The factors influencing the severity of a fire in a compartment are:

- fire load type, density and distribution
- combustion behaviour of the fire load
- compartment size and geometry
- ventilation conditions of the compartment
- thermal properties of the compartment boundary.

The occurrence of flashover in a compartment fire defines a transition in the fire development process. Therefore, many fire models are classified as pre- or post-flashover models, except for computational fluid dynamic (CFD) models which attempt to model all stages of the fire.

As shown in Figure 3.1, there are a number of options[2] available to calculate the fire severity. The level of complexity increases from simple fire models to CFD models. The input parameters for each of these models varies, with the advanced models requiring very detailed and accurate input data and simple models requiring nominal input.

The standard fire curves are defined time-temperature relationships used in standard fire tests and are not based on any physical parameters. The time equivalence, natural fire curves, localised fires, zone models and CFD models include (to varying degrees) the physical parameters listed above. Pre-flashover fires can be modelled using localised fires, two-zone models and CFD models. Post-flashover fires are modelled using natural fire curves, one-zone models, and CFD models with time equivalence providing a simple approach of relating a post-flashover fire to the time-temperature relationship used in a standard fire test. The major assumption of these post-flashover models is that the atmosphere temperature throughout the compartment is assumed to be uniform. CFD models attempt to predict the complete fire growth from pre to post-flashover behaviour, incorporating varying temperature distributions through the compartment.

A summary of the fire models[2], their complexity, predicted fire behaviour, input parameters and design tools are shown in Table 3.2.

Table 3.2 Options for modelling compartment fires[2]

Fire model	Nominal fires	Time equivalence	Natural fire curves	Localised fires	Zone models		CFD/field models
					One-zone	Two-zone	
Complexity	Simple	Intermediate			Advanced		
Fire behaviour	Post-flashover fires			Pre-flashover fires	Post-flashover fires	Pre-flashover/ localised fires	Complete temperature-time relationships
Temperature distribution	Uniform in whole compartment			Non-uniform along plume	Uniform	Uniform in each layer	Time and space dependent
Input parameters	• Constant time-temp. relationship • No physical parameters	• Fire load • Ventilation conditions • Thermal properties of boundary • Compartment size		• Fire load and size • Height of ceiling	• Fire load • Ventilation conditions • Thermal properties of boundary • Compartment size • Detailed input for heat and mass balance of the system		Detailed input for solving the fundamental equations of the fluid flow
Design tools	Simple equations for hand calculations		Spread-sheet	Simple equations	Computer models		

When considering the fire behaviour, the designer needs to define whether the fire remains localised or flashover occurs resulting in a fully developed fire. A localised fire will occur when there is no spread of fire to the whole compartment due to the propagation being so slow that the temperature rise is not sufficient to cause flashover, or there is insufficient combustible material in close proximity to the source of the fire. It is generally accepted[20,21] that flashover transition occurs when the upper smoke layer reaches temperatures of about 550°C to 600°C or the radiation to the floor exceeds about 20kW/m^2.

Scenarios where localised fires are most likely to occur include:

- large high spaces with relatively limited fire load, such as atria, circulation areas in airports, shopping malls, etc.
- areas where there are high levels of ventilation such as in open canopies, typically at hotel entrances, under link bridges at airports, etc.
- areas where fire load can be reliably controlled to relatively low levels or spaced such that fire cannot readily spread from one area of fire load to another.

The only feasible design method to stop flashover in a compartment, where there is sufficient ventilation, is to limit the fuel and distance between fuel items or to use a suppression system. Design methods for determining flashover are presented in the CIBSE Guide[22] on Fire Engineering or PD 7974-1[21].

3.2 Localised fire

Pre-flashover or localised fires are useful when flashover is unlikely to occur, or information on the pre-flashover stage is required. The available models[2], in order of complexity, to estimate pre-flashover fires are:

- design equations given in BS EN 1991-1-2[14] (see Section 3.2.1)
- design equation given in PD 7974-1[21]
- two zone models (see Section 3.2.2)
- CFD models (see Section 3.2.3).

