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Fire safety engineering — Guidance for use of fire zone models

Ingénierie de la sécurité incendie — Guide sur l'utilisation de modèles incendie de zone

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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order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn.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again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.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 13447 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

Introduction

This Technical Specification is intended for the use of fire safety practitioners and regulators who use or assess one- or two-zone fire models as part of a fire safety design or analysis. Examples of users include fire safety engineers, authorities having jurisdiction, such as territorial authority officials; and fire service personnel. It is expected that users of this Technical Specification are appropriately qualified and competent in the fields of fire dynamics. It is particularly important that the model users understand the theoretical background and limitations of zone fire models.

In addition to the typical clauses (1, 2, 3 and 4, this Technical Specification includes the following clauses:

— *5: Describes fire zone models in general including underlying principles and assumptions*

— *6: Discusses input parameters and data sources of fire zone models*

— *7: Discusses sensitivity of fire zone models to input variations*

— *8: Gives guidance on use and limitations of fire zone models*

Fire safety engineering — Guidance for use of fire zone models

1 Scope

This Technical Specification provides guidance for assessing the use of fire zone models for calculating gas temperature and concentrations and smoke layer position due to fire within an enclosure. It contains general guidance to be read in conjunction with specific model documentation provided by the model developers. It is not a basis for justifying the use of any particular model.

It is important that users of fire zone models understand the theoretical basis of a model and are capable of assessing the accuracy and validity of the results.

Zone models may also include additional sub-models for predicting related phenomena such as sprinkler, thermal or smoke detector activation, mechanical ventilation, glass fracture or flame spread. A detailed discussion of these related sub models is beyond the scope of this Technical Specification.

NOTE An overview of features covered by various zone models can be found in a survey by Olenick and Carpenter.[1]

This Technical Specification is not intended as a basis for regulation.

2 Normative references

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

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and the following apply.

3.1
zone model
calculation model for predicting the environment resulting from a fire in an enclosure where one or more distinct gaseous zones represent layers formed by thermal stratification of buoyant gases

4 Symbols (and abbreviated terms)

$\dot{Q}$ (kW)	Time-dependent rate of heat release
$\dot{m}$ (g/s)	Time-dependent fuel mass loss rate
Δh_c (kJ/g)	Effective heat of combustion

5 General description of fire zone models

5.1 What is a fire zone model?

A fire zone model is a calculation method for predicting the fire effects within an enclosure. The calculations are based on the conservation of mass and energy applied separately to control volumes that subdivide an enclosure into one or more zones. At any instant in time, the properties of each zone are assumed to be uniform. The fire is treated as a source of mass and energy and is a user-prescribed input to the calculation. Figure 1 showing a room elevation illustrates some conceptual features commonly included within a zone model. ISO 16735 gives algebraic formula for calculating specific characteristics of smoke layers generated by fire.[2]

A fire zone model is most commonly a numerical fire model in the form of a computer program but calculations can be done using spreadsheet applications or even by hand. Most commonly used zone models comprise two zones in the form of a hot upper layer and a cooler lower layer. This provides sufficient resolution for many simple pre-flashover fire simulations. However one-zone models have also been developed (e.g. for fully developed postflashover fires) where the assumption of a well-mixed uniform zone is appropriate. Alternatively, fundamental equations for mass and energy conservation can also be extended to more than two zones to provide greater resolution over the height of a compartment.

Multi-room zone models represent a case of multiple interconnected zones where rooms are connected by openings in either the walls or floor/ceiling.

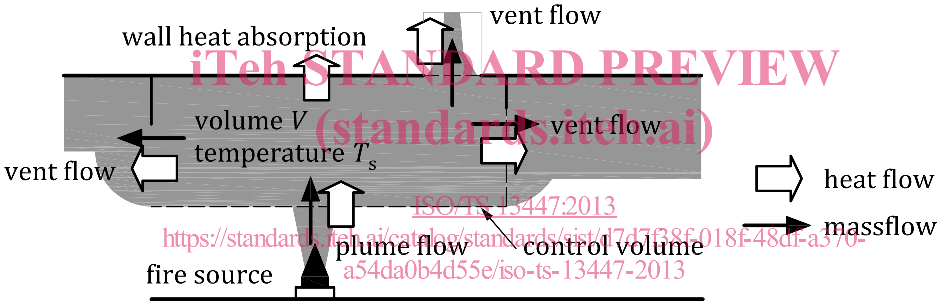

Figure 1 — General heat and mass conservation in an enclosure with a fire source

5.2 Applications

Zone models enable predictions to be made of the smoke temperature, smoke volume (and layer height) and species concentrations within an enclosure resulting from a fire of a given size.

Depending on the level of functionality included within a zone model, typical applications may include:

— predicting the smoke-filling time for a compartment of a given size and for a fire with known time-dependent characteristics ;

— evaluating the life safety tenability of a fire environment for comparison with design criteria ;

— reconstructing a past fire event to support or refute theories about the development of a fire ;

— determining the likely fire size at the time of sprinkler operation and/or the response time of a sprinkler (where a sprinkler response submodel is included) ;

— determining the smoke extract capacity for naturally or mechanically ventilated spaces ;

— determining the impact on important equipment to ensure its continued functionality.

