# DESIGN FIRES FOR USE IN FIRE SAFETY ENGINEERING

Christopher Mayfield and Danny Hopkin

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# 1 INTRODUCTION

The objective of this publication is to provide technical data and guidance for defining a robust, appropriate and acceptable design fire for the fire safety engineering design of a building. It explains:

- what a design fire is
- how it can be determined
- its limitations
- the experimental data (where available)
- current calculation methods used for defining a design fire.

Depending on the geographical location of a building, its legislative fire safety requirements may be achieved in a number of ways. Fire safety engineering is a generally accepted approach for demonstrating that the legislative fire safety requirements of a design have been achieved.

A building design which is supported by a performance-based fire safety engineered solution comprises a number of components. One of these critical components is the selection of an appropriate and relevant design fire. In a performance-based fire safety engineered solution the design fire will determine a number of important parameters for a given space, which include:

- the quantity of heat released
- the quantity of smoke produced
- the composition of the smoke
- the fire size
- the temperature of a smoke layer
- the time to involvement of all exposed combustible materials
- the fire duration.

Based on the values determined for the parameters, a fire engineered analysis can establish:

- if predetermined tenability criteria are exceeded
- if further fire protection measures are required (eg a smoke control system)
- the specification of such fire protection measures.

Clearly, there is great significance associated with the selection by the fire safety engineer of an appropriate design fire to ensure it is representative of the situation considered to fulfil the life safety requirements. In addition to this, it is important to determine if the fire safety measures proposed by a fire safety engineered solution are proportionate (ie not overly onerous, resulting in unnecessary expenditure), but nevertheless capable of meeting the life safety requirements to avoid potentially life-threatening omissions.

There are a number of different approaches to defining an appropriate design fire ranging from calculation based on fuel load surveys of real buildings and quantification to experimental determination. These different approaches will be described in detail.

This publication is aimed at those professionals involved in the fire safety engineering design process, either as a designer fulfilling a brief or a regulator/ approver of the design. It is intended that this publication will provide evidence to assist the review of the foundation of the fire engineered solution as part of any approval process.

More generally, those in the position of the responsible person, as defined by the Regulatory Reform (Fire Safety Order) 2005[1] (FSO), or those delegated as competent under the FSO by the responsible person, are likely to find this resource beneficial when undertaking a fire safety risk assessment in both fire safety engineered and non-fire safety engineered buildings. That is, it is important that the responsible person understands the design principles of his or her buildings so that he or she can ensure that they are managed on an ongoing basis, within their design limits. Specifically, the fire load is restricted to within the limits of the assumed design fire. This is particularly important where, for example, a change of use or change of ownership might occur.

Fire safety engineering design requires the identification of an appropriate fire size on which a design can be based[2,3]. This is one of the key decisions in fire safety engineering design and requires formulation of a quantitative description of the fire. Published reliable data is scarce and fire safety engineers often resort to a simple generic description based on assumption.

A summary of the most commonly used parameters in fire safety engineering are detailed as part of the summary of each of the experimental fires where available and include the following parameters:

- HRR
- heat of combustion
- mass of fire load
- optical density
- carbon dioxide concentration
- carbon monoxide concentration.

# 2 IMPORTANT FACTORS INFLUENCING QUANTIFICATION OF A DESIGN FIRE

***A design fire is a simplified approximation of a fire that is considered to be representative of a fire involving a specified hazard.***

For a design fire to be representative of a realistic fire situation, it should replicate the physical size and heat output of the fire changing with time. This allows the growing threat to occupants, property/business continuity, and firefighters to be calculated as time progresses[4]. Time-based calculations often form part of a holistic assessment, where the time to the onset of untenable conditions is compared with the time required for the safe evacuation of occupants of the building or the time recommended for the initiation of successful firefighting operations. To undertake a time-based assessment, fire growth curves need to be selected that are applicable to the exact circumstances of the building occupancies, fuel arrangements and suppression system performance, where appropriate[4]. Where this information is available it can be integrated into a fire engineered solution for a building following recommended fire safety engineering procedures, such as BSI's PD 7974[5] series of documents.

Several important factors which influence the characteristics of a fire are summarised in Box 1 and described in the sections below. They are well documented and should be considered in the quantification of a design fire.

## Building design
The geometry and layout of the building should be clearly understood and defined.

## Building fabric
Combustible construction elements and insulation types, presence of vapour barriers in roofs, and types of roof, floor and wall constructions should be identified.

## Environmental influences
Internal environmental conditions should be defined in terms of ambient temperatures, oxygen concentration, air movement, presence of HVAC systems and how these could impact on pre-fire and fire conditions

***Box 1:* Factors influencing the characteristics of a fire**

- Building design
- Building fabric
- Environmental influences
- Potential ignition sources and locations
- Types of combustible materials
- Distribution, arrangement and quantity of different fuels
- Ventilation conditions
- Possible interventions during the fire

## Potential ignition sources and locations
A hazard assessment covering both accidental and deliberate ignition events and the probabilities of each should be conducted and potential ignition sources and locations identified. Deliberate ignition can be characterised by multiple ignition sources. Depending on the hazards identified, the probability of them occurring and the resulting consequences, a design may involve fire protection measures to significantly reduce or eliminate either the hazard, probability and/or consequences of an ignition event. However, it is recognised that this may not always be achievable.

## Types of combustible materials
The type of occupancy and the use of the building will govern the types of combustible materials. The combustible materials may be present as construction products incorporated into the fabric of the building or the contents of the building, or both. During the early stages of a fire, the contents will typically be of primary concern.

## Distribution, arrangement and quantity of different fuels
The way that the different fuels are distributed within the building will have an effect on the characteristics of the fire so all readily available fuel should be considered including:

- wall and ceiling linings
- low-level localised storage of goods
- high-rack, high-density storage of goods
- distribution of furniture and types of furniture (eg office, residential)
- materials being processed.

*Table 1:* Fire load densities for different occupancies
Extract from PD 7974-1[5]

| Occupancy | Fire load density | | | |
|---|---|---|---|---|
| | Average (MJ/m²) | Fractile (MJ/m²) | | |
| | | 80% | 90% | 95% |
| Dwelling | 780 | 870 | 920 | 970 |
| Hospital | 230 | 350 | 440 | 520 |
| Hospital storage | 2000 | 3000 | 3700 | 4400 |
| Hotel bedroom | 310 | 400 | 460 | 510 |
| Offices | 420 | 570 | 670 | 760 |
| Shops | 600 | 900 | 1100 | 1300 |
| Manufacturing | 300 | 470 | 590 | 720 |
| Manufacturing and storage | 1180 | 1800 | 2240 | 2690 |
| Libraries | 1500 | 2250 | 2550 | – |
| Schools | 285 | 360 | 410 | 450 |

They will all result in different distributions of fuel load per square metre of floor area which is commonly referred to as the fire load density.

Traditionally, hazard assessment focuses on the building contents as the primary available fuel source(s). However, with new developments in the design of buildings leading to the use of more combustible construction, it might be necessary to consider the construction materials in the hazard assessment. This is occurring as a result of a concerted effort to use renewable materials (often cellulose-based) and highly thermally efficient materials (synthetic polymer-based). In the majority of cases, a building's fabric will be controlled by building regulation requirements (depending on the geographical location) and to the same extent any combustible elements of construction should be fire-separated from the areas containing the fire hazards within a building, to prevent them from becoming involved in fire.

Fire load densities for different types of occupancies are provided in Table 1 taken from PD 7974-1[5]. However, caution should be exercised when using these data as they are derived from a series of fire load surveys that were carried out before 1983 and presented in a CIB W14 workshop report. For some types of occupancy in particular, advances in technology and changes in design philosophy have resulted in significant changes, for example the increased use of IT and the move to open-plan accommodation in offices and dwellings.

Clearly, for goods stored in racking (eg in warehouses), the fire load per square metre of floor area could significantly exceed the value in Table 1.

Given the data in Table 1, the maximum heat that can be released from a fire, assuming that it is fully ventilated will be the fire load density (MJ/m²) × the floor area (m²).

If the fire load density is not known or there is a mixture of unevenly distributed fuels within the enclosure, then it is possible to calculate the maximum HRR (assuming that all of the fuel is consumed) using either equations 1 or 2 below, as appropriate.

$$Q_{TOTAL} = m_{TOTAL} \times \Delta H_C \quad \text{(Eqn 1)}$$

where:

$Q_{TOTAL}$ = total heat release (kJ)
$m_{TOTAL}$ = total mass loss (kg)
$\Delta H_C$ = heat of combustion of fuel (kJ/kg)

If the fuel load is mixed, equation 2 can be applied as follows:

$$Q_{TOTAL} = (m_{TOTAL} \cdot \Delta H_C)_{FUEL1} + (m_{TOTAL} \cdot \Delta H_C)_{FUEL2} + \ldots = \sum m_{TOTAL\,i} \times \Delta H_{C\,i} \quad \text{(Eqn 2)}$$

where i = fuel type.

Fire load density is the fire load per unit area. This is obtained by dividing $Q_{TOTAL}$ from equation 1 or 2 by the floor area of the enclosure of fire origin.

The distribution and orientation of any fire load is important in determining the rate of fire growth. Combustible material orientated vertically can yield a rapid rate of fire growth as a result of the increased potential for direct flame impingement on unburnt material leading to increased levels of radiative and convective heat transfer.

## Ventilation conditions

The ventilation of an enclosure within a building is of significance in determining the HRR of a fire. Assuming an enclosure of fire origin with defined dimensions and fire load. If there is sufficient ventilation to the space within which the fire is initiated, without intervention, the fire can grow until it has consumed all of the available fuel (Figure 1).

If ventilation of the same enclosure with an identical fire load is restricted, the fire growth and heat release will become limited by the available oxygen and the mass of fuel consumed by the fire will also be limited (Figure 2).

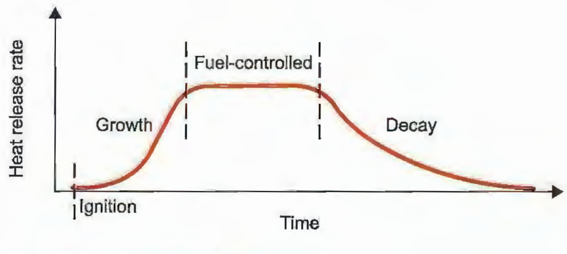



*Figure 1:* Fuel-controlled fire

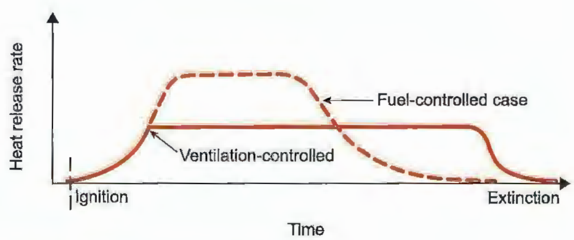



*Figure 2:* Ventilation-controlled fire

Both of the scenarios described above assume that the ventilation conditions within the enclosure of fire origin remain unchanged as a function of time.

While it is important to consider the availability of oxygen in the air, it is also important to be aware of circumstances where the thermal decomposition of certain materials produces oxygen (an oxidant) in addition to that already present in the air. This could result in a combustion reaction being supported in the absence of air (or at reduced oxygen level). In addition, the designated function of the building may also introduce additional sources of oxygen. For example, piped oxygen and/or cylinders of compressed oxygen are found commonly across a hospital site to satisfy the ongoing needs of patients. Such circumstances are not likely to be encountered widely, but every effort should be made as part of the fire safety engineering design process to take account of the presence of oxidising materials.

## Possible interventions during the fire

This is basically an event or series of events that can occur during the course of a fire and alter the fire's characteristics. Such interventions could include:

- breaking of windows to increase ventilation
- opening of doors by occupants during evacuation or by the fire service
- operation of HVAC system
- operation of fire dampers
- operation of smoke control ventilation system
- operation of suppression system.

All these interventions could influence the growth of a fire and should be considered in terms of the overall characterisation and definition of a design fire. Particular care is necessary since what represents a worst case for some interventions might be best case for others.

# 3 STEADY-STATE DESIGN FIRES

The simplest approach to specifying a design fire is based on assessing the largest size a fire is reasonably likely to reach in the situation being considered[4]. This is then used as the basis for the design of the fire protection systems and assumes that the HRR continues indefinitely.

Figure 3 shows an example of a plot of a generic HRR versus time representation of a steady-state design fire. Steady-state design fires have historically been employed as a basis for design, as there has previously been an acknowledged lack of data in relation to time-dependent design fires[2]. Steady-state design fires have been used in the design of smoke control systems in a range of building occupancies, but they were initially applied to the design of smoke control systems in enclosed and partially enclosed shopping centres.

