashover, the heat-release rate and the smoke obscuration in the exhaust duct.

Corner fires are more severe than wall fires due to the radiative heat exchange between the two burning walls. For this reason, corner tests have been preferred in the evaluation of pre-flashover fire performance of wall linings. However, the physical phenomena controlling fire growth in corner and wall scenarios are very similar, if not identical. Therefore, the description of fire growth in the corner test given below is also applicable to wall fires. The important physical phenomena can be identified on the basis of visual observations of and experience with full-scale tests. Fire size is primarily determined by the spread of flames over the walls, i.e. the increase in surface area of material involved.

The fire develops in the following manner.

a) At the start of a test, the ignition burner is lit. A diffusion flame develops and is in contact with the walls. For burner sizes and power levels commonly used in room/corner tests, the flame is turbulent. Figure 8 is a three-dimensional view of the room at this stage of the corner test.

b) The wall material in contact with the flame and plume is heated. The heat flux to the wall is a function of location. It is the highest in the flame region and decreases sharply in the plume region. At a certain time, part of the material in contact with the flame ignites. At ignition, the total flow of fuel gases suddenly increases. This results in a higher flame and an increase in heat flux to the parts of the wall above what is ignited. As the critical conditions for ignition are reached at locations above the burning zone, the flame works its way towards the ceiling. This phenomenon is referred to as upward spread. It is in the same direction as the main flow of gases, i.e. wind-aided (mode B.a).

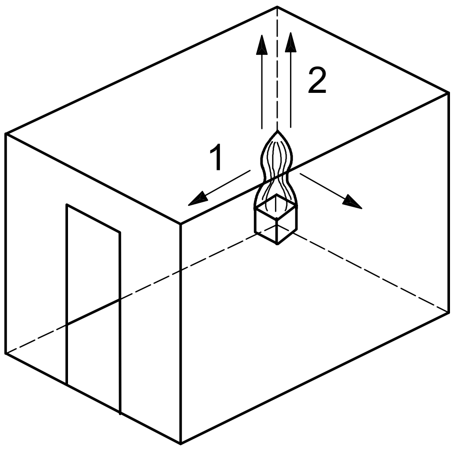
c) After the flame reaches the ceiling, it turns into a ceiling-jet flame. Just as for upward spread, the flame travel rate is the highest in the direction of the main flow of gases, i.e. along the interface between the ceiling and walls or over the ceiling itself, if it is combustible. Wind-aided flame spread also continues over a combustible ceiling (mode C.a).

d) While the flame spreads upward, as described in b), it also spreads laterally as shown in Figure 9. However, this opposed-flow spread rate (mode B.c) is much slower than in the case of upward spread for two reasons.

— Lateral flame spread is opposite in direction to the main flow of air entrained into the flame and plume.

— The heat flux to regions ahead (in the direction of flame spread) of the flame front is much smaller for lateral spread, as the flame does not cover that region. However, this heat flux is very important in a small region near the flame front;

e) As flames spread along the wall/ceiling interface, eventually they reach another corner. In tests where the ceiling is lined, it is very likely flashover occurs before this happens. With a non-combustible ceiling, flames also spread downward before flashover, as shown in Figure 10. The downward spread phenomenon has much in common with lateral spread as described in d). Flames are not exactly travelling in a direction against the entrained flow of gases. However, due to buoyancy, flames do not cover the region ahead of the flame front just as for lateral spread. Experimental observations indicate that downward spread becomes very significant shortly before flashover. This is because at that time heat flux to the ceiling and upper part of the walls increases dramatically, thus significantly enhancing this mode of flame spread.

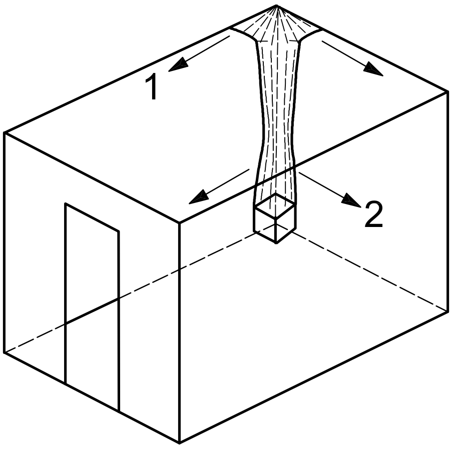


Key

1 lateral spread (opposed flow)

2 upward spread (wind-aided)

Figure 8 — Three-dimensional view of a corner fire in an early stage

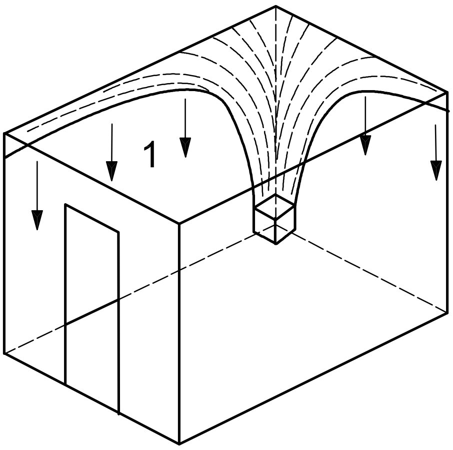


Key

1 wall/ceiling spread (wind-aided)

