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Fire safety engineering — Assessment, verification and validation of calculation methods —

Part 2: Example of a fire zone model

Ingénierie de la sécurité incendie — Évaluation, vérification et validation des méthodes de calcul —

Partie 2: Exemple d'un modèle de zone

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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.

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The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

ISO 16730 consists of the following parts, under the general title *Fire safety engineering — Assessment, verification and validation of calculation methods*:

— *Part 2: Example of a fire zone model* (Technical report)

— *Part 3: Example of a CFD model* (Technical report)

— *Part 4: Example of a structural model* (Technical report)

— *Part 5: Example of an Egress model* (Technical report)

The following parts are under preparation:

— *Part 1: General* (revision of ISO 16730:2008)

Introduction

Certain commercial entities, equipment, products, or materials are identified in this document in order to describe a procedure or concept adequately or to trace the history of the procedures and practices used. Such identification is not intended to imply recommendation, endorsement, or implication that the entities, products, materials, or equipment are necessarily the best available for the purpose. Nor does such identification imply a finding of fault or negligence by the International Standards Organization.

For the particular case of the example application of ISO 16730-1 described in this document, ISO takes no responsibility for the correctness of the code used or the validity of the verification or the validation statements for this example. By publishing the example, ISO does not endorse the use of the software or the model assumptions described therein and states that there are other calculation methods available.

Fire safety engineering — Assessment, verification and validation of calculation methods —

Part 2:
Example of a fire zone model

1 Scope

This part of ISO 16730 shows how ISO 16730-1 is applied to a calculation method for a specific example. It demonstrates how technical and users' aspects of the method are properly described in order to enable the assessment of the method in view of verification and validation.

The example in this part of ISO 16730 describes the application of procedures given in ISO 16730-1 for a fire zone model (CFAST).

The main objective of the specific model treated here is the simulation of a fire in confined compartments with a natural or forced ventilation system.

2 General information on the zone model considered

The name given to the zone model considered in this Technical Report is “CFAST”. CFAST is a two-zone fire model capable of predicting the environment in a multi-compartment structure subjected to a fire. It calculates the time-evolving distribution of smoke and fire gases and the temperature throughout a building during a user-prescribed fire. This Technical Report describes the equations which constitute the model, the physical basis for these equations, and an evaluation of the sensitivity and predictive capability of the model.

The modelling equations take the mathematical form of an initial value problem for a system of ordinary differential equations (ODEs). These equations are derived using the conservation of mass, the conservation of energy (equivalently, the first law of thermodynamics), the ideal gas law, and relations for density and internal energy. These equations predict as functions of time quantities such as pressure, layer height, and temperature given the accumulation of mass and enthalpy in the two layers. The model then consists of a set of ODEs to compute the environment in each compartment and a collection of algorithms to compute the mass and enthalpy source terms required by the ODEs.

3 Methodology used in this Technical Report

For the calculation method considered, checks based on ISO 16730-1 and as outlined in this Technical Report are applied. This Technical Report lists in Annexes A and B the important issues to be checked in the left-hand column of a two-column table. The issues addressed are then described in detail, and it is shown how these were dealt with during the development of the calculation method in the right-hand column of the Annexes A and B cited above, where Annex A covers the description of the calculation method and Annex B covers the complete description of the assessment (verification and validation) of the particular calculation method. Annex C describes a worked example and Annex D adds a user's manual.

Annex A
(informative)

Description of the calculation method

A.1 Purpose	
Definition of problem solved or function performed	The model has been developed for solving practical fire problems in fire protection engineering while at the same time providing a tool to study fundamental fire dynamics and smoke spread. It is intended for system modelling of building and building components. It is not intended for detailed study of flow within a compartment such as is needed for smoke detector siting. Space scales from ~1 m^3 to 1 000 m^3 and time scales from ~1 s to approximately a few hours.
(Qualitative) description of results of the calculation method	The outputs of the model are the sensible variables that are needed for assessing the environment in a building subjected to a fire. These include temperatures of the upper and lower gas layers within each compartment, the ceiling/wall/floor temperatures within each compartment, the visible smoke and gas species concentrations within each layer, target temperatures, and sprinkler activation time.
Justification statements and feasibility studies	The model predicts the environment within compartmented structures resulting from a fire prescribed by the user. It is an example of the class of models called finite element. This particular implementation is called a zone model and, essentially, the space to be modelled is broken down to a few elements. The physics of the compartment fire phenomena is driven by fluid flow, primarily buoyancy. The usual set of elements or zones are the upper and lower gas layers, partitioning of the wall/ceiling/floor to an element each, one or more plumes, and objects such as fires, targets, and detectors. One feature of this implementation of a finite element model is that the interface between the elements (in this case, the upper and lower gas layers) can move, with its position defined by the governing equations. The attached bibliography[1-4] has a compendium of all validation testing which has been done.

A.2 Theory	
Underlying conceptual model (governing phenomena)	The modelling equations take the mathematical form of an initial value problem for a system of ordinary differential equations (ODEs). These equations are derived using the conservation of mass, the conservation of energy (equivalently, the first law of thermodynamics), and the ideal gas law. These equations predict as functions of time quantities such as pressure, layer height, and temperature given the accumulation of mass and enthalpy in the two layers. The assumption of a zone model is that properties such as temperature can be approximated throughout a control volume by an average value.
Theoretical basis of the phenomena and physical laws on which the calculation method is based	The equations used take the mathematical form of an initial value problem for a system of ordinary differential equations (ODEs). These equations are derived using the conservation of mass, the conservation of energy (equivalently, the first law of thermodynamics), the ideal gas law, and relations for density and internal energy. These equations predict as functions of time quantities such as pressure, layer height, and temperature given the accumulation of mass and enthalpy in the two layers.