Research into smoke control in enclosed and partially enclosed shopping centres and the subsequent guidance produced[2] used the methodology of selecting a fixed fire size. By basing the design of the smoke control system on the maximum likely fire size means that, as stated previously, any fire size up to the maximum fire will be managed by the system and a degree of flexibility can be retained. For example, even if the occupancy changes, the designer may be able to demonstrate that the maximum likely fire size is still within the bounds of the original smoke control system design.

If, in the design of the fire safety precautions for a building, it is determined between the approver and the designer that a steady-state design fire is most appropriate for the situation being considered, then the size of the steady-state fire must be defined based on a credible fire area dependent on the fuel sources likely to be present. The basis of the design fire must be clearly explained so that its limitations are easily understood. If there is a design fire within this publication that is representative of the design scenario, the fixed fire size for design will need to be defined based on consideration of the fire growth curve. Selection of a peak HRR for a steady-state design may represent an onerous design condition, but only in relation to the fuel load for which the data are available.

If the design fire (transient or steady state) is going to be employed to determine the specification of a smoke control system, consideration should be given to the proportion of the total heat released which is convection. A number of the design fires presented in this publication have had the fraction of the total heat released as convection plotted or stated. In cases where this has not been possible, it can be determined by the application of an appropriate correction factor based on the type of fuel load to determine the convected fraction.

It is the convective portion of the total heat released which relates to the entrainment of air into the rising plume above the fire, thus the rate of smoke being produced, which is normally expressed in terms of mass/

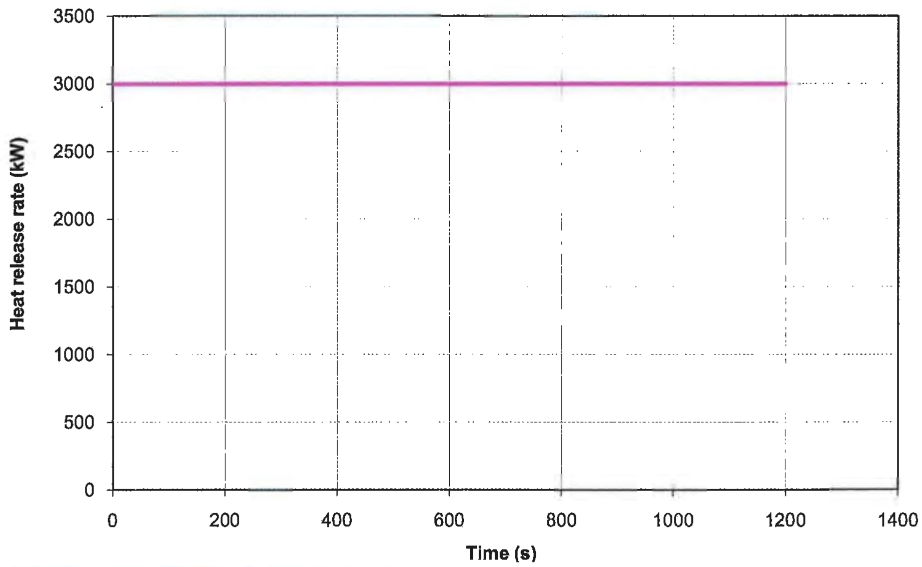



*Figure 3:* Example of a generic steady-state design fire

*Table 2:* Examples of the fraction of the total heat released which is transferred as convection for a range of different fuel types

| Material | Convective fraction |
|---|---|
| Ethanol | 0.74 |
| Kerosene | 0.65 |
| Benzene | 0.40 |
| Octane | 0.67 |
| Silicone | 0.84 |
| Poly(methyl methacrylate) (PMMA) | 0.69 |
| Douglas fir | 0.62 |
| Polystyrene | 0.41 |
| Polyurethane | 0.42 |

volume per unit of time. Values for the proportion of the total heat released that is released as convection (convective factor) are given in the literature[2, 4, 6]. The values given in Table 2 are taken from reference [6] and are a selection of the convective fraction values which could be applied by the designer.

The remaining fraction of the total heat released which is not transferred via convection is mainly transferred via radiation. Radiative heat transfer has little bearing on the rate of smoke production, hence it is discounted in the design of smoke control systems. However, radiative heat transfer is relevant to the overall fire growth characteristics as it is a significant factor in flame spread, fire spread, time–temperature analysis and also in the calculation of the temperature of the structure.

Steady-state design fires are a conservative representation of a realistic fire scenario for a particular set of circumstances. However, when implemented in a transient analysis, the results may be unconservative in the early phases, particularly in relation to detection time. As such, their application in design may result in the over-specification of fire safety provisions at cost to a project. It is probable that as the database of time-dependent fire curves increases and broadens in variety, together with advances in fire modelling, the steady-state fire as a design tool may become restricted. However, calculations based on the use of steady-state design fires provide a relatively simplistic method of giving an initial quantitative evaluation of the impact a particular fire may have on a particular set of circumstances.

# 4 TIME-DEPENDENT DESIGN FIRES

This type of design fire provides a closer approximation to a real fire than a steady-state design fire. It is generally accepted that there are five stages characteristic of the development of a fire:

- ignition
- pre-flashover (growth)
- flashover
- fully developed
- decay.

Where the fully developed and decay stages occur during the post-flashover phase of the fire, these can be represented schematically as given in Figure 4.

After ignition of the first item(s) has occurred, the speed of fire growth is dependent on the transfer of heat to adjacent combustible materials and products and the ease with which they are ignited. As a consequence, fire growth rates will vary significantly. The following sections explain how these may be approximated.

## 4.1 t-SQUARED FIRE GROWTH CURVES

As has already been discussed, the growth phase of a fire is sensitive to many variables, such as the:

- distribution of combustible material within a space
- properties of the materials
- configuration of the materials.

However, despite these uncertainties, for fully ventilated fires, it has been found that the rate of development approximates to a parabolic growth (a t-squared growth) following an initial incubation period[5, 7, 8]. Thus:

$$\dot{Q} = \alpha_f (t - t_o)^2 \qquad \text{(Eqn 3)}$$

where:

$\dot{Q}$ = HRR at any time (kW)
$\alpha_f$ = fire growth coefficient (kW/s²)
$t$ = time (s)
$t_0$ = incubation time of fire (s)

The coefficient $\alpha_f$ appears to lie in the range of $10^{-3}$ kW/s² for slowly developing fires to 1 kW/s² for rapid fire growth[7]. Four standard fire curves have been defined and validated[9]; the values of the coefficients are set out in Table 3.

The t-squared curve is quadratic without any limit; it does not have a steady state and decay period. When the coefficients $\alpha_f$ presented in Table 3 are plotted for each of the four fire growth coefficients (slow, medium, fast and ultrafast) they appear as shown in Figure 5. These fire growth coefficients are derived from the time taken to reach the HRR of 1 MW.

The fire growth coefficient is a valid way of predicting the likely rate at which a fire will develop to its maximum HRR for horizontally spreading fires, but alone, it does not provide the user with the maximum heat release value. Users should be aware that the fire growth coefficient

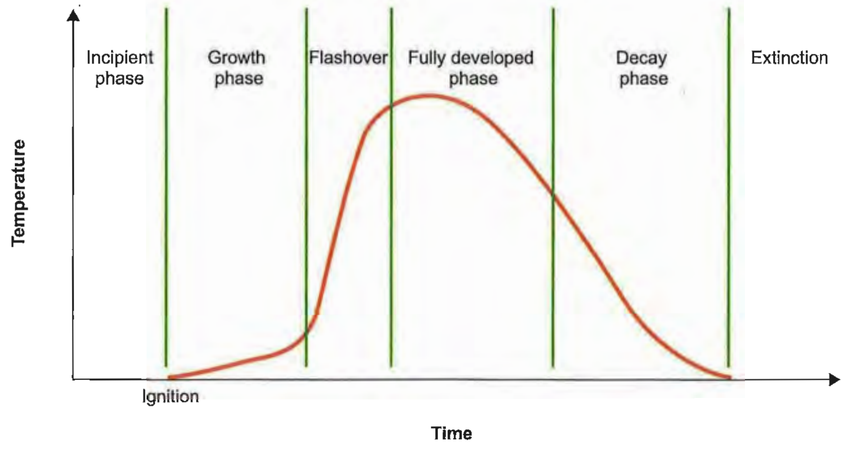



*Figure 4:* Phases of fire development

*Table 3:* The four standard fire growth coefficients. Data from Chitty & Fraser-Mitchell[9]

| Fire growth coefficient | Time to reach 1 MW (s) | Coefficient $\alpha_f$ | Fire scenario |
|---|---|---|---|
| Slow | 600 | 0.00293 | Densely packed paper |
| Medium | 300 | 0.01172 | Traditional mattress or armchair |
| Fast | 150 | 0.0469 | PU mattress or PE pallets |
| Ultra fast | 75 | 0.1876 | High rack storage |

PU = polyurethane, PE = polyethylene.

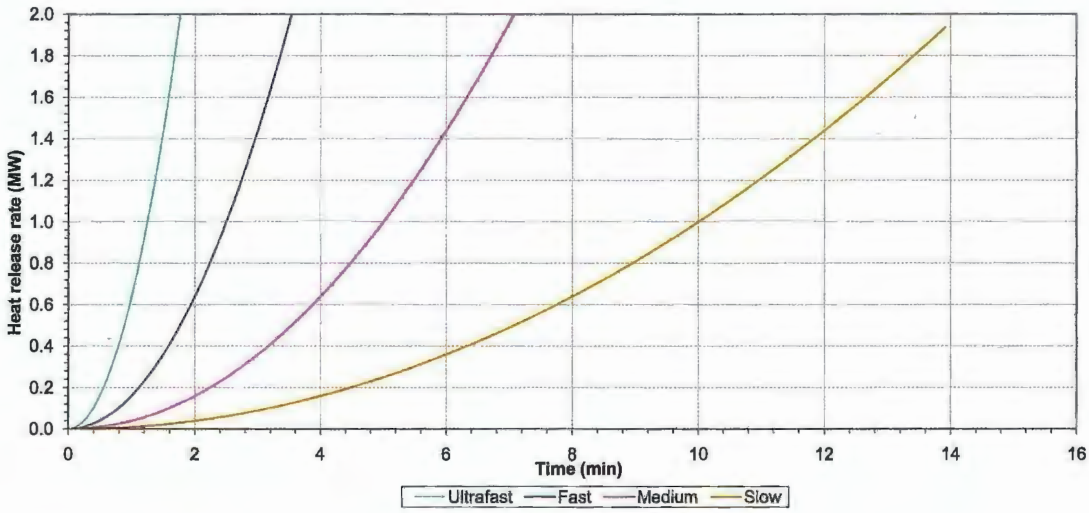



*Figure 5:* The t-squared fire growth curves

alone does not give an assessment of the likely duration of the fire as this is dependent on the amount of fuel available and the ventilation conditions in the vicinity of the fire. Where this approach is used as part of the process to develop a theoretical fire curve, it is necessary to carry out further calculations (eg the size of the fire at the onset of flashover) to set an upper limit to what would otherwise be an infinite fire growth[2].

The peak HRR values and the time associated to reach the peak HRR, shown in chapters 6 and 7, have allowed a fire growth coefficient to be determined, where possible, for the experimental fires detailed in this publication.

## 4.2 OTHER CALCULATION METHODS

There are a number of different methods for calculating the HRR in an enclosure fire, most of which are based on experimental data. As such, they could be described as semi-empirical or, in some cases, fully empirical. Due to this, they are all limited to the conditions relating to the experimental design, in particular, in relation to the ventilation conditions and heat transfer characteristics. More information can be found in PD 7974-1[5].

## 4.3 EXPERIMENTAL DESIGN FIRES

In some cases, the fire performance of a particular fuel arrangement may not be known or quantified. In such cases, it may be necessary and advisable to measure the parameters for the particular fuel arrangement and to use them as the basis for the design fire description within a fire safety engineering design.

Such an experiment should be carefully designed in discussion with the end user of the data to ensure that it is representative and appropriate. It may also be advisable to consult with the approvals authority during the planning stages to ensure that all concerns are adequately addressed. A typical checklist of factors that will be considered will include those listed in Box 2.

A large-scale experiment carried out under an appropriately sized calorimeter will produce data on parameters such as HRR, rate of production of smoke and chemical species such as CO, $CO_2$ (and others as specified) as a function of time. Additional localised measurements can also be made of parameters including temperatures, velocities, heat transfer, chemical species concentrations and optical density. It is important to note that any parameters determined experimentally are likely to be specific to the test configuration and apparatus.