2 lateral spread (opposed flow)

Figure 9 — Three-dimensional view after flames reach the ceiling



Key

1 downward spread

Figure 10 — Three-dimensional view shortly before flashover

From the description above, it is clear that both wind-aided and opposed-flow flame spread characteristics of a material (modes C.a and B.b) are important factors for its performance in ISO 9705 [3].

A key parameter output from the LIFT [17] surface spread of flame test is the flame-spread parameter, ϕ. The usefulness of ϕ could be much enhanced if it can be shown to be accurate for predicting large-scale lateral or downward flame spread over linings. For example, Karlsson [54] has done some work on this type of validation versus the ISO 9705 test.

7.2 Room/corridor scenarios

7.2.1 General

The description of fire growth for any particular scenario includes a combination of some flame-spread mechanisms. Differences observed in real fire behaviour for the same material in different scenarios result from the gas-phase behaviour, which determines the thermal environment to which the materials are exposed. In this context, the flame-spread mechanisms contributing to fire growth in three different room-corridor scenarios will not be discussed.

In each case, the room doorway opens into the corridor and once flashover has occurred in the room, it becomes the ignition source for the corridor. The corridor is open at one or both ends. The rate of fire growth in the corridor is dependent on the location of the lining materials for which there are a number of options. The most important of these include the following:

a) combustible wall lining;

b) combustible ceiling lining;

c) combustible wall and ceiling linings;

d) combustible floor lining;

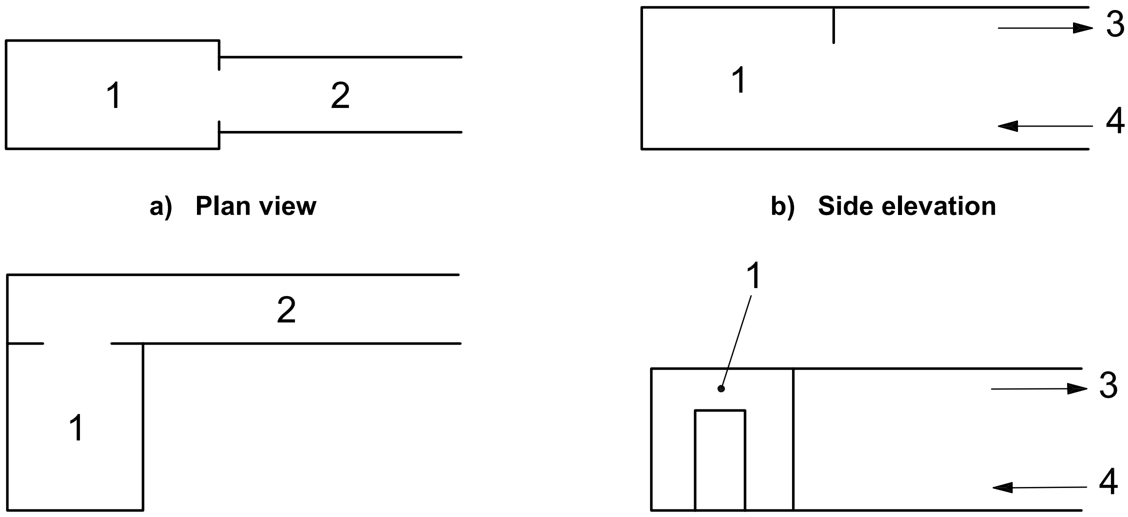
e) combustible wall, ceiling and floor lining.

Fire growth results from flame spread along the ceiling lining as well as downwards and laterally over the wall linings. The most severe rate of fire growth is likely to occur when the ceiling is lined in addition to the walls and floor. Flames on the ceiling produce enhanced radiative heat transfer to the other vertical and horizontal surfaces. Clearly, the dimensions of the corridor influence this process. The following scenarios assume that both the ceiling and the walls have combustible linings.

7.2.2 Scenario A

In room-corridor scenario A, illustrated in Figure 11 a) and b), it is probable that a fire will become ventilation controlled at a relatively early stage of corridor involvement because the room would become involved first. The design of the corridor in relation to the room influences the initial spread of flame into the corridor.

