TECHNICAL REPORT

ISO/TR 13387-5

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Fire safety engineering —

Part 5:
Movement of fire effluents

Ingénierie de la sécurité contre l'incendie —

Partie 5: Mouvements des effluents du feu

Reference number
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Contents

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet iso@iso.ch

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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 main task of ISO technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard (“state of the art“, for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13387-5, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

It is one of eight parts which outlines important aspects which need to be considered in making a fundamental approach to the provision of fire safety in buildings. The approach ignores any constraints which might apply as a consequence of regulations or codes; following the approach will not, therefore, necessarily mean compliance with national regulations.

ISO/TR 13387 consists of the following parts, under the general title *Fire safety engineering*:

— *Part 1: Application of fire performance concepts to design objectives*

— *Part 2: Design fire scenarios and design fires*

— *Part 3: Assessment and verification of mathematical fire models*

— *Part 4: Initiation and development of fire and generation of fire effluents*

— *Part 5: Movement of fire effluents*

— *Part 6: Structural response and fire spread beyond the enclosure of origin*

— *Part 7: Detection, activation and suppression*

— *Part 8: Life safety — Occupant behaviour, location and condition*

Introduction

Fire effluent, i.e. smoke and gaseous species, cause a substantial threat to life and property. One of the fire safety objectives when designing a building is to ensure that the occupants are ultimately able to leave the building without being subject to hazardous or untenable conditions. In premises with significant financial or cultural value, one of the fire safety objectives is to prevent the damage to property. To meet these objectives one may either limit the generation of fire effluent or control the flow of fire effluent. The former is discussed in ISO/TR 13387-4, whereas the latter is the topic of this Technical Report.

Assessment of fire effluent flow within a building, and assessment and design of smoke control and venting systems is a common feature in fire safety design of a building. In most of the existing fire safety regulations measures are taken to control the movement of fire effluents. Typically in prescriptive codes, the requirements are set as the minimum effective area of smoke vents as a percentage of the total roof area. The required smoke vent area may vary within the range of 0,25 % to 5 % of the roof area.

Engineering methods for the design of smoke control systems have been available for a long time in the form of nomograms or calculation methods (see reference [1] of the bibliography). In both approaches, however, the design of smoke control is treated as an isolated form from the rest of the fire safety design, although in real fires the movement of fire effluent highly depends on the interaction with other features of the design.

Phenomena controlling smoke movement have been actively studied during recent decades. Calculation methods and computer codes have been developed to make the necessary evaluations. At the same time advances in experimental techniques have made it possible to produce input data for the calculation methods and to run large-scale tests for assessing the validity and limitations of the models.

This part of ISO/TR 13387 is intended for use together with the other Technical Reports produced by SC 4 as described in clause 5. For some applications this document alone may be sufficient.

Clause 6 of the report describes and provides guidance on the methods available to describe the processes involved in movement of fire effluent.

Clause 7 describes and provides guidance on the use and evaluation of different types of engineering methods available to describe the movement of fire effluent, i.e. hand calculations, zone models, field or Computational Fluid Dynamics (CFD) models, and experiments.

Clause 8 briefly describes different techniques available to control movement of fire effluent. The quantitative information may be related to specific test conditions and/or specific commercial products, and the application of data under different conditions may result in significant errors.

Fire safety engineering —

Part 5:
Movement of fire effluents

1 Scope

This part of ISO/TR 13387 is intended to provide guidance to designers, regulators and fire safety professionals on the use of engineering methods for the prediction of movement of fire effluents within and outside of a building. It is not intended as a detailed design guide, but could be used as the basis for the development of such a guide.

This part of ISO/TR 13387 also provides a framework for critically reviewing the suitability of an engineering method for assessing the potential for movement of fire effluent during the course of fire. The document also provides guidance on the means to assess the effectiveness of fire safety measures meant to reduce the adverse effects of movement of fire effluents. The methods for calculating the effects of design fires for use in the design and assessment of fire safety of a building are also addressed.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 13387. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TR 13387 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO/TR 13387-1, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives.*

ISO/TR 13387-2, *Fire safety engineering — Part 2: Design fire scenarios and design fires.*

ISO/TR 13387-3, *Fire safety engineering — Part 3: Assessment and verification of mathematical fire models.*

ISO/TR 13387-4, *Fire safety engineering — Part 4: Initiation and development of fire and generation of fire effluents.*

ISO/TR 13387-6, *Fire safety engineering — Part 6: Structural response and fire spread beyond the enclosure of origin.*

ISO/TR 13387-7, *Fire safety engineering — Part 7: Detection, activation and suppression.*

ISO/TR 13387-8, *Fire safety engineering — Part 8: Life safety — Occupant behaviour, location and condition.*

ISO 13943, *Fire safety — Vocabulary*.