**Box 2: Typical checklist of factors to consider when designing an experimental fire**

- Identification of types of combustible materials
- Mass of each type of combustible material
- Probability of involvement of each combustible material in fire
- Type of fire load
- Distribution of fire load
- Calculation of fire load density
- Ignition scenario
- Parameters to be measured
- Ventilation conditions, whether an enclosure is required, etc.
- Large-scale calorimetry (such as the 10 MW calorimeter in BRE Global Burn Hall) will be required to measure the parameters, heat release rate, rate of smoke produced, rate of production of chemical species (eg CO, $CO_2$...). There are only a few large-scale calorimeters available worldwide
- Estimation of maximum heat release and assessment of whether the laboratory facility has the necessary capacity to carry out the experiment safely (if not, re-visit the fuel load or consider mitigation measures, or both)
- Suppression system to be included or not
- Fire-fighting provisions

*Figure 6:* Office fire during early phases of development

*Figure 7:* Fully developed luggage store fire

*Figure 8:* Developing fire in an indoor play area

### 4.3.1 Heat release rate

The total heat release rate (HRR) of the gases produced from a fire are measured by monitoring the amount of oxygen that has been removed from a given mass of gas under a large calorimeter hood. The method requires all the gaseous products to be collected by a large extraction hood and duct system in which the required properties of the combustion gases are subsequently monitored. The oxygen concentration is measured as a function of time using a paramagnetic type analyser, while the concentrations of $CO_2$ and CO are typically measured using infrared gas analysers.

The total heat release can also be measured using the mass loss rate of fuel. This is determined by using a load cell arrangement on which the fuel is mounted, typically on a metal framework on which four load cells are mounted at each corner. The load cells used are essentially strain gauges which generate a voltage according to load.

### 4.3.2 Smoke production rate

The total smoke production rate is measured within the collection hood and duct of the calorimeter. It is typically determined by measuring the obscuration of light across the duct. For more details, see ISO 24473[10].

# 5 FULLY DEVELOPED FIRES

Nominal or standard fire curves are the simplest representation of fully developed post-flashover fire for design applications. Such fires are normally adopted in the performance-based design of fire exposed structures (structural fire engineering). They include the standard (ISO 834[11]) fire curve which is used in the derivation of fire resistance[12, 13] as well as more severe representations of fire behaviour such as the hydrocarbon fire. Less severe representations also exist such as the external fire curve (used for elements of a structure outside the building envelope)[14]. Nominal fire curves essentially assume that flashover occurs instantaneously at the point of ignition, the fire then continues to grow indefinitely with no cooling. Three fire curves taken from Eurocode 1, Part 2[15] are shown below in Figure 9. The use of the standard fire (ISO 834[13]) curve as a design fire means that the performance of the structure can be directly benchmarked against regulatory fire resistance requirements. Although more realistic representations of a compartment fire exist, ie parametric design fires (discussed below), the standard fire curve is still largely used in the performance-based design of timber structures.

The corresponding equations for each curve, taken from Eurocode 1, Part 2[15], are shown below for completeness:

*Standard (ISO) fire curve:*

$$\Theta_g = 20 + 345\log_{10}(8t + 1) \quad \text{(Eqn 4)}$$

*External fire curve:*

$$\Theta_g = 660(1 - 0.687e^{-0.32t} - 0.313e^{-3.8t}) + 20 \quad \text{(Eqn 5)}$$

*Hydrocarbon fire curve:*

$$\Theta_g = 1080(1 - 0.675e^{-0.167t} - 0.675e^{-2.5t}) + 20 \quad \text{(Eqn 6)}$$

where:

$\Theta_g$ = the compartment gas temperature (°C)

$t$ = time from ignition (min).

## 5.1 PARAMETRIC DESIGN FIRES

The parametric design fire curve, as specified in Eurocode 1 Part 2[15], is a step forward in complexity from nominal fire curves and relates the time–temperature response of a compartment to the available ventilation, fire load density and thermal characteristics of the compartment boundary. Similar to the nominal fire curves, the parametric approach is a post-flashover model assuming instantaneous flashover at ignition and is almost exclusively adopted by structural fire engineers undertaking performance-based designs. The application of parametric design fires is largely limited to

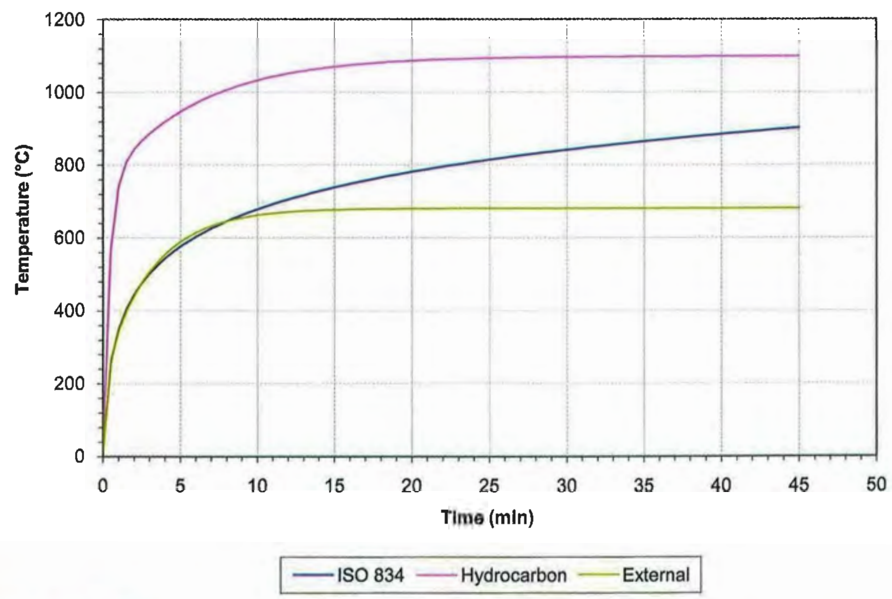



*Figure 9:* Nominal fire curves

relatively small compartments and becomes inaccurate for large open-plan spaces typical in many multistorey structures. Unlike the nominal fire curves, the parametric approach includes a cooling phase and is often used to design structures to survive compartment burnout. The parametric curve is given as:

$$\Theta_g = 1325(1 - 0.324e^{-0.2t^*} - 0.204e^{-1.7t^*} - 0.472e^{-19t^*}) \quad \text{(Eqn 7)}$$

where:

| | | | |
|---|---|---|---|
| $\Theta_g$ | = | temperature in the fire compartment | (°C) |
| $t^*$ | = | $t.\Gamma$ | (h) |
| $t$ | = | time | (h) |
| $\Gamma$ | = | $[O/b]^2/(0.04/1160)^2$ | (dimensionless) |
| b | = | $\sqrt{(\rho c \lambda)}$ and should lie between 1000 and 2000 | ($J/m^2s^{½}K$) |
| O | = | opening factor ($A_v\sqrt{h}/A_t$) | ($m^{½}$) |
| $A_v$ | = | area of vertical openings | ($m^2$) |
| h | = | height of vertical openings | (m) |
| $A_t$ | = | total area of enclosure | ($m^2$) |
| $\rho$ | = | density of boundary enclosure | ($kg/m^3$) |
| c | = | specific heat of boundary of enclosure | (J/kgK) |
| $\lambda$ | = | thermal conductivity of boundary | (W/mK) |

The concept of parametric time ($t^*$) is used to modify the predicted time–temperature relationship. The background theory to this calculation approach was developed by Wickström[16]. The values 0.04 and 1160 relate to the opening factor and the thermal inertia of the standard fire compartment as used in the original test programme. The cooling phase of the time–temperature response is assumed to be linear and is dependent on the parametric time at which peak compartment temperatures are reached. An example of the parametric approach is shown in Figure 10.

## 5.2 Time-equivalence

The concept of time-equivalence is used to relate the severity of real fires to the time–temperature relationship in a standard fire resistance test[15, 16]. Figure 11 illustrates the concept of time-equivalence, relating the actual maximum temperature of a structural member (ie beams and columns) from an anticipated fire severity, to the time taken for the same member to attain the same temperature when subjected to the standard fire.

Generally, time-equivalence can either be determined by using a simple equation or taken from experimental data from natural and standard fire resistance tests. Although simple to use, the time-equivalence is a crude approximate method of modelling real fire behaviour and bears little relationship with real fire behaviour. In addition, the limitations of the method should be clearly understood. The main limitation is that the method is only applicable to the types of members used in the derivation of the adopted formulae. The method is most applicable to unprotected steel frame structures although modification factors exist for concrete and protected steel frames. The most commonly used form of the time-equivalence method adopted today is that of Eurocode 1 Part 2[15] which is shown below for completeness:

The equivalent time of fire exposure, $t_{e,d}$, is calculated using:

$$t_{e,d} = q_{f,d}.k_b.w_f \quad \text{(Eqn 8)}$$

where:

$q_{f,d}$ = design fire load density ($MJ/m^2$)

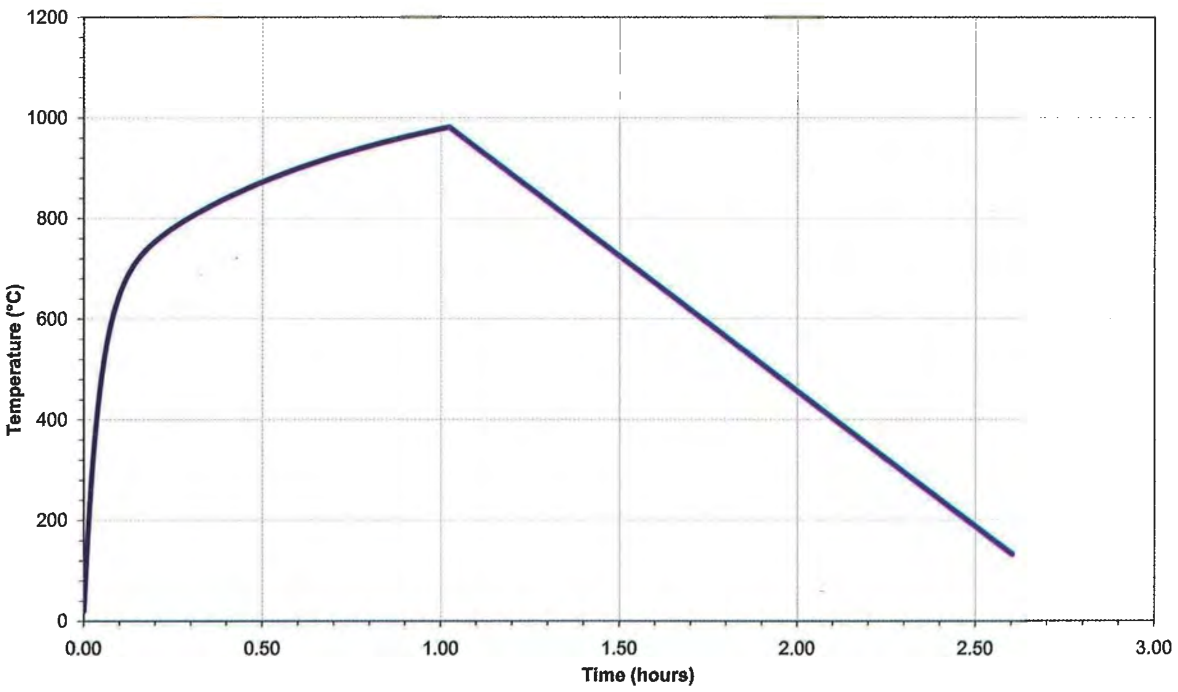



*Figure 10:* Example of a parametric design fire

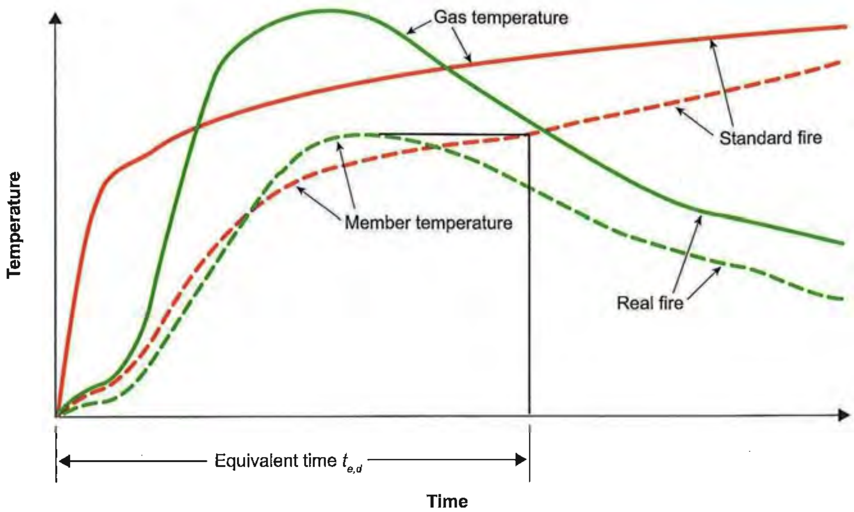



*Figure 11:* The concept of time-equivalence

$k_b$ = conversion factor dependent on thermal properties of compartment boundaries ($min.m^2/MJ$), typically taken as 0.09 in the UK (as per the National Annex to BS EN 1991-1-2[17])

$w_f$ = ventilation factor (dimensionless)

where, $w_f$ is given by:

$$w_f = \left(\frac{6}{H}\right)^{0.3} \cdot \left[0.62 + 90(0.4 - \alpha_v)^4 / (1 + b_v \cdot \alpha_h)\right] \geq 0.5 \quad \text{(Eqn 9)}$$

$\alpha_v$ = Av/Af, where Av and Af are the area of the vertical ventilation openings and the area of the compartment floor, respectively

H = the height of the compartment (m)

$\alpha_h$ = Ah/Af, where Ah is the area of horizontal ventilation openings

$b_v$ = $12.5(1 + 10\alpha_v - \alpha_v^2) \geq 10$ (Eqn 10)

# EXPERIMENTAL FIRE DATA

The following two chapters present 29 experimental fires which have been categorised into two groups:

- *Occupancies* (Table 4), which considers design fire scenarios that are representative of a type of building occupancy. These experimental fire scenarios can include a number of different combustible materials. The arrangement of the combustible contents was intended to represent that of a typical example of such an occupancy.
- *Commodities* (Table 5), of which some of the examples, like the occupancies, may contain a number of different combustible materials. The fire tests are intended to document the fire performance of stand-alone items. For example, this resource considers a car to be a commodity and a car park to be an occupancy.