The general behaviour responsible for fire spread along either corridor is similar, with the airflow entering the room through the corridor. This results in an inflow of cooler air along the lower regions of the corridor and an outflow of hot combustion products along the upper regions of the corridor. After ignition with burning of the wall and ceiling linings, flame spread along the ceiling lining is wind-aided (mode C.a) and rapid, with flame radiation and convection being the dominant modes of energy transfer. Flame spread along the wall lining below the ceiling layer is generally opposed-flow lateral and downward spread (modes B.b and B.c). This is obviously slower and proceeds only under the influence of radiation from the flames and hot gases below the ceiling.



a) Plan view

b) Side elevation

c) Plan view

d) Side elevation

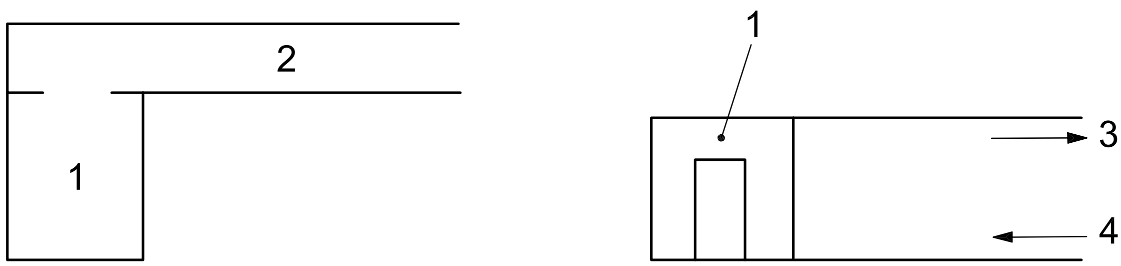
Key

1 room fire
2 corridor
3 flame spread
4 air

Figure 11 — Room/corridor scenario A

7.2.3 Scenario B

Room-corridor scenario B is illustrated in Figure 12. An additional ventilation opening has been included in the wall of the room, opposite the doorway. The significance of this vent depends entirely on its dimensions and position. If it is below some critical size, the flame-spread behaviour can be expected to be similar to that described for scenario A. However, provided that it is located at floor level and is large enough to more than meet the requirement for the air supply to the room fire, then a situation can be created where the flow of gases along the corridor occurs in only one direction. This can result in a scenario similar to scenario C with wind-aided flame spread across all linings. Downward flame spread on the vertical wall linings is always opposed flow due to the buoyancy effects of fires.



a) Plan view

b) Side elevation

Key

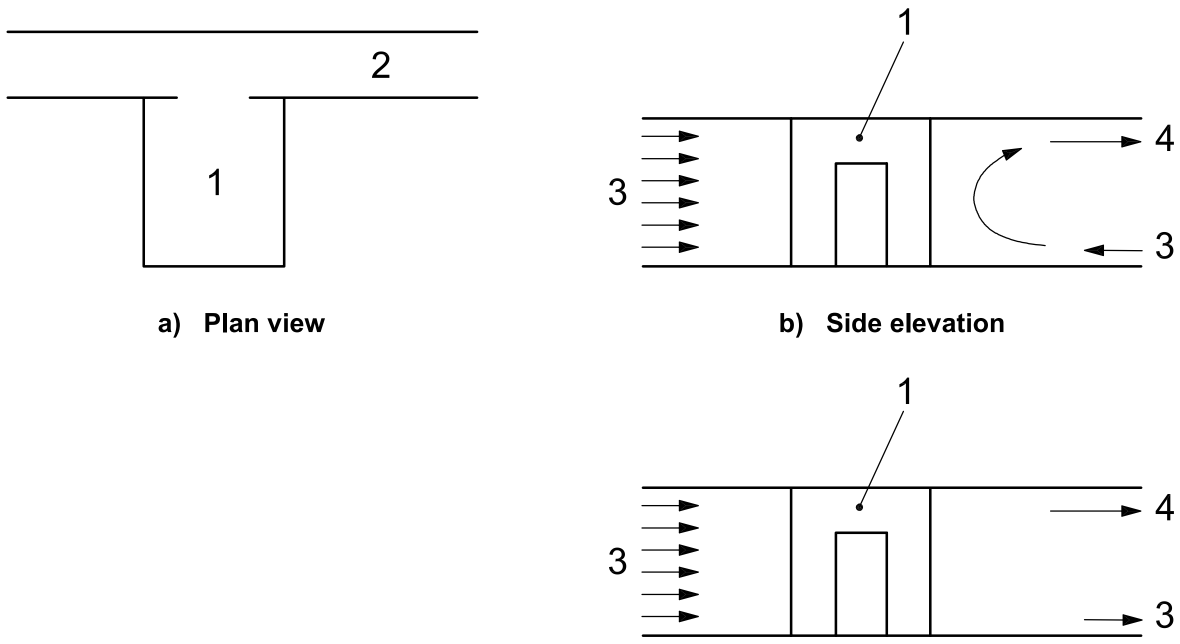
1 room fire
2 corridor
3 flame spread
4 air
5 vent

Figure 12 — Room/corridor scenario B

7.2.4 Scenario C

In room-corridor scenario C, illustrated in Figure 13, the corridor is open at both ends and force-ventilated, resulting in an initial air velocity through the corridor. The effect of the additional air velocity due to forced ventilation is to lengthen the flames under the ceiling. This increases the area of fuel exposed to flame radiation and convection and tends to accelerate the rate of flame spread.