3 Terms and definitions

For the purposes of this part of ISO/TR 13387, the definitions given in ISO 13943, ISO/TR 13387-1 and the following apply.

3.1
ceiling jet
horizontal gas stream under a ceiling

3.2
extinction coefficient
a constant determining the decay of light intensity in smoke per unit path length, given by $K = (1/l) \ln(I_0/I)$

It is expressed in m^{-1}.

3.3
fire effluent
all gaseous, particulate or aerosol effluent from combustion or pyrolysis

3.4
opening factor
$A_v (h_v)^{1/2}/A_T$

It is expressed in $m^{1/2}$.

3.5
plume
buoyant gas stream above a localized fire

3.6
vent
an opening for passage of fire effluent out of an enclosure

3.7
ventilation factor
$A_v (h_v)^{1/2}$

It is expressed in $m^{5/2}$.

4 Symbols and abbreviated terms

A_{fuel} surface area of fuel, expressed in m^2

A_T total area of bounding surfaces in an enclosure, expressed in m^2

A_v area of an opening, expressed in m^2

C_i concentration of species i, expressed in kg/m^3

C_{in} concentration of species i in a flow into an enclosure, expressed in kg/m^3

c specific heat capacity, expressed in J/(kg·K)

f_X yield of species X, where X = CO, CO_2, ...

g acceleration due to gravity, expressed in m/s^2

h_v height of an opening or height of a shaft, expressed in m

I intensity of light after passing through smoke, expressed in W/m^2

I_0 intensity of light in clean air, expressed in W/m^2

K extinction coefficient, expressed in m^{-1}

k thermal conductivity, expressed in W/(m·K)

$\dot{m}_{fuel}$ mass loss rate of fuel, expressed in kg/s

$\dot{m}_X$ generation rate of species X, where X = CO, CO_2, ..., expressed in kg/s

$\dot{Q}$ heat release rate, expressed in W

P pressure, expressed in Pa

T_g gas temperature or outside ambient temperature, expressed in K

T_0 initial surface temperature or inside temperature, expressed in K

t time, expressed in s

V_{encl} volume of enclosure, expressed in m^3

ρ density, expressed in kg/m^3

Δ difference (as in ΔP or $\Delta\rho$)

5 Subsystem 2 of the total design system

The approach adopted in the work of ISO/TC 92/SC 4 is to consider the global objective of fire safety design. The global design, described in more detail in the framework document ISO/TR 13387-1, is sub-divided into what are called subsystems of the total design. The key principles of the global design approach are that interdependencies among the subsystems are evaluated and that pertinent considerations for each subsystem are identified.