A summary of the most commonly used parameters in fire safety engineering are detailed as part of the summary of each of the experimental fires where available, including the following:

- heat release rate
- heat of combustion
- mass of fire load
- optical density
- carbon dioxide concentration
- carbon monoxide concentration.

Indicative gas concentrations and smoke production parameters are included where available. However, these parameters alone may not be appropriate for adoption in computational models. Full tranisent definition of many of the experimental fires contained in this publication are available in BRE's *Design fires database*[18].

*Table 4:* Summary of the experimental fire occupancy scenarios included in Chapter 6

| Section no. | Occupancy |
|---|---|
| 6.1 | Bar/Night club |
| 6.2 | Car parks |
| 6.3 | Carpet store |
| 6.4 | Clothes store |
| 6.5 | Indoor play area |
| 6.6 | Library |
| 6.7 | Living room |
| 6.8 | Luggage store |
| 6.9 | Office |
| 6.10 | Prison cell |
| 6.11 | Reception |
| 6.12 | Retail store |
| 6.13 | Video store |

*Table 5:* Summary of the experimental fire commodities included in Chapter 7

| Section no. | Commodity |
|---|---|
| 7.1 | Beds |
| 7.2 | Boxes |
| 7.3 | Buses |
| 7.4 | Cars |
| 7.5 | Chairs |
| 7.6 | Christmas trees |
| 7.7 | Computers |
| 7.8 | Curtains |
| 7.9 | Flight luggage |
| 7.10 | Hand cart (selling flowers) |
| 7.11 | Pallets |
| 7.12 | Pool fires |
| 7.13 | Soft toys |
| 7.14 | Televisions |
| 7.15 | Upholstered furniture |
| 7.16 | Wardrobe |

# 6 OCCUPANCIES

## 6.1 Bar/Night club

### TEST TYPE

Two free-burn experiments (with and without sprinklers)

### SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 m$^2$ coverage per head and 5 mm/min/m$^2$ delivered water density.

### FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| Upholstered bench seating constructed from chipboard, foam seat and back, covered in dralon-type material. Solid wooden chairs and tables. Upholstered stools with material covers and foam fillings. Additional items in the unsprinklered test included four jackets with polyester outer shell and hollow-fibre fillings | 132.7 | 8 |

### MEASUREMENTS TAKEN

Heat release rate (total and convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

### PEAK MEASURED PARAMETERS

| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 2900 s) | 2.51 (2025) | 3.12 (1485) | 14289 (2058) | 615 (1356) |
| Sprinklered (No sprinkler activated, Test terminated at 1500 s) | 0.81 (108) | 2.31 (648) | 4381 (498) | 423 (237) |

Numbers in parentheses = time to peak parameters in seconds

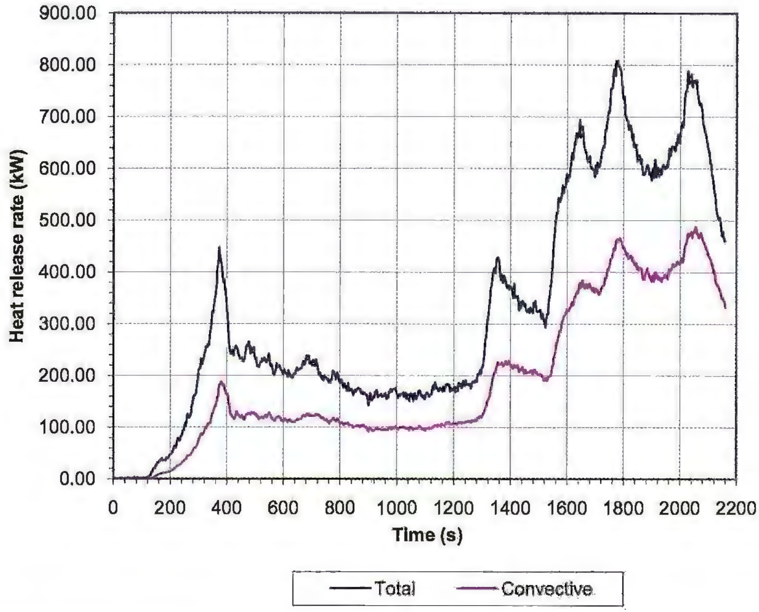
### FIRE DESIGN PARAMETER

For $0 < t \leq 372$ s, $\alpha = 0.0045$ kW/s$^2$ (unsprinklered)

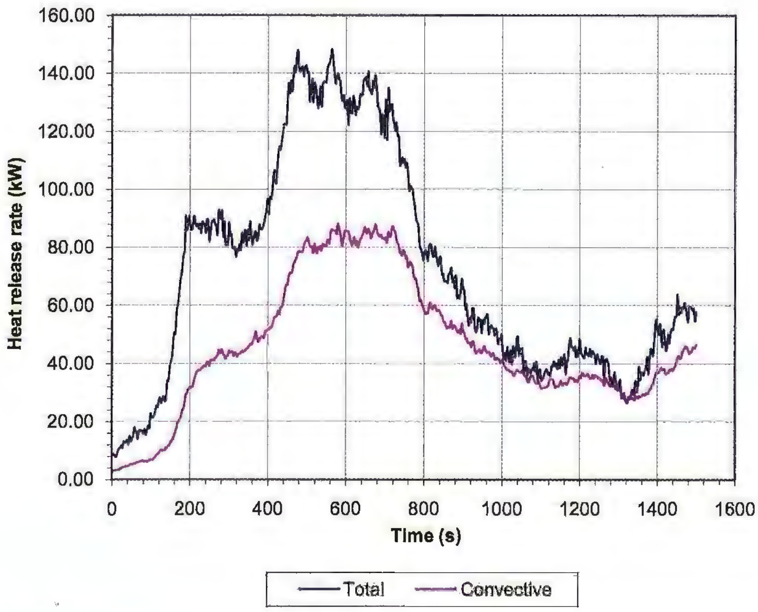
### REFERENCE

Clarke P & Smith DA. Characterisation of fires for design purposes: a database for fire safety engineers. Interflam 2001. Proceedings of 9th Conference, Volume 1. London, Interscience Communications, 2001. p 1157

## HEAT RELEASE RATE DATA




Heat release rate of an unsprinklered bar




Heat release rate of a sprinklered bar

# 6.2 Car parks

## TEST TYPE

Three experiments simulating an open-sided carpark (with and without sprinklers) and one experiment simulating a car park stacker

## SPRINKLER SPECIFICATION

Six standard-response sprinkler heads (to BS EN 12845: 2004 specification), 5 mm/min with coverage of 12 m² per head. Mean pressure of 2.5 bar with a maximum flow rate of 510 litres/min.

## FIRE LOAD

| Test no. | Description |
|---|---|
| 1 | Free burn: 3 cars in a 'typical' open-sided car park. *Parking space 1:* large hatchback (petrol); *Parking space 2:* unoccupied; *Parking space 3:* small car (petrol); *Parking space 4:* large estate (diesel). Fuel levels in all cars approximately 20 litres of either diesel or petrol. Fire service intervention after 24 minutes. |
| 2 | Sprinklered burn: 3 cars in a 'typical' open-sided car park. *Parking space 1:* MPV (petrol); *Parking space 2:* unoccupied; *Parking space 3:* small car (petrol); *Parking space 4:* 4×4 (petrol). Fuel levels in all cars approximately 20 litres of either diesel or petrol. Fire service intervention after 85 min. Sprinkler operation: 2 heads after 4 minutes, 4 heads after 42 minutes, 6 heads after 45 minutes. |
| 3 | Free burn: 3 cars in a 'typical' open-sided car park. *Parking space 1:* MPV (petrol); *Parking space 2:* unoccupied; *Parking space 3:* mid-sized estate (diesel); *Parking space 1:* 4×4 (petrol). Fuel levels in all cars approximately 20 litres of either diesel or petrol. Fire service intervention after 10.5 minutes. |
| 11 | Free burn: 2 cars in a stacker configuration (one directly above the other). *Lower parking space:* 4×4; *Upper parking space*: family estate. Fuel levels in all cars approximately 20 litres of either diesel or petrol. Fire service intervention after 24.5 minutes. |

## MEASUREMENTS TAKEN

Heat release rate, temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## FIRE DESIGN PARAMETERS

For $0 < t \leq 1269$ s, $\alpha_1 = 0.0101$ kW/s² unsprinklered

For $0 < t \leq 3231$ s, $\alpha_2 = 0.00065$ kW/s² sprinklered

For $0 < t \leq 600$ s, $\alpha_3 = 0.0306$ kW/s² unsprinklered

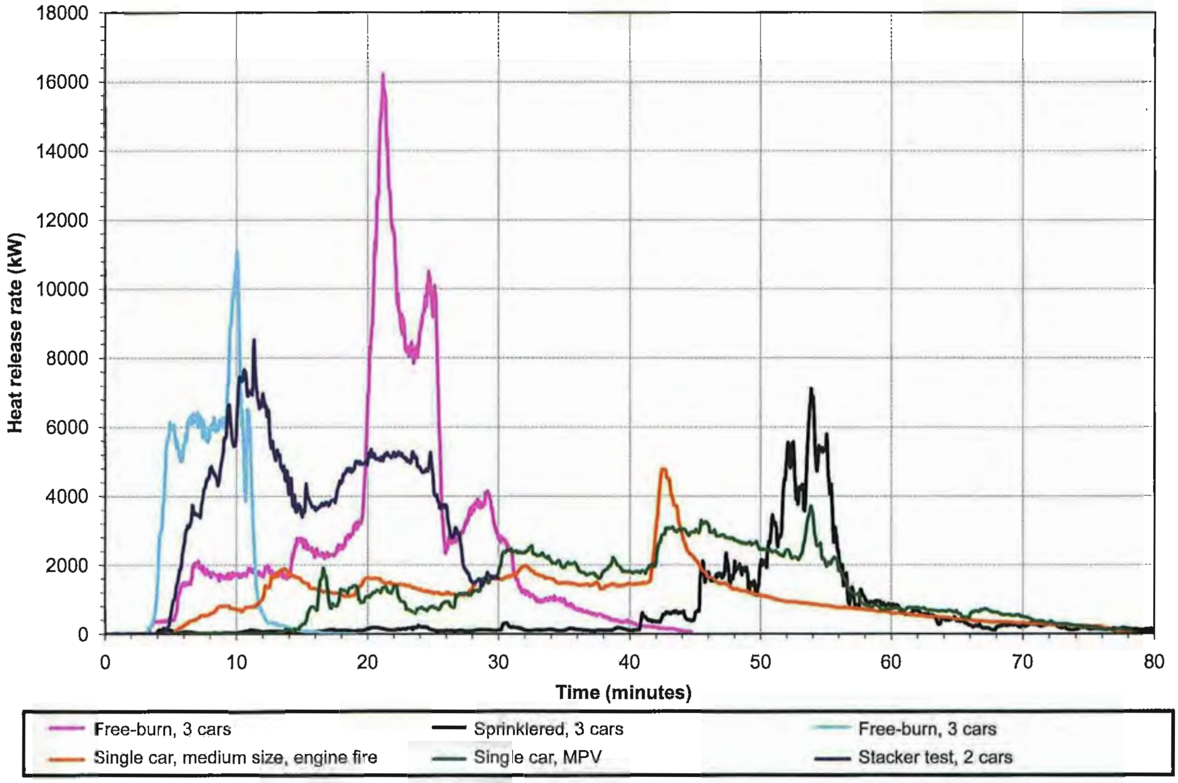
For $0 < t \leq 678$ s, $\alpha_{11} = 0.0164$ kW/s² unsprinklered

## REFERENCES

BSI. BS EN 12845: 2004 + Amendment 2: 2009 Fixed firefighting systems. Automatic sprinkler systems. Design, installation and maintenance

Shipp M, Fraser-Mitchell J, Chitty R et al. Fire spread in car parks; a summary of the CLG/BRE research programme and findings. 2009. Available from http://www.info4fire.com/in-depth-content/full/fire-spread-in-car-parks

## HEAT RELEASE RATE DATA




Total heat release rates from car park fires

# 6.3 Carpet store

## TEST TYPE

Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 $m^2$ coverage per head and 5 mm/min/$m^2$ delivered water density.

## FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| Carpet mixes included polypropylene/wool/hair, 100% polypropylene, 80% wool, wool/polypropylene mix. Also included vinyl flooring and foam rubber underlay. Backing materials were either hessian, felt or foam rubber. | 117 | 15 |

## MEASUREMENTS TAKEN

Heat release rate (total and convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 1400 s) | 2.23 (1116) | 3.97 (1110) | 30845 (1134) | 907 (1137) |
| Sprinklered (First sprinkler activated at 380 s, Test terminated at 500 s) | 3.72 (240) | 2.79 (381) | 12858 (399) | 2350 (225) |

Numbers in parentheses = time to peak parameters in seconds

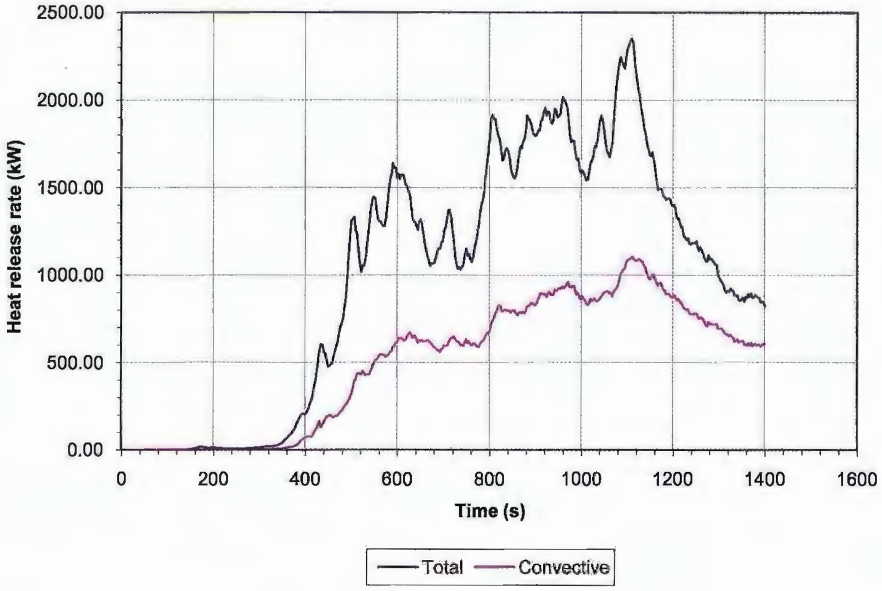
## FIRE DESIGN PARAMETER

For $0 < t \leq 591$ s, $\alpha = 0.0238$ kW/$s^2$ (unsprinklered)

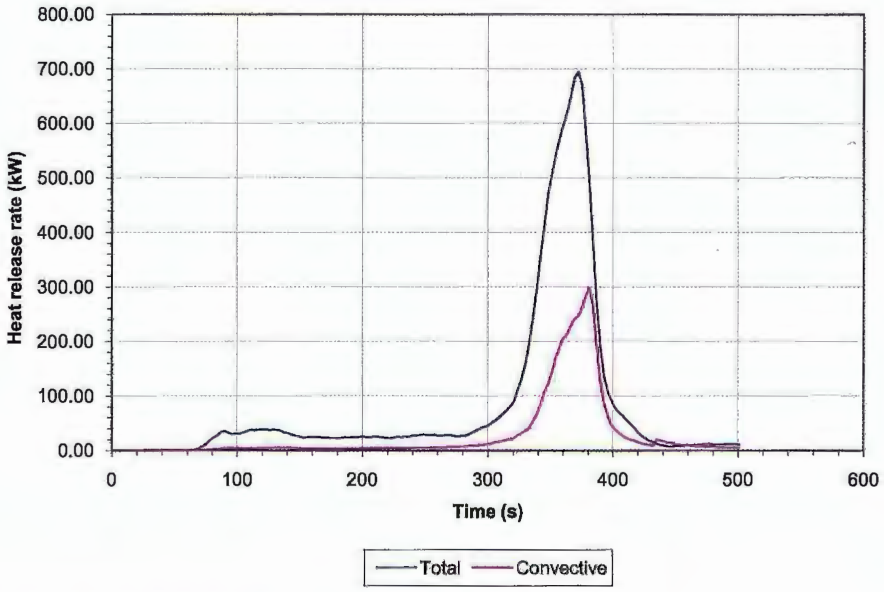
## REFERENCE

Clarke P & Smith DA. Characterisation of fires for design purposes: a database for fire safety engineers. Interflam 2001. Proceedings of 9th Conference, Volume 1. London, Interscience Communications, 2001. p 1157

## HEAT RELEASE RATE DATA




Heat release rate of an unsprinklered carpet store




Heat release rate of a sprinklered carpet store

# 6.4 Clothes store

## TEST TYPE

Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 $m^2$ coverage per head and 5 mm/min/$m^2$ delivered water density.

## FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| All synthetic materials including nylon, polyester, acrylic and cotton mixes. Each item was hung on a plastic coat hanger. Items included T-shirts, tracksuit trousers, bomber jackets and fleece tops. | 144.6 | 363 |

## MEASUREMENTS TAKEN

Heat release rate (total and convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 310 s) | 4.00* (228) | – | 100867 (309) | 4922 (282) |
| Sprinklered (First sprinkler activated at 290 s, Test terminated at 500 s) | 1.04 (336) | 3.12 (297) | 26451 (312) | 710 (315) |

*Limit of measuring range for instrument

Numbers in parentheses = time to peak parameters in seconds

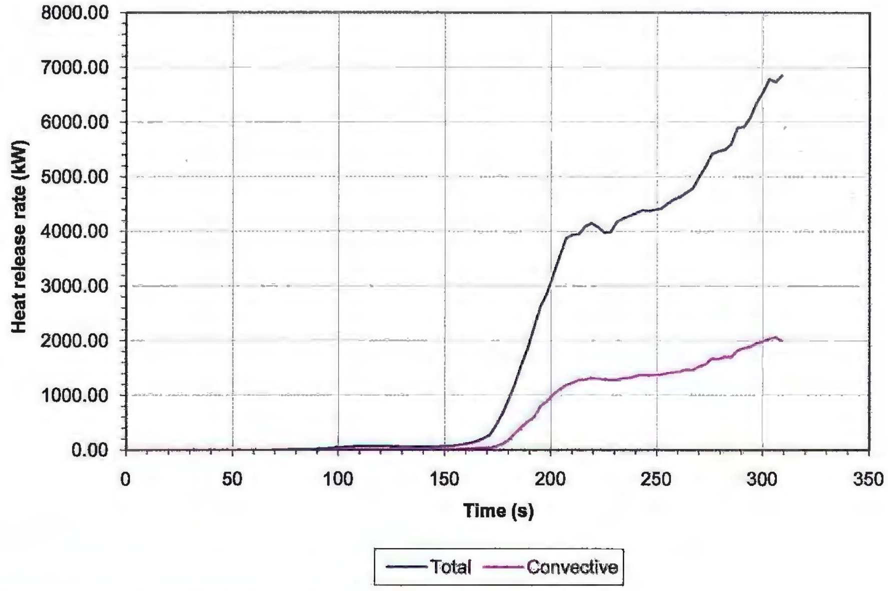
## FIRE DESIGN PARAMETER

For $150 < t \leq 310$ s, $\alpha = 0.308$ kW/$s^2$ (unsprinklered)

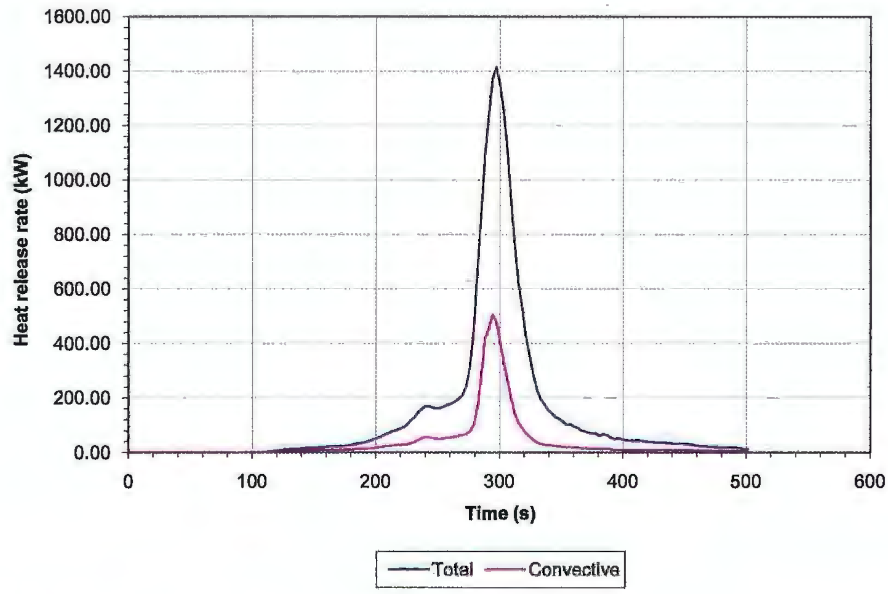
## REFERENCE

Clarke P & Smith DA. Characterisation of fires for design purposes: a database for fire safety engineers. Interflam 2001. Proceedings of 9th Conference, Volume 1. London, Interscience Communications, 2001. p 1157

## HEAT RELEASE RATE DATA




Heat release rate of an unsprinklered clothes store




Heat release rate of a sprinklered clothes store

# 6.5 Indoor play area

## TEST TYPE

Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 m² coverage per head and 5 mm/min/m² delivered water density.

## FIRE LOAD

| Description |
|---|
| • The steel framework was covered in pipe lagging material (expanded foam), with the padded flooring constructed of plywood and foam covered with PVC. All padded areas were PVC-covered foam. A GRP slide and polypropylene rotation moulded crawl tube were present. Netting material was nylon. |

## MEASUREMENTS TAKEN

Heat release rate (total and convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 360 s) | 4.00* (330) | 3.62 (357) | 201347 (369) | 8550 (369) |
| Sprinklered (First sprinkler activated at 440 s, Test terminated at 800 s) | 1.02 (633) | 2.72 (432) | 7024 (453) | 931 (423) |

*Limit of measuring range for instrument

Numbers in parentheses = time to peak parameters in seconds

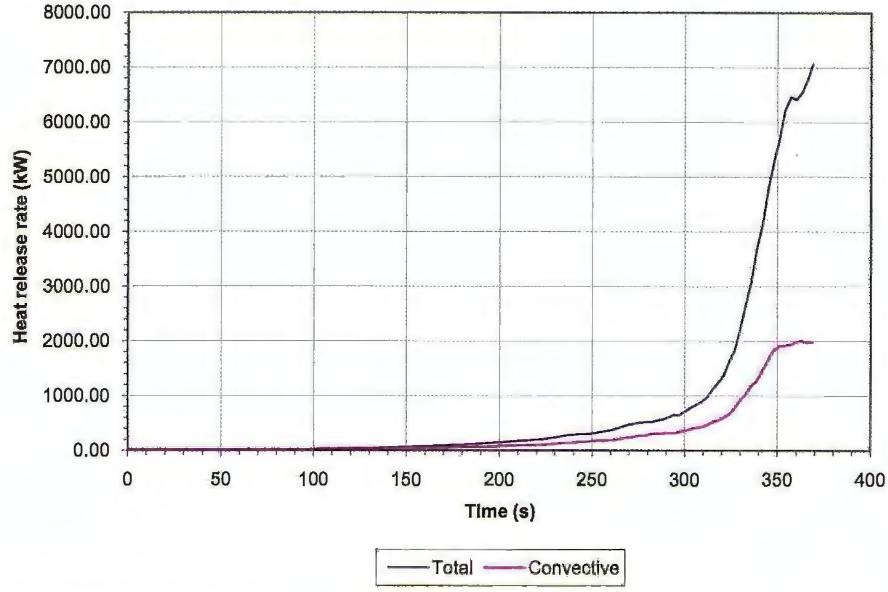
## FIRE DESIGN PARAMETER

For $100 < t \leq 370$ s, $\alpha = 0.1$ kW/s² (unsprinklered)