The mechanism of flame spread over a floor lining depends on the magnitude of the air velocity produced by forced ventilation. If the forced velocity is less than some critical value, air can be entrained into the fire from the opposing direction. This occurs at a low level, so flame spread over a floor lining is opposed flow and makes only a minor contribution to fire growth [Figure 13 a)]. However, if the forced velocity is greater than the critical value, the overall flow is unidirectional and the flame spread over the floor lining is wind-aided. In this instance, a floor lining can make a more major contribution to fire growth through its involvement [Figure 13 b)].



a) Plan view

b) Side elevation

c) Side elevation

Key

1 room fire

2 corridor

3 air

4 flame spread

Figure 13 — Room/corridor scenario C

7.2.5 Scenario D

An additional scenario of a sloping corridor open at both ends and without forced ventilation, e.g. an escalator shaft, is considered. The entrainment of air into a fire occurring across the full width of the base of an inclined corridor is restricted, which results in the flame leaning up the incline (see Figure 5). The angle of lean depends on the inclination of the corridor base [33], [34] leading to flame attachment at some critical angle of inclination (greater than 30° from the horizontal). As the flame lean increases, flame radiation to the corridor base becomes greater, producing a potential for very rapid wind-aided flame spread. This specific problem is approximately two-dimensional. However, if the fire does not extend across the full width of the base or the ends of the corridor (one or both) are closed, the problem is no longer two-dimensional and is obviously more complex.

7.2.6 Applicability of test-data for room-corridor scenarios

Since both opposed-flow and wind-aided flame spread contribute to fire growth in the room corridor scenarios considered, it can be necessary for both mechanisms to be addressed in a robust assessment of spread of flame. Data applicable to both of these mechanisms are unlikely to come from a single bench-scale test. The LIFT method [17] in conjunction with the cone calorimeter [6] might be capable of providing a solution.

When using the cone calorimeter, it might be possible to derive data applicable to wind-aided flame spread, since that degradation process is primarily driven by flame radiation, in addition to background radiation from the walls, hot-gas layer, etc. However, it is not clear that the cone calorimeter can provide data relevant to opposed-flow flame spread. This is simply because gas-phase conduction at the flame leading edge, in addition to imposed radiation, is crucial. Two very different energy-transfer mechanisms are dominant in each case and any attempt to predict opposed-flow flame spread that neglects gas-phase conduction should be treated with caution.

Finally, consideration should be given to the thermal exposure and ventilation conditions in bench-scale tests, in particular ISO 5658-2 and the cone calorimeter ISO 5660-1. The test conditions should attempt to simulate real fire exposures so that reliable spread-of-flame classifications can be produced. It is not yet clear how this can be achieved for the range of conditions typical of real fires.

7.3 Façade scenarios

Flame spread over and inside facades can be measured as described in ISO 13785-1 and ISO 13785-2. These methods specify tests for determining the reaction to fire performance of products and façade systems when exposed to heat and flames from a simulated interior compartment fire with flames emerging through a window opening and impinging directly on the façade. ISO 13785-1 is an intermediate-scale screening method using 2,4 m high by 1,2 m wide test specimen exposed to a 100 kW propane line burner. ISO 13785-2 is a large-scale method using a test specimen that is at least 5,7 m high by 3,0 m wide.

7.4 Large-scale vertical flame-spread tests

7.4.1 Upward flame spread along a vertical combustible surface (mode B.a) is a key process governing the transition from the local combustion of an ignition source to the full involvement of an enclosure by fire, especially in an enclosure with a high ceiling compared with the wall widths. A similar wind-aided spread process occurs in large-scale tests on external façades [35]. Flames spreading upwards over the external surface or within the cavity of a combustible facade assembly govern the occurrence of self-sustained fire remote from the influence of the ignition source (such as a flashed-over room or a fire in a rubbish skip against the external wall) that causes localized combustion. The resulting flames can spread vertically upwards on the exterior wall surface of tall buildings or within the cavity.