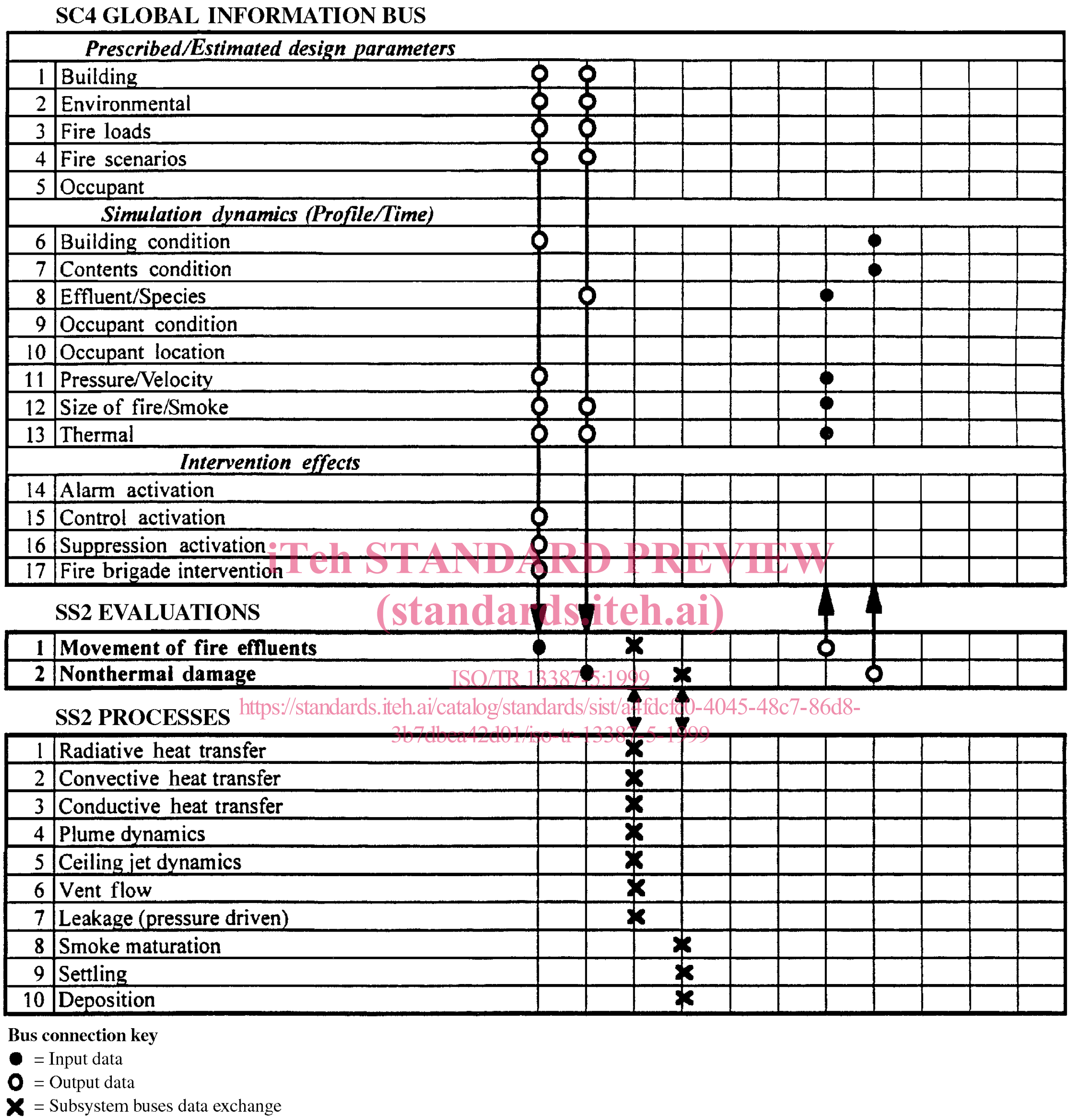
In the framework document, the total fire safety design is illustrated by an information bus analogy (see Figure 1). The information bus has three layers: global information, evaluation and process buses. The information bus analogy of Subsystem 2 (SS1), movement of fire effluents, is illustrated in Figure 1. SS2 draws on other subsystems for a prescription or characterization of fire. SS2 provides information on movement of fire effluents for the other subsystems to be employed.

SS1, for example, provides information on heat, smoke and species generation, which then is applied by SS2 for the calculation of smoke movement out of the room and in the building. The information may then be used by SS5 to assess evacuation and rescue provisions. The prediction of activation of fire detectors, sprinklers or smoke vent opening devices is provided by SS4. The prediction of spread through barriers or openings beyond the room of fire origin is provided by SS3.

The evaluations and the processes needed to do the evaluations are discussed in detail in clause 6.

ISO TC 92/SC 4 FIRE SAFETY ENGINEERING BUS SYSTEM

Subsystem 2 (SS2) — Movement of fire effluents



For explanations of terms used in conjunction with the global information bus, see ISO/TR 13387-1.

Figure 1 — Illustration of the global information, evaluation and process buses for SS2

6 Subsystem 2 evaluations

In this clause various processes of movement of fire effluents and the threat to life, property and environment shall be discussed. The required input information and the possible output information shall be identified. Areas for which shortages in engineering methods and lack of knowledge are known to exist will be addressed. The text will make reference to existing acknowledged literature, whenever such is available.

6.1 Movement of fire effluents

6.1.1 Role in fire safety engineering design

The flow chart in Figure 2 outlines the main stages of evaluating the movement of fire effluents within and beyond the room of origin. In using the flow chart it is assumed that all the source terms needed for evaluating movement of fire effluents shall be given by SS1 (ISO/TR 13387-4) or as design fires described in ISO/TR 13387-2.