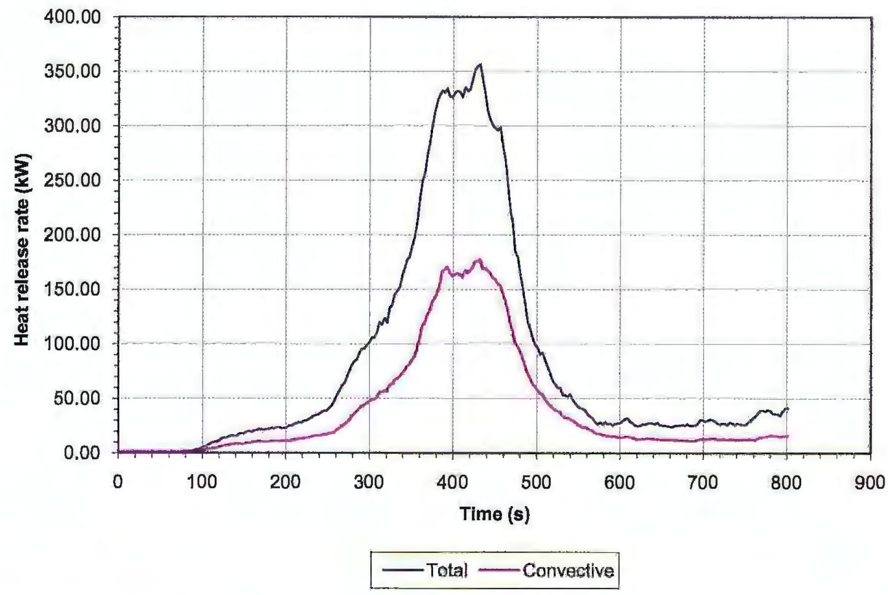
## REFERENCE

Clarke P & Smith DA. Characterisation of fires for design purposes: a database for fire safety engineers. Interflam 2001. Proceedings of 9th Conference, Volume 1. London, Interscience Communications, 2001. p 1157

## HEAT RELEASE RATE DATA




Heat release rate of an unsprinklered play area




Heat release rate of a sprinklered play area

# 6.6 Library

## TEST TYPE

Two free-burn experiments (with and without sprinklers)

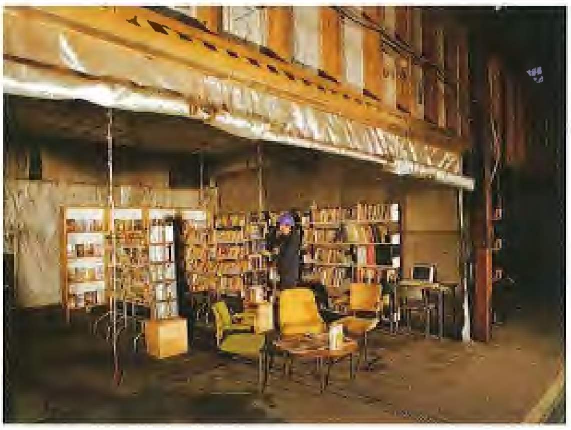
## SPRINKLER SPECIFICATION

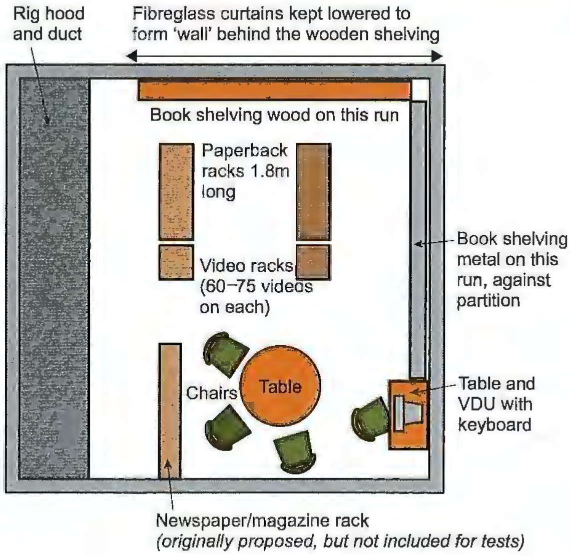
Four fast response heads on a 3.4 m square grid. Each sprinkler head had a coverage of 12 m$^2$ and flow rate of 60 l/min.

## FIRE LOAD

**Description**

- One wooden shelving unit fixed to the rear wall (2100 mm high, 4 bays long) filled with hardback books side by side (80%) and paperback books stored in a display fashion.
- One metal shelving unit fixed to the wall perpendicular to the wooden shelving (1800 mm high, 5 bays long) filled with hardback books side by side (80%) and paperback books stored in a display fashion.
- Two paperback racks (1800 mm long) and two video racks (60–75 videos in each) were placed in the centre of the room.
- A small wood/plastic top table with a VDU, keyboard and chair were placed at the end of the metal shelving together with a table and three chairs.






## MEASUREMENTS TAKEN

Heat release rate (total), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

| | $CO_2$ (%) | CO (ppm) |
|---|---|---|
| Unsprinklered (Test terminated at 16 mins) | 4.00 (1080) | 1000 (1080) |
| Sprinklered (First sprinkler activated at 3.5 mins, Test terminated at 20 mins) | 1.40 (240) | 900 (720) |

Numbers in parentheses = time to peak parameters in seconds

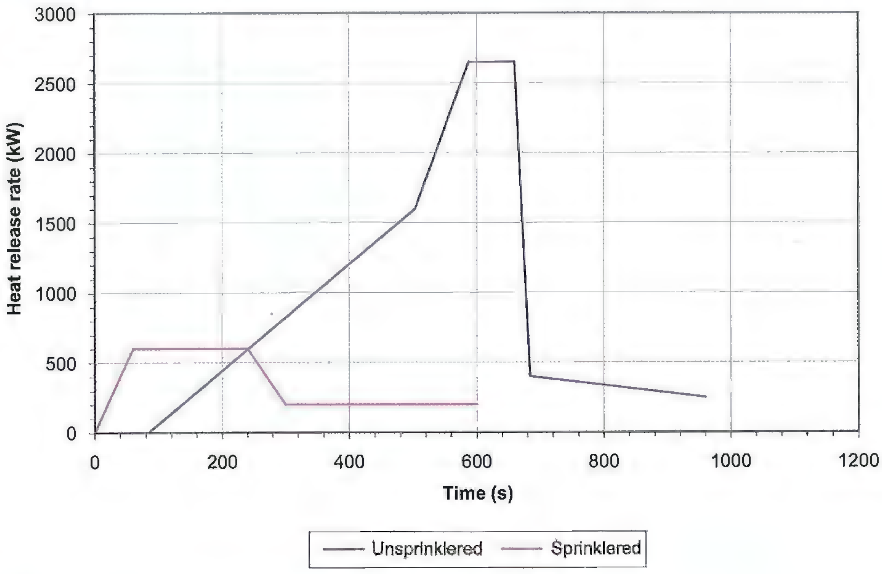
## FIRE DESIGN PARAMETER

For $0 < t \leq 580$ s, $\alpha = 0.008$ kW/s$^2$ (unsprinklered)

## REFERENCE

Webb J & Samme P. The characterisation of library fires using a sprinklered calorimeter. Private communication, 1996

## HEAT RELEASE RATE DATA




Total heat release rate of a library with and without sprinklers

Unsprinklered test after 6 minutes (approximate fire size of 1 MW)

# 6.7 Living room

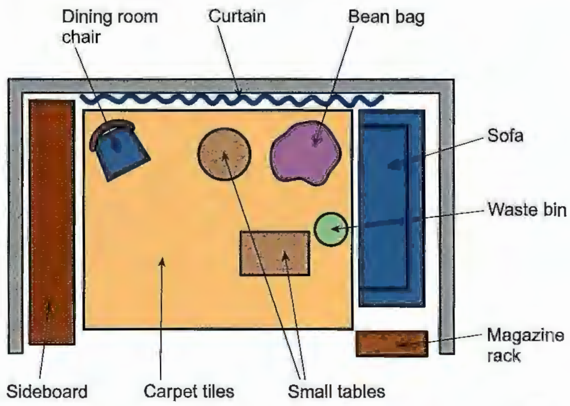
## TEST TYPE

One free-burn experiment (no sprinklers operated)

## FIRE LOAD

**Description**

- The contents of the room primarily consisted of: 3-seater settee, 1 dining room chair, 1 beanbag, 2 small coffee tables, 1 sideboard, curtains and books.
- The central area of the floor was laid with carpet tiles (see diagram, right).
- The seating was part-covered by a throw rug.
- Other furnishings included wicker ornaments, newspapers, magazines in a rack and candles on horizontal surfaces.
- The curtains were hung from a steel pole (*Note:* there was no window).
- Books and toys were located on the sofa and sideboard.
- A small wastepaper bin containing crumpled newspaper sheets was located between the beanbag and the settee.




## MEASUREMENTS TAKEN

Heat release rate (total), temperatures, oxygen depletion, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

| | $CO_2$ (%) | CO (%) | Minimum $O_2$ (%) |
|---|---|---|---|
| Unsprinklered (Test terminated at 24 mins) | 0.94 (660) | 0.026 (660) | 19.9 (660) |

Numbers in parentheses = time to peak parameters in seconds

## FIRE DESIGN PARAMETER

For $300 < t \leq 660$ s, $\alpha = 0.04$ kW/s$^2$

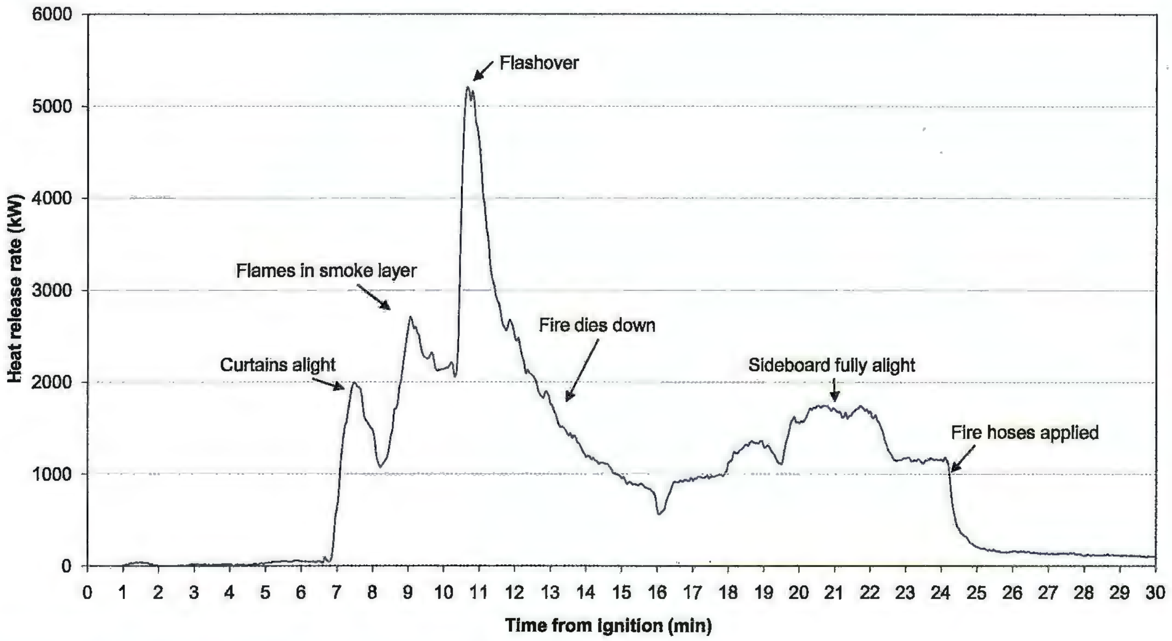
## ACKNOWLEDGEMENT

The data for this design fire were contributed by Martin Shipp, BRE Global.

## REFERENCE

DeHaan JD. Kirk's fire investigation. 6th edition. New Jersey, Pearson Education/Prentice-Hall, 2006

## HEAT RELEASE RATE DATA




Total heat release rate of an unsprinklered living room

# 6.8 Luggage store

## TEST TYPE

Four free-burn experiments (unsprinklered, fast-response sprinklers and two with standard sprinklers)

## SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 $m^2$ coverage per head and 5 mm/min/$m^2$ delivered water density.

## FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| Mainly manmade fibres. Nylon outer shells with PVC waterproof interliner, polyester inner pockets and compartment dividers. Some cases had fabric shells with similar liners to the other cases. Rucksacks were mainly nylon weave with polyester inner linings. | 92 | 57 |

## MEASUREMENTS TAKEN

Heat release rate (total and convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 175 s) | 4.0* (110) | 3.95 (175) | 64994 (175) | 5059 (175) |
| Sprinklered (Fast-response sprinkler activated at 110 s, Test terminated at 500 s) | 4.0* (150) | – | 53978 (220) | 4322 (220) |
| Sprinklered (Standard-response sprinkler 1 activated at 60 s, Test terminated at 400 s) | 4.0* (60) | 4.05 (140) | 47747 (145) | 3479 (130) |
| Sprinklered (Standard-response sprinkler 2 activated at 100 s, Test terminated at 460 s) | 4.0* (105) | 3.81 (115) | 40658 (155) | 2730 (155) |

*Limit of measuring range for instrument

Numbers in parentheses = time to peak parameters in seconds

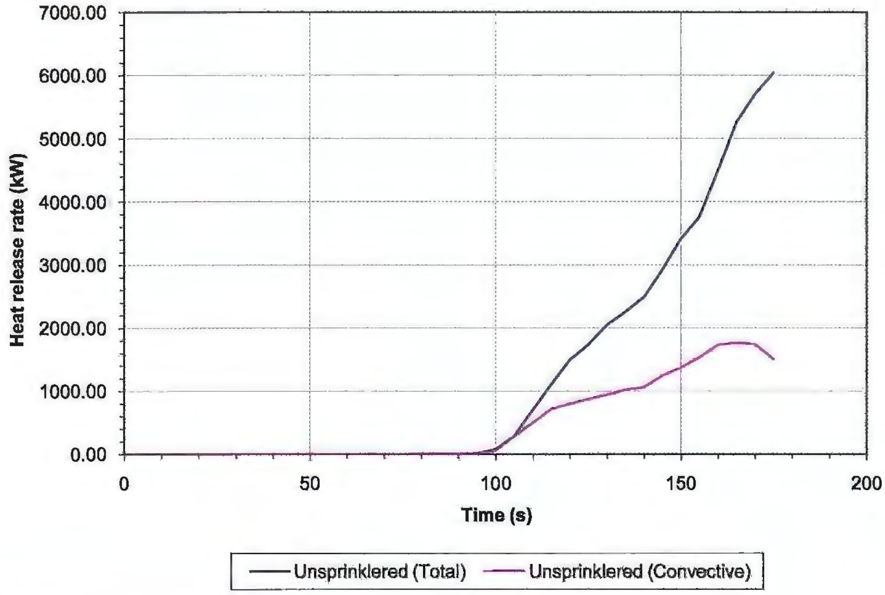
## FIRE DESIGN PARAMETER

For $75 < t \leq 175$ s, $\alpha = 0.6054$ kW/$s^2$ (unsprinklered)

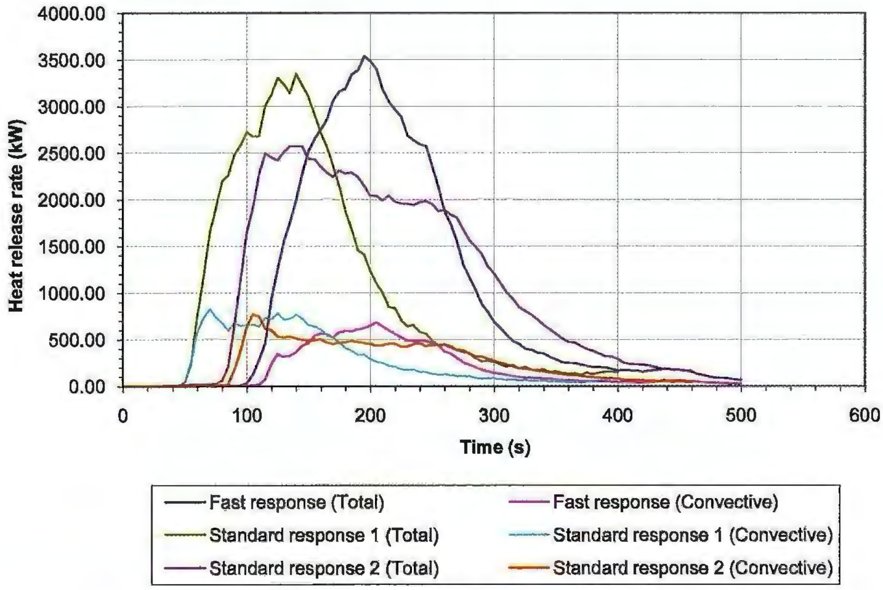
## REFERENCE

Clarke P & Smith DA. Characterisation of fires for design purposes: a database for fire safety engineers. Interflam 2001. Proceedings of 9th Conference, Volume 1. London, Interscience Communications, 2001. p 1157

## HEAT RELEASE RATE DATA




Heat release rate of an unsprinklered luggage store




Heat release rate of a sprinklered luggage store

# 6.9 Office

## TEST TYPE

Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 m² coverage per head and 5 mm/min/m² delivered water density.

## FIRE LOAD

| Description | Mass (kg) | No. of Items |
|---|---|---|
| Melamine-faced chipboard desks, material- and foam-covered MDF dividing screens on each desk, computer monitors, keyboards and general office items, which were mainly constructed from plastics. Upholstered office chairs with material covers, foam seat and back with polypropylene trim. | 245.6 | 70 |

## MEASUREMENTS TAKEN

Heat release rate (total and convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 1800 s) | 2.21 (846) | 4.13 (1575) | 107157 (1779) | 11803 (1728) |
| Sprinklered (First sprinkler activated at 950 s, Test terminated at 1200 s) | 0.84 (903) | 2.54 (924) | 6063 (942) | 493 (1137) |

Numbers in parentheses = time to peak parameters in seconds

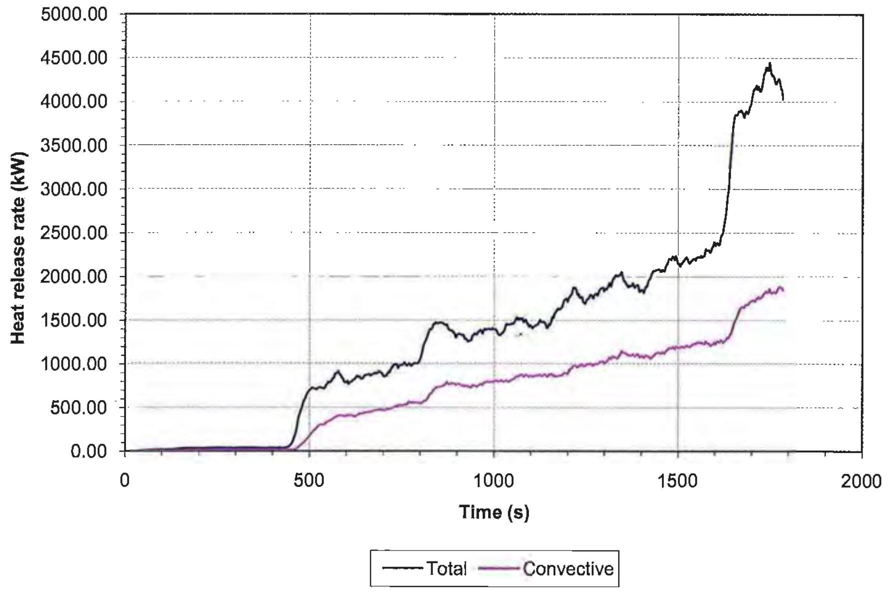
## FIRE DESIGN PARAMETER

For $500 < t \leq 1200$ s, $\alpha = 0.0003$ kW/s² (unsprinklered)

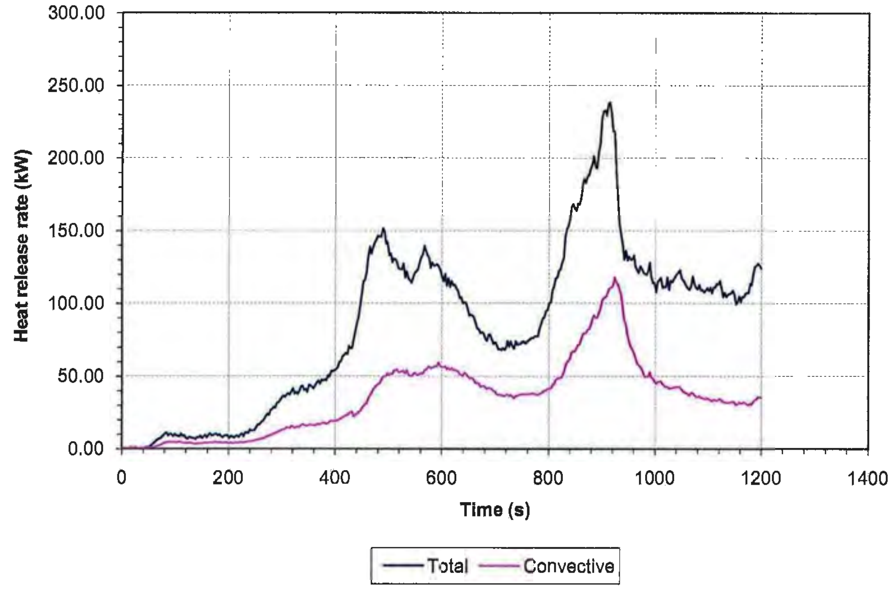
## REFERENCE

Clarke P & Smith DA. Characterisation of fires for design purposes: a database for fire safety engineers. Interflam 2001. Proceedings of 9th Conference, Volume 1. London, Interscience Communications, 2001. p 1157

## HEAT RELEASE RATE DATA




Heat release rate of an unsprinklered office




Heat release rate of a sprinklered office

# 6.10 Prison cell

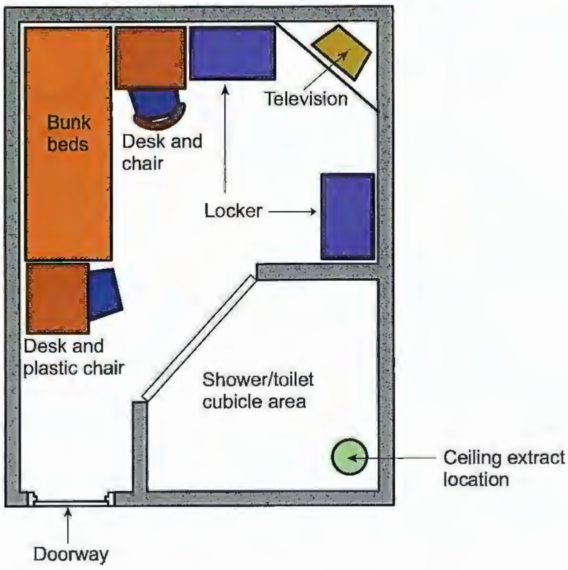
## TEST TYPE

Single experiment (free burn, no sprinklers operated). Cell contained representative prison-issue furniture and personal items.

## FIRE LOAD

**Description**

- Double-occupancy prison cell measuring internally 3 m × 4 m and 3 m high, giving a total volume of 36 $m^3$.
- The room was of blockwork construction, internally clad with plasterboard.
- Fire load comprised 2 prison-issue matresses, 2 prison-issue bedside lockers, one of which was placed on its side on the lower level of a bunk bed. The locker on the bunk bed was filled with: 12 crisp packets, 4 boxes of cereal, a pair of jeans, a vest, 2 toilet rolls, 2 plastic bottles, a newspaper, a magazine, 10 single CD cases, a computer keyboard, a prison issue duvet cover, sheet and pillow slip. Additionally, 2 desks, 2 chairs (one of which was plastic), 2 pairs of shoes, a towel, 3 shirts, a television and 2 pairs of jeans.
- Fire was manually extinguished after approximately 18.5 minutes.
- Door was open throughout the test.