Preheating of the unburnt surface beyond the pyrolysis front during upward flame spread along a flat wall is primarily dependent on the heat flux normal to the surface from the wall fire and external radiation. Determination of the wall flame heat transfer from heat-release rates suggests that upward flame spread can be predicted from the heat-release rate and the ignitability of the specimen, assuming one-directional thermal conduction within the specimen [36], [37], [38], [39], [40]. However, grooves or roughness on the surface make the heating and pyrolysis of the surface rather complicated through the increase of the surface exposed to the heating, establishment of two- or three-dimensional thermal conduction within the specimen, and the radiation between heated elements of the surface. A large-scale test is necessary on the upward flame spread at least for the following purposes:

— validation of upward flame-spread models based on the bench-scale ignitability and heat release rate tests;

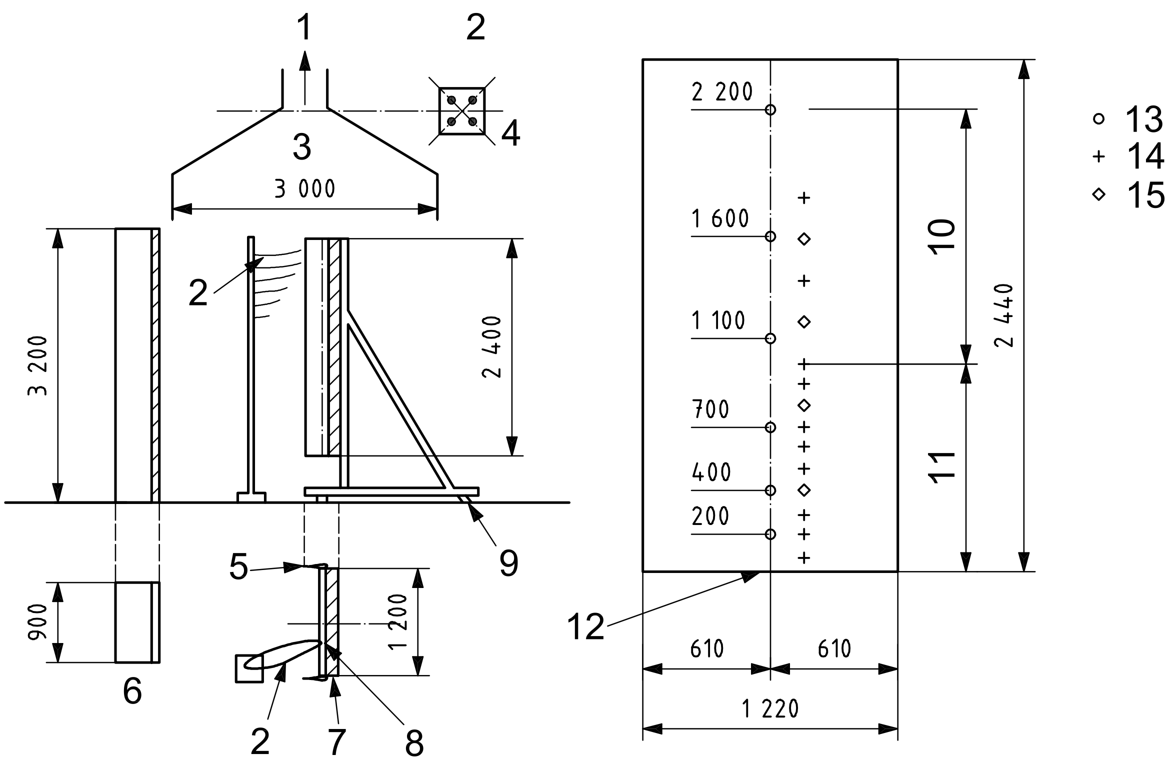
— evaluation of upward flame spread over an uneven vertical combustible surface or over assemblies of building materials.

7.4.2 Pre-normative research in large-scale vertical flame spread tests is continuing and no method has yet been developed into an International Standard [41]. However, it is considered to be valuable to provide information here on the BRI experimental procedure developed in Japan during 1990-93.

An arrangement for large-scale vertical flame spread tests is shown in Figure 14 [42]. A water-cooled copper sidewall is located on each side of the specimen to keep the flame spread one-dimensional. The radiant panel is used as the source of external radiation to the specimen. Measurements are made on heat release rate using the oxygen consumption method, its convective fraction using thermocouples at the entrance of the duct, temperature of surface/backsurface of the specimen, and surface heat flux. Weight loss can be measured with load cells beneath the specimen table. Measurement of flame height, xf, local extinction etc. can be made visually on a videotape [36], [37], [42] or by radiation measurement [43]. The specimen is ignited with a line burner generating a uniform flame at the bottom of the specimen surface.

Unlike opposed-flow flame spread, it is usually difficult to observe the location of the pyrolysis front, x_p, visually in a wind-aided flame-spread test since a wall flame can cover the unburnt surface beyond the pyrolysis front. For a non-charring material such as PMMA, the beginning of a plateau in the time-history of surface temperature at nearly the pyrolysis temperature indicates the arrival of the pyrolysis front at that height [36]. For a charring material, surface temperature tends to rise even after the pyrolysis has started at that height due to the char formation; however experiments have shown that the surface temperature at the beginning of a plateau in the time-history of surface-heat flux at the same height is close to the ignition temperature and the beginning of the heat-flux plateau nearly indicates the arrival of the front of the zone contributing fuel to the wall flame at that heat (Figure 15) [42]. Change of the colour of the surface starts earlier than the beginning of the heat-flux plateau. Development of wall fire can stop at some height. This maximum height of the pyrolysis front, X_{poff}, is worth measuring for the evaluation of fire safety related to upward flame spread.