6.1.1.1 Input

The evaluation of movement of fire effluents (see Figure 1) may require as input information the following:

— building parameters (for example, thermal properties, geometry, location of openings, etc.);

— environmental parameters (for example, velocities and prevailing direction of wind, outside temperature, temperature distribution in the building, internal air movements caused by mechanical ventilation systems);

— size of fire/smoke (for example, rate of heat release of the fire, plume mass flow, smoke generation rate);

— thermal profile (for example, temperature distribution in the plume);

— pressure/velocity profile (for example, pressure profile in the room of origin);

— effluent species profile (for example, species generation rate, mass flow of species in the plume).

6.1.1.2 Output

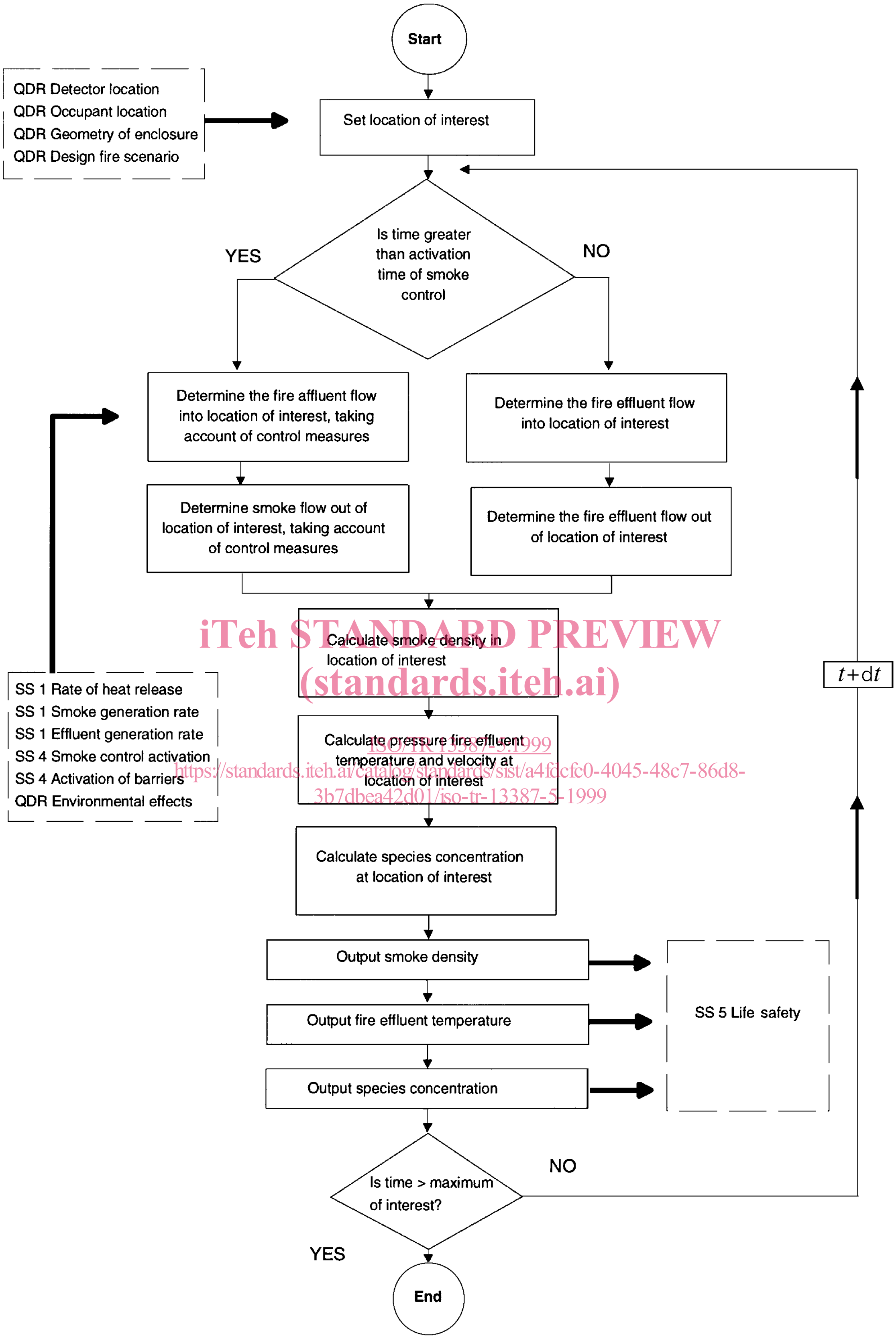
The evaluation of movement of fire effluents (see Figure 1) provides information about the following:

— size of fire and/or smoke (for example, smoke density distribution in the building);

— thermal profile (temperature and heat flux distribution in the building);

— pressure/velocity profile (for example, pressure at smoke vents, flow through vents, velocity in the corridor jet);

— effluent species profile (for example, gaseous species concentration distribution in the building);



The dark arrows indicate interaction with the global information in Figure 1.