5.3 Advantages

The simplified physics included in zone models mean they are less computationally demanding and are relatively quick to run compared to other state-of-the-art models (e.g. computational fluid dynamics) that attempt to describe the physics using the best available methods. It is an advantage to run a large number of simulations for the same computing resource because it allows the sensitivity of the outputs to the various input parameters to be investigated in greater depth. This is particularly useful for design applications where the exact fire input parameters are not known, yet may have a large influence on the predicted outputs.

The principal advantage of using a computer based zone model over algebraic equations is the flexibility it provides to address some of the transient effects such as heat release, species yields, conduction, automatically opening vents or operating fans based on the fire environment. In addition some zone models offer multi-compartment and /or multi-fire capabilities.

However, use of simplified physics also means zone model simulations may have more limitations in predicting the fire environment than more detailed models for a given scenario. Nonetheless, the accuracy achieved by a zone model can be sufficient for many applications especially where uncertainty in design leads to added conservatism in the selection of model inputs.

5.4 General principles, assumptions and consequences

5.4.1 General

A zone model subdivides a room into one or more control volumes (or zones) with an assumed uniform gas temperature and density throughout the volume. In the simplest case, a single zone model can be used for cases where the fire environment in the room is to be treated as a 'well stirred reactor' such as a fully developed post-flashover fire. However, for growing pre-flashover fires, two zones separated by a horizontal layer interface is the most common approach. Models with more than two zones (vertically stacked) have also been developed[3][4] but are less common.

For small compartments of simple geometry, zone models are often assumed to be sufficiently accurate for most situations involving growing pre-flashover room-scale fires. However, this will be dependent on the goals of the analysis. The user needs to consider whether adequate validation has been demonstrated for the selected model in relation to the chosen scenario in the proposed analysis. In subclause 8.8 a more thorough discussion on zone model limitations is available.

5.4.2 Conservation of mass and energy

Fundamental (conservation) equations of energy and mass transport are applied to each control volume. Mass flows enter and leave each control volume via the plume and through openings in the wall or ceiling or via ducts/fans forming part of a mechanical ventilation system. There are also enthalpy flows associated with each mass flow entering and leaving the control volume and heat transfer terms like radiation and reradiation, along with the combustion energy released by the burning fuel. Heat losses by conduction through surfaces or by radiation through openings determine the net heat transferred to or from the control volume and the resultant change in the average temperature of the control volume gases.

The position of the interface between the adjacent zones depends on the volume of each zone relative to the volume of the room. The conservation equations generally solve for the volume and gas temperatures of each zone as well as the room pressure. Many other formulations of the conservation equations may also be used.[5] Most zone models represent each volume as a horizontal layer of gas with a constant cross-section (defined by the area of the room and a height that varies with time). A constant cross-section is not a necessary condition and some models allow for variations such as sloping ceilings. However, most zone models assume the compartment to be a rectangular volume defined by a length, width and height, and since in this case, the cross-sectional area does not change during the calculation this in effect makes the zone model a one-dimensional analysis with properties able to vary only over the height dimension but not across the area of the enclosure.

Zone models do not explicitly solve equations for conservation of momentum. This means that hot gases are assumed to rise and spread instantaneously beneath a ceiling ignoring the finite time needed for the plume and ceiling jet flows to reach the ceiling and to spread to the far reaches of the enclosure. This assumption is usually reasonable for small enclosures, but for large enclosures in practice it may take many 10s of seconds for a flow of gases from the fire to reach the furthest location in the enclosure. Neglecting this effect may be conservative or non-conservative, at least in theory, depending on the design goal. E.g. for the activation time of a detector neglecting the effect would underestimate the detection time and reduce the safety margin between time of evacuation and untenable conditions. However initial conservatism associated with instantaneous spread beneath a ceiling may be reduced or reversed at later times after the hot layer is established with non-uniformities in the position of the smoke layer occurring in compartments of large area due to gravity waves, heat losses, and loss of buoyancy etc.

A two-zone model differentiates the upper and lower layer by a difference in the layer properties (e.g. temperature, density, concentration). Each uniform layer is treated as an ideal gas. An upper layer can exist at any time from the beginning of the calculation and it may or may not be a real smoke layer. A non-smoke upper layer can be developed by ventilation conditions alone wherever there are ambient temperature differences between rooms or from a room to the outside.[6] However, this would usually be of little consequence when evaluating the fire environment for the purpose of determining human survivability.

Variation of air temperature over the height of a compartment under ambient non-fire conditions is generally ignored. In practice, these temperature gradients could lead to early stratification of smoke at some distance below the ceiling which can be important when attempting to model the performance of smoke detection systems. These effects are usually only important earlier in the fire development when the plume flows are relatively weak and the gas temperature rise is modest and again would usually be of little consequence when evaluating the fire environment for human survivability.