A.3 Implementation of theory	
Governing equations	The modelling equations used take the mathematical form of an initial value problem for a system of ordinary differential equations. These equations are derived using the conservation of mass, the conservation of energy (equivalently, the first law of thermodynamics), and the ideal gas law. These equations predict as functions of time quantities such as pressure, layer height, and temperature given the accumulation of mass and enthalpy in the two layers. The assumption of a zone model is that properties such as temperature can be approximated throughout a control volume by an average value. The formulation uses the definitions of density, internal energy, and the ideal gas law. These rates represent the exchange of mass and enthalpy between zones due to physical phenomena such as plumes, natural and forced ventilation, convective and radiative heat transfer, and so on. For example, a vent exchanges mass and enthalpy between zones in connected rooms, a fire plume typically adds heat to the upper layer and transfers entrained mass and enthalpy from the lower to the upper layer, and convection transfers enthalpy from the gas layers to the surrounding walls.

Mathematical techniques, procedures, and computational algorithms employed, with references to them	The equations used in zone fire modelling are ordinary differential equations (ODEs), which are stiff. The term "stiff" means that large variations in time scales are present in the ODE solution. In our problem, pressures adjust to changing conditions more quickly than other quantities such as layer temperatures or interface heights. Special solvers are required in general to solve zone fire modelling ODEs because of this stiffness, which are used here. There are two assumptions which reduce the computation time. The first is that relatively few zones or elements per compartment are sufficient to model the physical situation. The second assumption is to close the set of equations without using the momentum equation in the compartment interiors. This simplification eliminates acoustic waves. Though this prevents one from calculating gravity waves in compartments (or between compartments), coupled with only a few elements per compartment allows for a prediction in a large and complex space very quickly.
Identification of each assumption embedded in the logic; limitations on the input parameters that are caused by the range of applicability of the calculation method	The model has been developed for solving practical fire problems in fire protection engineering while at the same time providing a tool to study fundamental fire dynamics and smoke spread. It is intended for system modelling of buildings and building components. It is not intended for detailed study of flow within a compartment such as is needed for smoke detector siting. It includes the activation of sprinklers and fire suppression by water droplets. The most extensive use of the model is in fire and smoke spread in complex buildings. The efficiency and computational speed are inherent in the few computation cells needed for a zone model implementation. Most of the use is for reconstruction of timelines for fire and smoke spread in residential, commercial, and industrial fire reconstructions. Some applications of the model have been for design of smoke control systems.

	Compartments: The model is generally limited to situations where the compartment volumes are strongly stratified. However, in order to facilitate the use of the model for preliminary estimates when a more sophisticated calculation is ultimately needed, there are algorithms for corridor flow, smoke detector activation, and detailed heat conduction through solid boundaries. This model does provide for non-rectangular compartments, though the application is intended to be limited to relatively simple spaces such as attics and ship corridors. There is no intent to include complex geometries where a complex flow field is a driving force. For these applications, computational fluid dynamics (CFD) models are appropriate.
	There are also limitations inherent in the assumption of stratification of the gas layers. The zone model concept, by definition, implies a sharp boundary between the upper and lower layers, whereas in reality, the transition is typically over about 10 % of the height of the compartment and can be larger in weakly stratified flow. For example, a burning cigarette in a normal room is not within the purview of a zone model. While it is possible to make predictions within 5 % of the actual temperatures of the gas layers, this is not the optimum use of the model. It is more properly used to make estimates of fire spread (not flame spread), smoke detection and contamination, and life-safety calculations.
	Heat release rate: There are limitations inherent in the assumptions used in the application of the empirical models. As a general guideline, the heat release should not exceed about 1 MW/m^3. This is a limitation on the numerical routines due to the coupling between gas flow and heat transfer through boundaries (conduction, convection, and radiation). The inherent two-layer assumption is likely to break down well before this limit is reached.
	Radiation: Since the model includes a sophisticated radiation model and ventilation algorithms, it has further use for studying building contamination through the ventilation system, as well as the stack effect and the effect of wind on air circulation in buildings.
	Ventilation and leakage: In a single compartment, the ratio of the area of vents connecting one compartment to another to the volume of the compartment should not exceed roughly 2 m^{-1}. This is a limitation on the plug flow assumption for vents. An important limitation arises from the uncertainty in the scenario specification. For example, leakage in buildings is significant, and this affects flow calculations especially when wind is present and for tall buildings. These effects can overwhelm limitations on accuracy of the implementation of the model. The overall accuracy of the model is closely tied to the specificity, care, and completeness with which the data are provided.
	Thermal properties: The accuracy of the model predictions is limited by how well the user can specify the thermophysical properties. For example, the fraction of fuel which ends up as soot has an important effect on the radiation absorption of the gas layer and, therefore, the relative convective versus radiative heating of the layers and walls, which in turn affects the buoyancy and flow. There is a higher level of uncertainty of the predictions if the properties of real materials and real fuels are unknown or difficult to obtain, or the physical processes of combustion, radiation, and heat transfer are more complicated than their mathematical representations in the model.