QDR = Qualitative design review has been discussed in ISO/TR 13387-1.

Figure 2 — Flow chart for movement of fire effluents

6.1.2 Processes of movement of fire effluents

6.1.2.1 General

The spread of a fire effluent is caused, primarily, by its buoyancy and the increase in volume resulting from the entrainment of air. Its spread can be controlled by means of smoke barriers, smoke extraction and opposing flows (pressure differentials). The techniques most commonly used to limit the extent of smoke spread are summarized in clause 8.

The temperature of a fire effluent, and hence its buoyancy, depends on the rate of heat release of the fire and the entrainment of cool air into the smoke plume. Entrainment reduces both the concentration of smoke particles and the temperature. This increases visibility but also increases the volume of smoke.

The effluent plume from a fire within an enclosure will rise to ceiling level and then spread horizontally to form a layer beneath the ceiling. Generally, the mass flow of the burnt fuel is so small compared with the mass flow of the entrained air that for practical purposes it may be ignored. For smooth ceilings or ceilings of limited extent the entrainment is small during horizontal flow and can usually be ignored. However, when the smoke flows around obstacles (for example, beams) or through apertures (for example, a doorway), the rate of entrainment increases.

Smouldering fires typically have low buoyancy and the smoke may never form an upper layer due to higher initial temperature close to the ceiling or forced flow in the enclosure.

6.1.2.2 Plumes

The buoyant gas stream above a localized burning area is called a fire plume. The fire plume is characterized by its temperature and velocity distribution, which can be transformed into mass and energy flows at various heights above the source.

Plume models have been a subject of active research especially in the early 1980's. By simplifying approximations to basic laws and fits to experimental data, a number of semi-empirical plume models have been developed. General discussions on fire plumes have been presented, for example, in detail in reference [2] and in a summarized form in references [3] and [4]. Useful reading to the user of plume models is also the review paper[5] in which various expressions describing plume and ceiling flows are compared and discussed. Several papers comparing the results obtained by plume models have been published in journals or presented in conferences during the last ten years; one of the most recent and useful ones is reference [6].

Many of the plume models used in fire-safety engineering describe the fire as a point source. The effect of the finite diameter of the fire is taken into account by assuming the fire is a virtual source below or above the actual fuel surface depending on the diameter and the rate of heat release of the fire, i.e., the ratio of the buoyancy and the momentum of the gas stream. Expressions can be found, however, also for sources of other geometries. At one extreme a fire source can be regarded as a two-dimensional line source. Non-circular flat fuel sources, which are almost square, can be treated as circular sources with an effective diameter resulting in the same area as in the real source. For some burning objects like rack storage the depth of the fire source cannot be neglected. Semi-empirical equations are derived for these special cases.

If the burning object is close to a wall or a corner, the plume equations for circular fire sources are transferred by using a virtual source extending as a mirror image on the other side of the wall. The simple imaging method results in temperatures which are close to those measured in wall or corner plumes, although the effects of the wall surfaces on the turbulence are neglected. For finite sources adjacent to the wall, the plume expressions are scarce, and considerable engineering judgement is needed when analysing such fire scenarios, for example, by zone models (see 7.3).

When selecting a fire plume one should pay attention to the assumptions made when developing the plume expression. Usually, the heat release rate in the plume property expressions equals the convective fraction of heat release rate. The convective heat release rate is typically assumed to be 70 % of the total heat release rate. However, the commonly used McCaffrey plume expressions use the total heat release rate[7]. The expressions are always fitted to a limited set of experimental data and therefore the empirical coefficients may not be applicable to the scenario under consideration. The most commonly used plume models have been originally calibrated against small fire (heat release rates < 1 MW). It is necessary to be particularly careful when extending the application to a