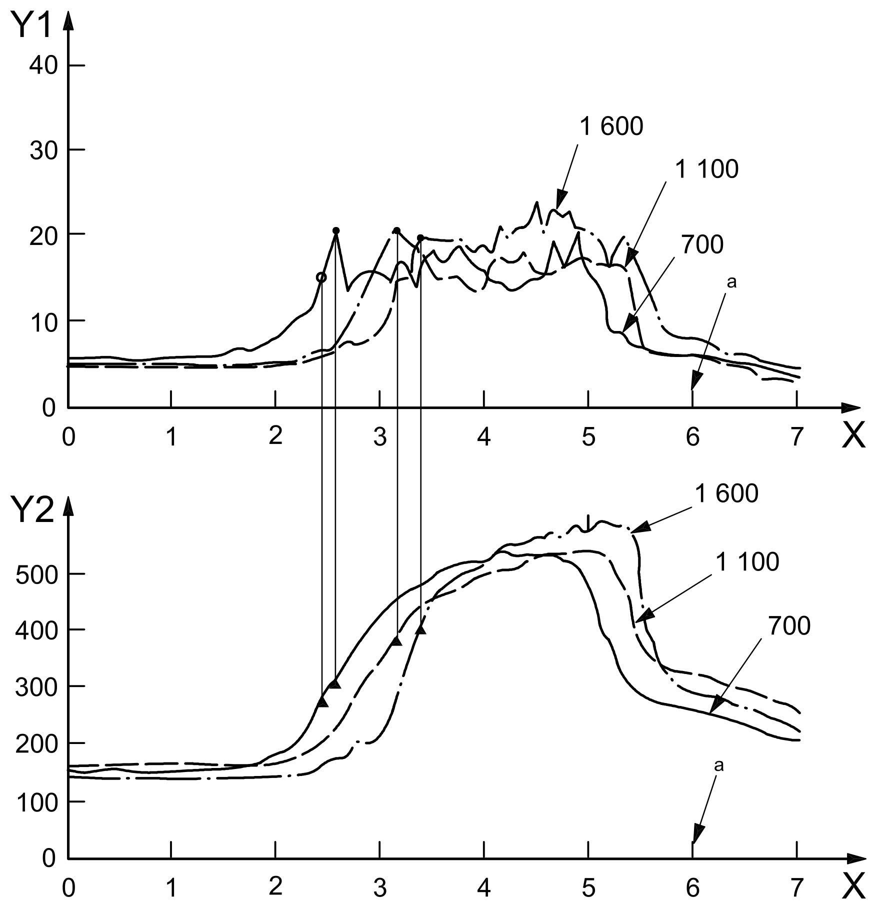
Dimensions in millimetres



Key

1 gas analysis
2 thermocouples
3 hood
4 duct section
5 side wall (100 mm long)
6 radiant panel
7 insulation (25 mm thick)
8 specimen
9 load cell
10 200 mm intervals
11 100 mm intervals
12 ignition source
13 heat flux gauge
14 surface temperature
15 backsurface temperature

Figure 14 — Experimental arrangement and specimen for large scale vertical flame-spread test (BRI, Japan)



Key

X time from ignition, expressed in minutes

Y1 heat flux, expressed in kW/m^2

Y2 surface temperature, expressed in degrees Celsius

a Burner off.