5.4.3 Vents

Zone models typically use the Bernoulli equation to relate the pressure and velocity within a flowing stream of (incompressible) fluid allowing the mass flow through a vent opening to be calculated while friction losses are ignored. The mass flow rate of gases through a wall opening is dependent on the hydrostatic pressure profile either side of the opening. A detailed description of the governing algebraic equations is given in ISO 16737.[7]

In large buildings with many hundreds or thousands of compartments and vents, the use of a traditional two zone model becomes impractical, and more efficient network models[8] have been developed that use a simpler lumped-parameter approach to conserve mass, energy and momentum at the vent connections (or ventilation nodes). However further discussion of network models is beyond the scope of this Technical Specification.

5.4.4 Fire growth

Normally zone models do not model the fire growth i.e. the actual rate of heat release from the fire. The user is required to provide either the rate of heat release or the fuel mass pyrolysis rate and heat of combustion. If the zone model also calculates the concentration of oxygen in each layer then the burning rate and corresponding heat release rate may be constrained to a lower level that can be supported by the available oxygen supply. In this case the model may also track unburned fuel as an additional species which may be allowed to burn in other rooms or outside the enclosure provided sufficient oxygen is available at that location.

If there is a considerable amount of unburned fuel in remote spaces from the room of origin this would suggest that the room of origin may be a well stirred condition indicating a one-zone approach is reasonable.

Preflashover fire growth may be simulated based on the characteristics of actual fuel objects (room contents) or by the use of a generic fire growth curve such as a t-squared fire. In the former case, unless the model includes the capability of estimating the ignition and burning of secondary objects, the simulation can only be based on the initial burning object and it will not be possible to evaluate the fire environment beyond the time that more than one object would be involved in practice. In the latter case of a t-squared or similar generic curve describing the rate of heat release, fire growth may be assumed to continue until restricted by the oxygen supply, or until an assumed peak burning rate is reached. If fully developed or post-flashover burning is to be simulated then the selected model shall have been validated for that purpose.

5.4.5 Plumes

ISO 16734[9] describes a set of equations for quasi steady, axisymmetric fire plumes.

The fire is considered as a point source of energy and particulates manifested by a plume that transports mass from the lower to the upper layer through a process called entrainment. The plume volume is assumed to be small in comparison with the volume of the compartment. No mass is transferred across the interface between the layers except via the plume and vent mixing flows. At some stage during the course of a fire, negatively buoyant flows may be generated due to convective cooling of gases in contact with wall surfaces, resulting in mixing of smoke with air contaminating the "smoke-free" layer. Entrainment is calculated using both theory and empirically derived terms. A variation of about 20 % in entrainment may be expected between the empirically derived entrainment coefficients commonly used.[10] It is assumed that the plume is unaffected by ventilation systems or wind as well as any other induced flows (e.g. due to make-up air supplies). If these effects are present the plume can be disturbed or blown over increasing the total amount of air entrained into the plume and leading to an increase in the thickness of the upper layer and corresponding reduction in temperature. In cases where these induced flows are high, smoke-logging of the space may be observed.

6 Input parameters and data sources for zone fire models

6.1 Enclosure geometry

Zone models usually require enclosures to be represented as rectangular volumes with uniform cross-sectional area over their height. Non rectangular spaces can be modelled as an equivalent rectangular volume such that floor area and perimeter length are conserved. This maintains both the volume and surface area to correctly represent heat transfer. It is also required that the height be conserved because the plume entrainment and smoke production calculations are strongly influenced by the vertical distance between the fire and the smoke layer interface.

Some zone models allow for variations in cross section area over the height of an enclosure (e.g. for a sloping ceiling) in the calculation of the upper layer volume and layer height. However, this capability may not be very important in situations where the occupants are located well below the sloping roofline, where the cross-sectional area of the smoke layer interface is the same as the floor area. If however occupants are assumed to be located at elevations nearer the roof, it is important to carefully consider the time history of the smoke layer, particularly in the early stages of fire development.

In cases where a zone model requires the enclosure to be represented by a rectangular volume, a space with a pitched roof shall be represented by an equivalent rectangular volume. The height of the rectangular volume may be equal to the highest level of the roof, and the floor area adjusted such that the overall volume of the enclosure is conserved. Alternatively, where the height of the clear layer is the primary calculation of interest, the average height of the roof may be used and the floor area and perimeter length conserved. The first representation will more closely represent the entrainment rate and the volume/depth of the smoke layer in cases where the fire plume is located beneath the peak of the roof, however the differences in the calculated clear layer height are not great and generally either assumption may be acceptable.

If in practice the plume is horizontally offset from the peak of a sloping roof (see Figure 2), the actual entrainment is expected to be less due to the lower height over which entrainment occurs. In this case, it is usually conservative to locate the plume beneath the highest part of the roof to generate the greater smoke volume and faster smoke-filling rate. Therefore it generally acceptable to ignore the impact of lower offset plumes where conditions within the lower part of the enclosure are the primary concern.