3.2.1 Fire plume models

BS EN 1991-1-2[14] (EC1) provides a simple approach for determining the thermal action of localised fires. The temperatures are dependent on whether or not the flame is impacting on the ceiling of the compartment (see Figure 3.3). For the case where the flame remains below the ceiling, EC1[14] provides guidance on calculating the temperatures in the plume along its vertical axis. For the case where the flame impacts on the ceiling EC1[14] provides guidance on calculating the heat flux at the level of the ceiling together with the flame length (L_h) as shown in Figure 3.3.

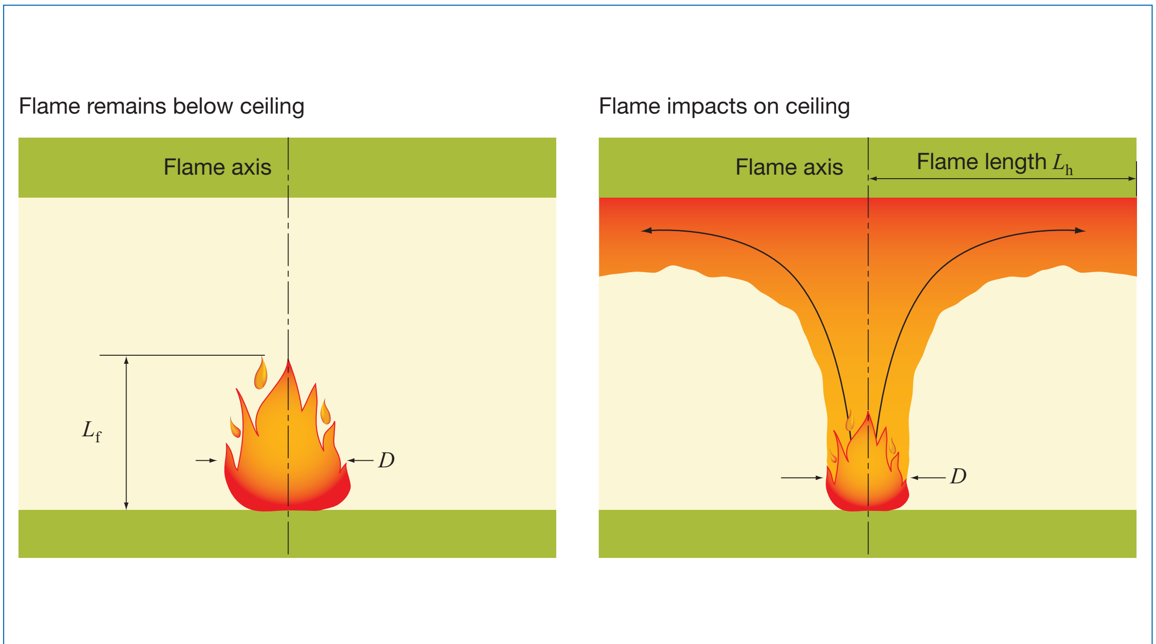

Figure 3.3 Definition of localised fire[2]

4.1 Introduction

The temperature distribution through a structural member is dependent on the radiation and convective heat transfer coefficients at the member's surface and conduction of heat within the member. The available design approaches are shown in Figure 4.1.

For materials with a high thermal conductivity, such as steel, it may be sufficiently accurate to ignore thermal gradients within members and assume a uniform temperature. This assumption is valid provided the member is not in contact with a material of low thermal conductivity, which will act as a heat-sink and thus create a thermal gradient through the member. Simple design equations[16-17] exist to predict the temperatures of steel members which are fully exposed to fire or steel members that support a concrete floor slab and are exposed on three sides.