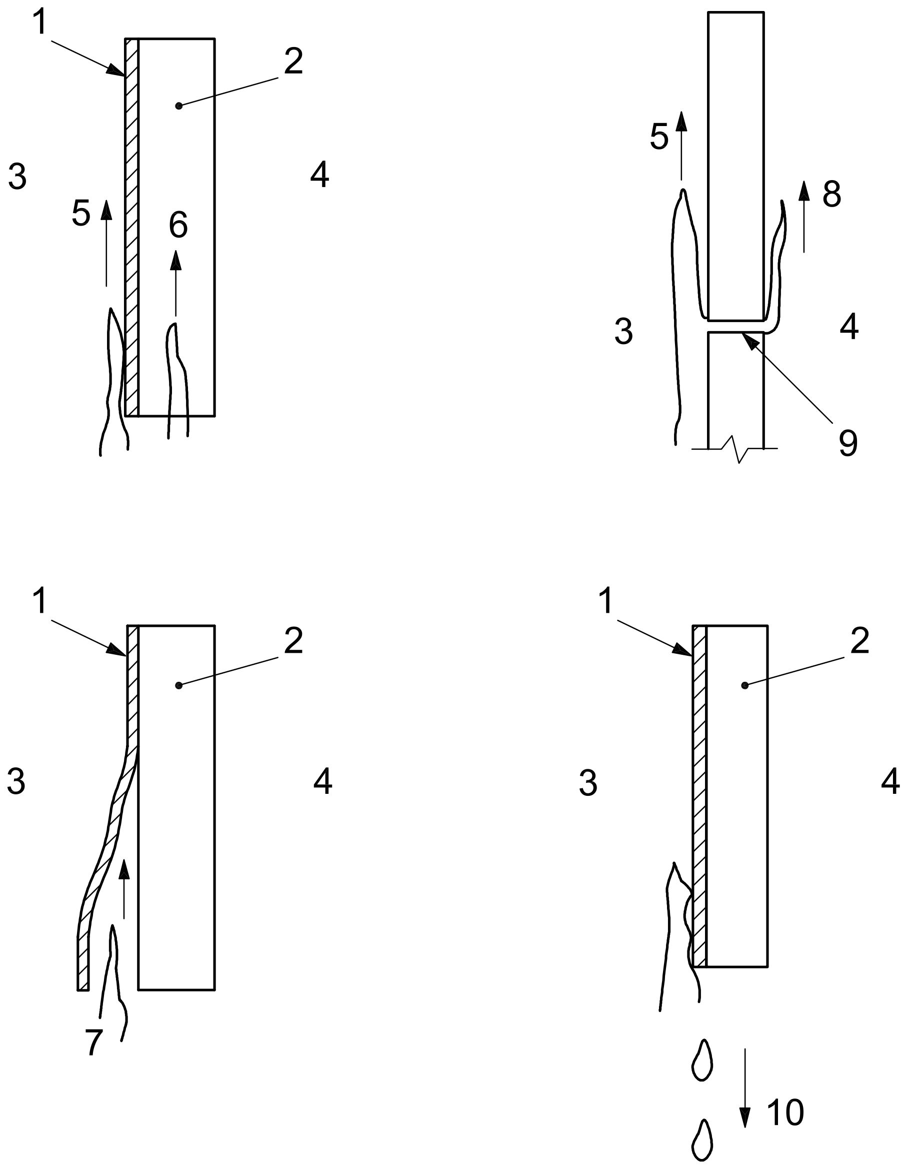
Figure 15 — Time histories of surface heat flux and surface temperature during an upward flame-spread test at three positions

8 Flame spread within assemblies

Figures 16 and 17 can assist schematically to explain some flame-spread mechanisms that can occur within composites or assemblies. For example, a cavity can be created behind a facing due to shrinkage of materials behind the facing after exposure to heat and this can provide an additional route for flame spread.

Flame spread in ducts (horizontal or vertical) and concealed spaces (such as ceiling voids or floor spaces) can pose a serious problem. The geometry of this type of space is usually such that at least two of the bounding surfaces are in close proximity to each other and this tends to result in high interactive radiative heat feedback between surfaces. These spaces can also contain a high density of fuel in the form of cables or piping. In such geometries, the spread of flame can be very rapid with a mechanism similar to that described for B.a [see 3.3 a)]. The spread of flame over combustible surfaces (linings or services) in such confined spaces can be ventilation-controlled.

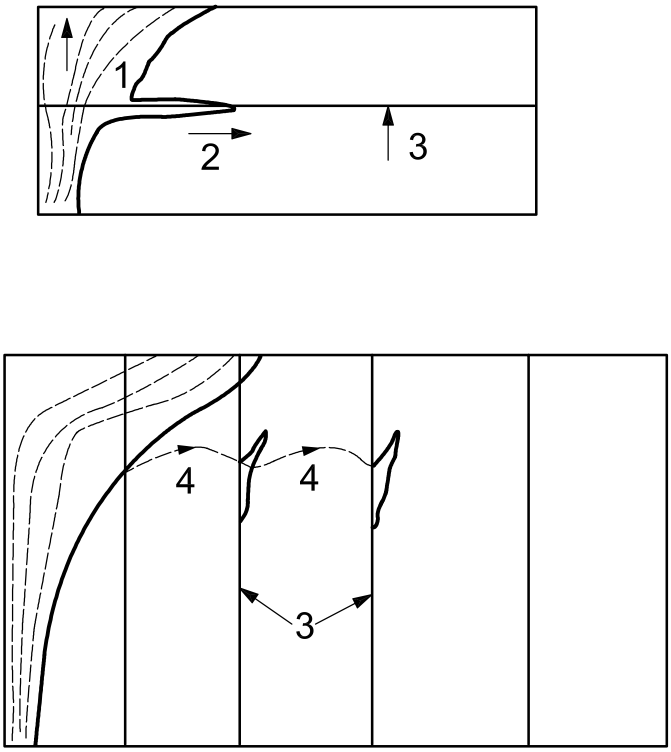
The Schlyter test [44], [45] has been developed similarly to the Brandschacht test (see Table 3) to evaluate the vertical flame spread over the surface of materials and particularly for the assessment of ducts.



Key

1 facing
2 substrate
3 front
4 back (either to open or to air-gap within the building assembly)
5 spread over face
6 spread up edge or joint
7 spread behind delaminating facing
8 spread over rear face due to passage through joint (or cracks in product)
9 joint
10 downward spread from flaming droplets/particles

Figure 16 — Vertical spread of flame (side view of vertically oriented products)



Key

1 spread over face

2 spread along joint

3 joint

4 leapfrogging of flames from joint to joint (over protective facing)

Figure 17 — Horizontal spread of flame (front view of vertically oriented products)

9 Flame spread by flaming droplets/particles

9.1 Description of flame-spread process with flaming droplets/particles

The production of flaming droplets and/or particles characterizes certain materials and assemblies (such as thermoplastics, bitumen, wood laminates, etc). These burning droplets/particles can be either glowing or flaming when they fall and under some conditions can induce fire propagation from one unconnected surface to another, causing secondary flame spread. This can give rise to a potential for an increase in both fire growth and in burning area due to flame spread to combustible material situated below the fire (for example, carpets, furniture, stored items, adjacent roof-coverings, etc). This behaviour can be described as discontinuous flame spread.

A mechanism for downward spread from flaming droplets/particles is shown in Figure 16.

9.2 Test methods to characterise flaming droplets/ particles

A number of test methods have been developed to observe or classify burning droplets and particles, either as part of their scope [26], [27], [46], [47], [48], [49], [50], [51] or as a dedicated test [68, 52]. However there are no test methods that have been developed within ISO/TC 92 that allow quantification of this phenomenon alone. Burning droplets are observed in the ISO 9705 small-room test but evaluation of the number and burn duration of these occurrences can prove difficult in practice due to smoke obscuration in the room and the limited view angle through the doorway opening. The large flame envelope also makes the observation of flaming droplets/particles difficult, unless they fall outside the burner zone.

Wall exposure conditions are considered in ISO 5658-2 and ISO 5658-4 with thermal exposures up to 50 kW/m^2. These tests can also be used for characterisation of products that can form burning droplets/particles. There are no criteria for this behaviour in these ISO standards but some specifiers have included criteria based on operator observations.

NF P92-505 [68], [69] is a small-scale test based on the exposure of a horizontally orientated test specimen to a heat flux of 30 kW/m^2. Products are classified if flaming material ignites a cotton wool pad situated directly below the test specimen. Small-scale flame tests used for classifying electrical products [46], [47], [48] also allow some characterization of flaming droplet behaviour. However, the small size of the test specimens and the limited thermal attack of the ignition source restrict their applicability.

9.3 Typical fire scenarios involving flaming droplets/ particles

Typical scenarios in which flaming droplets/particles may cause fire spread are exemplified below.

a) Fire in an electrical enclosure:

In this scenario, a fire caused by an electrical fault spreads to other components and the walls, top and floor of the enclosure. The fire can be simulated with a small flame-ignition source and an electrical component in a vertical or horizontal orientation.

b) Fire in a room:

The scenario can be a large room (walls-only type test) or a small room (walls and ceiling test). This scenario fits with the adoption by the European Commission of the SBI corner test with a 30 kW flame ignition source. In the European classification system for construction products, flaming droplets/particles are classified by the SBI test as d0, d1 or d2. The classification achieved depends on the burn duration of flaming droplets/particles that have fallen outside the burner zone. This characterization is limited in its applicability for fire-safety engineering use since the test specimen is constructed as a corner wall configuration without a ceiling.

c) Fire in a ceiling:

The fire is initiated within the ceiling (including suspended structure) or within a plenum. The fire can start from an electrical fault from lighting or other components. The fire can then involve other products within the ceiling area that produce flaming droplets or particles. If the integrity of the ceiling is inadequate, these flaming droplets/particles can subsequently fall below the ceiling and propagate the fire further at the lower level.

d) Fire in a roof

Roofs can become involved in fires from either internal or external exposure. Much testing has been done based on the simulation of external fire conditions using flaming brands with or without radiation (typically 12 kW/m^2) and with or without wind. Penetration of the roof is a key parameter and the potential to spread the fire by flaming droplets/particles exacerbates this situation. This scenario has been addressed by ISO/TC 92/SC 2 in ISO 12468-1 [53].

The hazards associated with internal roof fires are similar to those described for fires in ceilings [see Clause 9 c)]. In these cases the hazard from flaming droplets/particles is that they can ignite combustibles in the loft space. Since many roofs are not flat but are installed with pitches up to 45°, there is an added hazard from roofing components that melt and potentially spread the fire downwards by means of flaming droplets/particles [56], [57], [70].

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