Estimating the heat transfer in materials with a low thermal conductivity and/or high moisture content, such as concrete and masonry, becomes extremely complex due to the high thermal gradients. To carry out a performance-based approach, which investigates the structural response of the building, it is extremely important to obtain an accurate estimate of the temperature gradient through the structural members. Simple design charts are given in codes[15-19] defining the temperature distribution through members, which have been derived from standard fire tests. These charts can only be used if the standard fire curve is assumed to define the fire behaviour.

If parametric curves, zone models or CFD models are adopted to estimate the fire behaviour then either simple or advanced heat transfer models should be used. The use of simple or advanced heat transfer models requires knowledge of:

- the geometry of the member
- thermal properties of the materials, including the effects of moisture
- heat transfer coefficients at the member's boundaries.

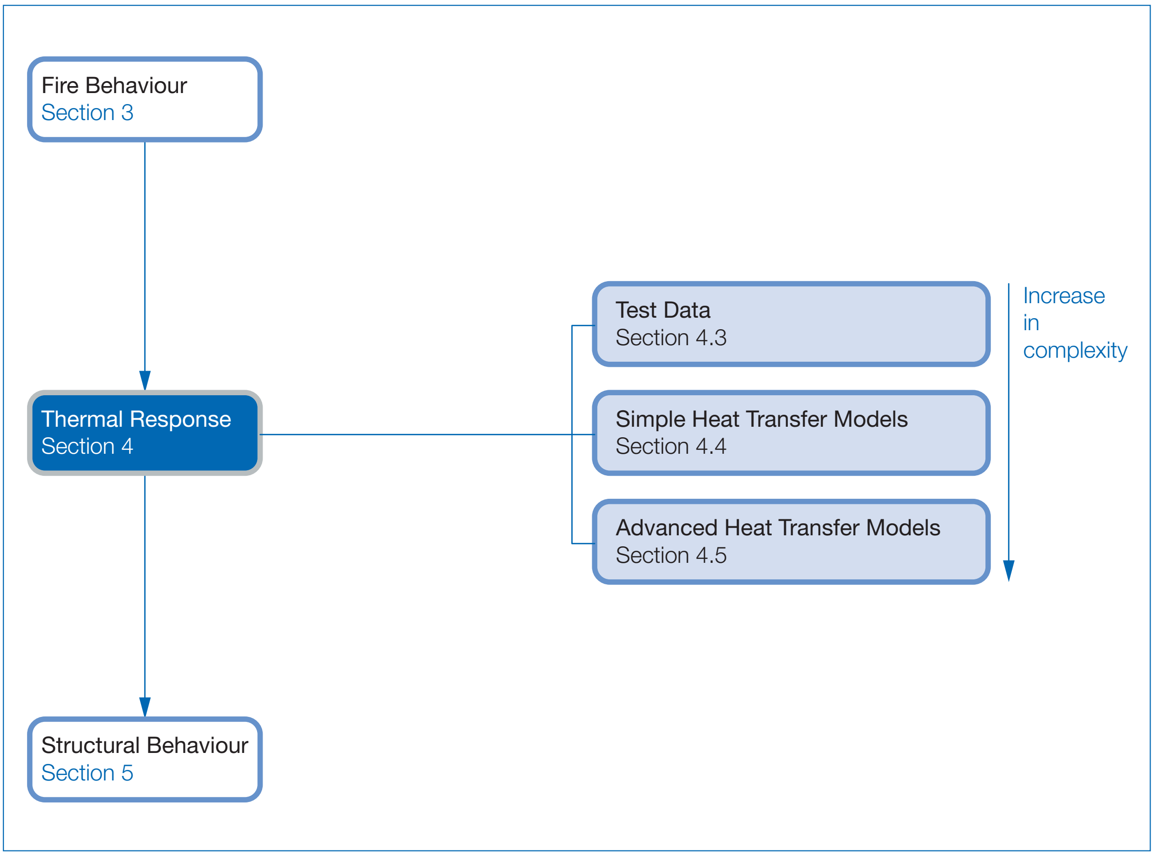

Figure 4.1 Available methods to define the thermal response