## PEAK MEASURED PARAMETERS

| Minimum oxygen (%) | $CO_2$ ($m^3$/s) | CO ($m^3$/s) | HCN (ppm) | HCL (ppm) | Volume flow rate ($m^3$/s) |
|---|---|---|---|---|---|
| 0.2 (mid-height) | 0.165 (1074) | 0.03 (396) | 1030 (600) | 51 (600) | 20 (600) |

Numbers in parentheses = time to peak parameters in seconds

## MEASUREMENTS TAKEN

Heat release rate (total), temperatures, optical density, HCN, HCL, $CO_2$ and CO concentrations

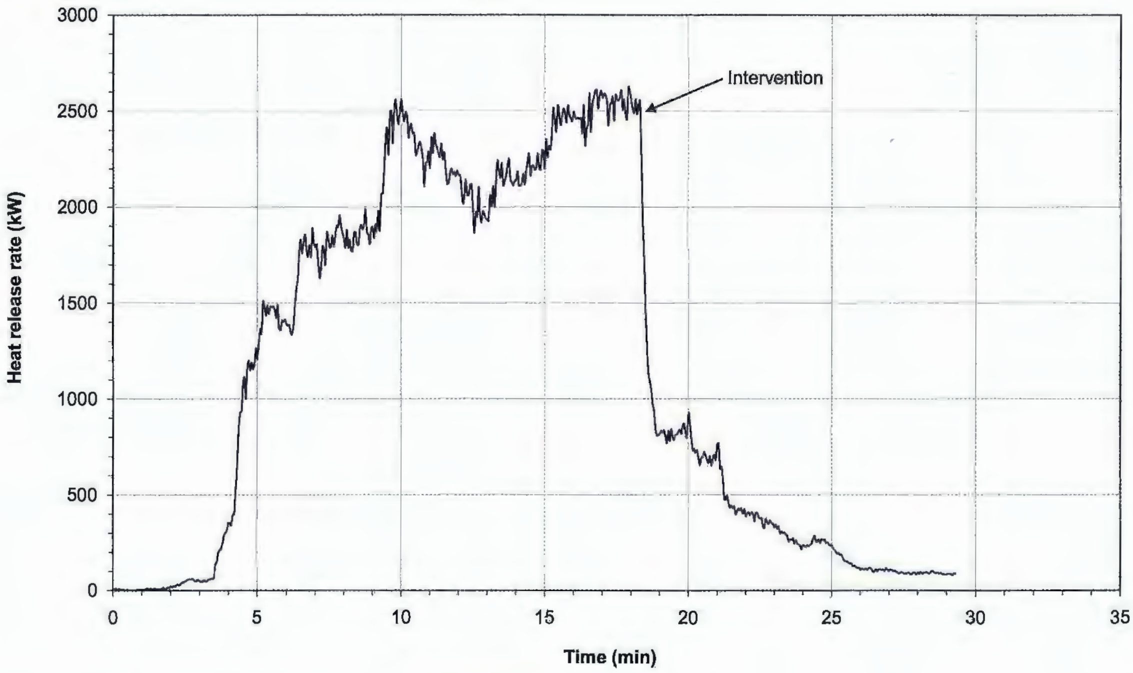
## FIRE DESIGN PARAMETER

For $0 < t \leq 600$ s, $\alpha = 0.0069$ kW/s²

## REFERENCE

Annable K. Watermist systems for prison cells. 2010. Available at www.info4fire.com/in-depth-content/full/water-mist-systems-for-prison-cells

## HEAT RELEASE RATE DATA




Total heat release rate from a typical prison cell (unsprinklered)

# 6.11 Reception

## TEST TYPE

Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 m² coverage per head and 5 mm/min/m² delivered water density.

## FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| Computer monitors, keyboards, TV/monitor, polypropylene wastebasket, videocassettes and recorder as well as general office items such as ring binders and paper. Two office-style leather faced chairs with foam seat and back. Two visitors' seats material-covered with hollow-fibre cushions and one material-covered sofa with hollow fibre. | 86.5 | 19 |

## MEASUREMENTS TAKEN

Heat release rate (total & convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 1700 s) | 4.00* (975) | 4.23 (1062) | 51615 (1515) | 12589 (1629) |
| Sprinklered (First sprinkler activated at 360 s, Test terminated at 500 s) | 2.14 (366) | 2.90 (345) | 10628 (378) | 642 (381) |

*Limit of measuring range for instrument

Numbers in parentheses = time to peak parameters in seconds

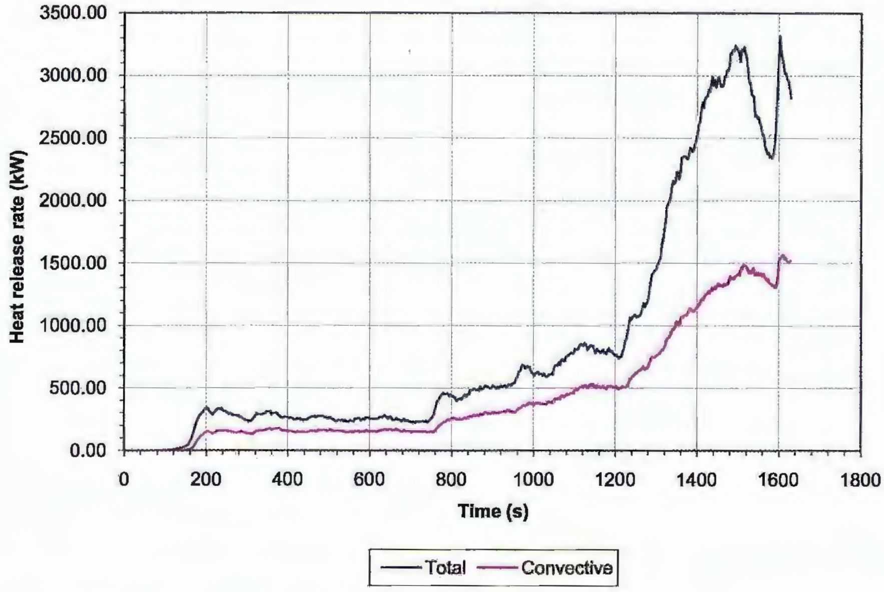
## FIRE DESIGN PARAMETER

For $180 < t \leq 1400$ s, $\alpha = 0.003$ kW/s² (unsprinklered)

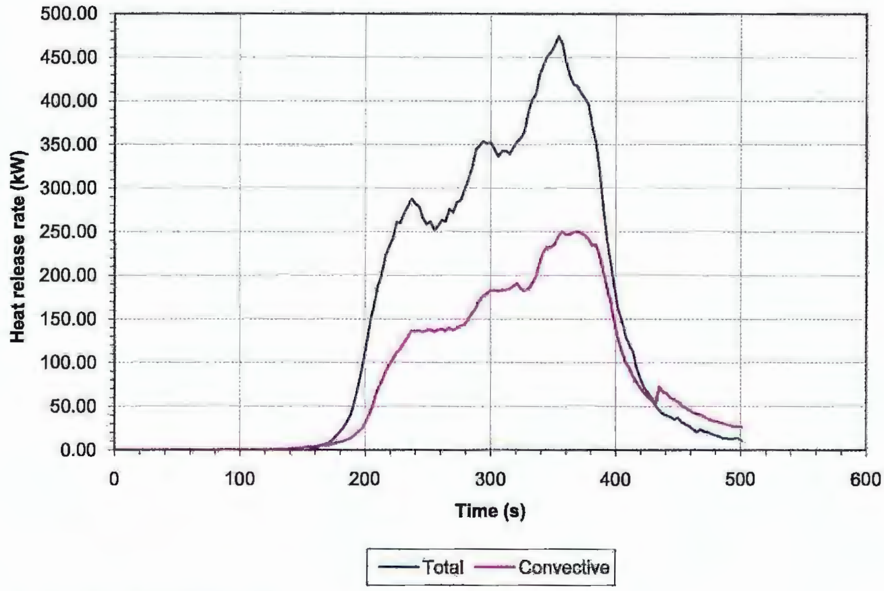
## REFERENCE

Clarke P & Smith DA. Characterisation of fires for design purposes: a database for fire safety engineers. Interflam 2001. Proceedings of 9th Conference, Volume 1. London, Interscience Communications, 2001. p 1157

## HEAT RELEASE RATE DATA




Heat release rate of an unsprinklered reception area




Heat release rate of a sprinklered reception area

# 6.12 Retail store

## TEST TYPE

Single free-burn experiment (without sprinklers)

## FIRE LOAD

**Description**

- Retail store complete with luggage, plastic manikin, bags, plastic shoes, LCD display, chairs, storage cupboard and plastic toys arranged over both the floor area and in hanging displays.

## MEASUREMENTS TAKEN

Heat release rate, temperatures, volume flow, rate of smoke production, $O_2$, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

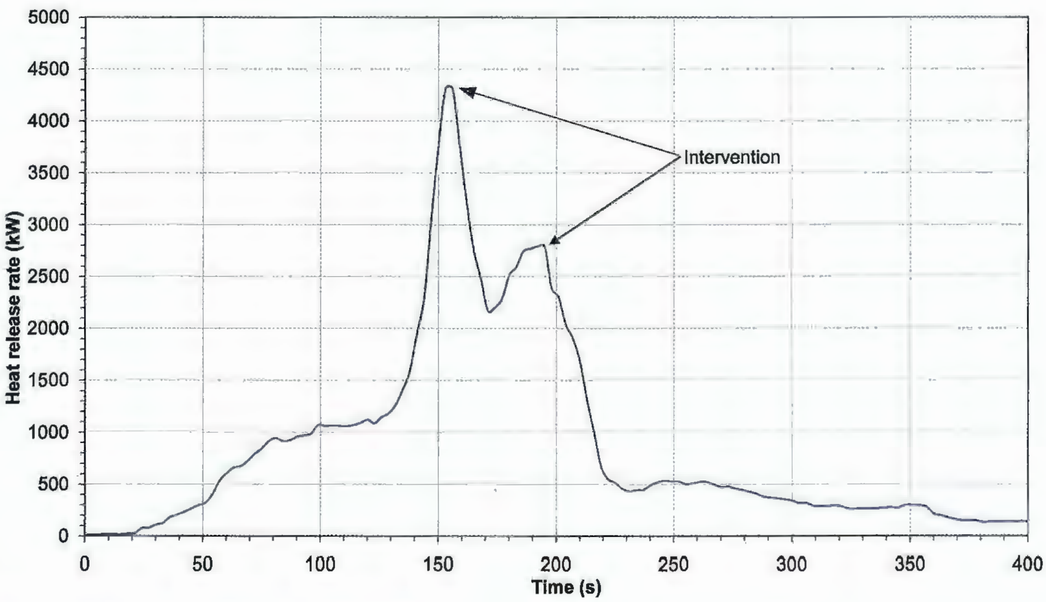
| | CO (%) | $CO_2$ (%) | $O_2$ minimum (%) | Smoke production rate ($m^3/s$) | Volume flow rate ($m^3/s$) |
|---|---|---|---|---|---|
| Unsprinklered | 0.08 (1128) | 1.66 (1122) | 19.07 (1113) | 14.77 (1152) | 16 (1122) |

Numbers in parentheses = time to peak parameters in seconds

## FIRE DESIGN PARAMETER

For $0 < t \leq 153$ s, $\alpha = 0.184$ kW/s² (unsprinklered)

## HEAT RELEASE RATE DATA




Total heat release rate of an unsprinklered retail store

# 6.13 Video store

## TEST TYPE
Single free-burn experiment (without sprinklers)

## FIRE LOAD

**Description**

- Video cassettes in plastic or cardboard boxes, empty compact disc cases. Shelving formed from moulded polypropylene video and CD trays supported by a metal framework. The layout was intended to represent a corner aisle of a video shop. The tests represented malicious ignition of the bottom row of the centre video rack.

## MEASUREMENTS TAKEN
Heat release rate, temperatures, optical density, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

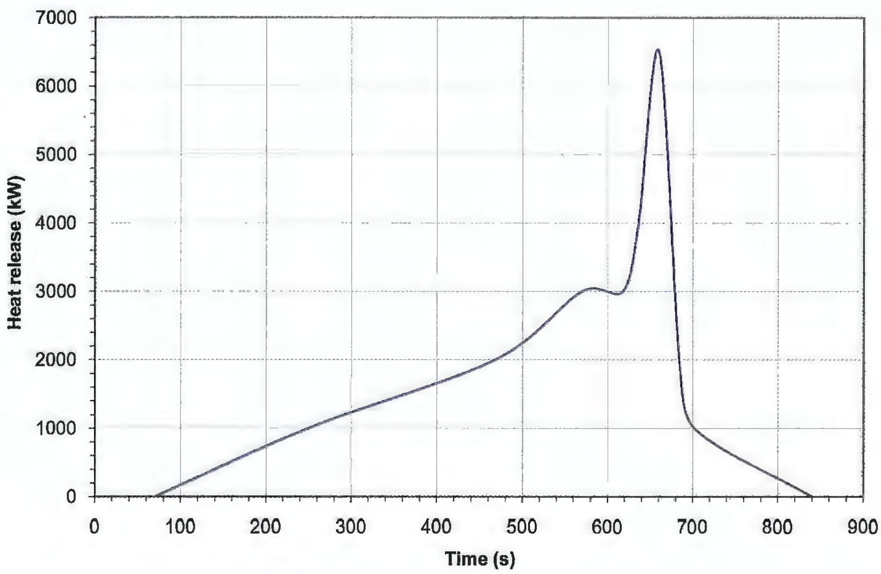
| | Optical density (OD/m) | $CO_2$ (%) | CO (ppm) |
|---|---|---|---|
| Unsprinklered | 2.5 (240) | 4.1 (660) | 7000 (660) |

Numbers in parentheses = time to peak parameters in seconds

## FIRE DESIGN PARAMETER
For $100 < t \leq 660$ s, $\alpha = 0.02$ kW/s² (unsprinklered)

## REFERENCE
Samme P & Webb J. The characterisation of video shop fires using a sprinklered calorimeter. Private communication, 1997

## HEAT RELEASE RATE DATA




Total heat release rate of an unsprinklered video store

# 6 Notes

# 7 COMMODITIES

## 7.1 Beds

### FIRE LOAD

| Experiment no. | Description | Mass (kg) | No. of items |
|---|---|---|---|
| 1 | Double bed, bedding, night table | 53.70 | 1 |
| 2 | Double bed, bedding, night table | 53.70 | 1 |

### MEASUREMENTS TAKEN

Heat release rate (total)

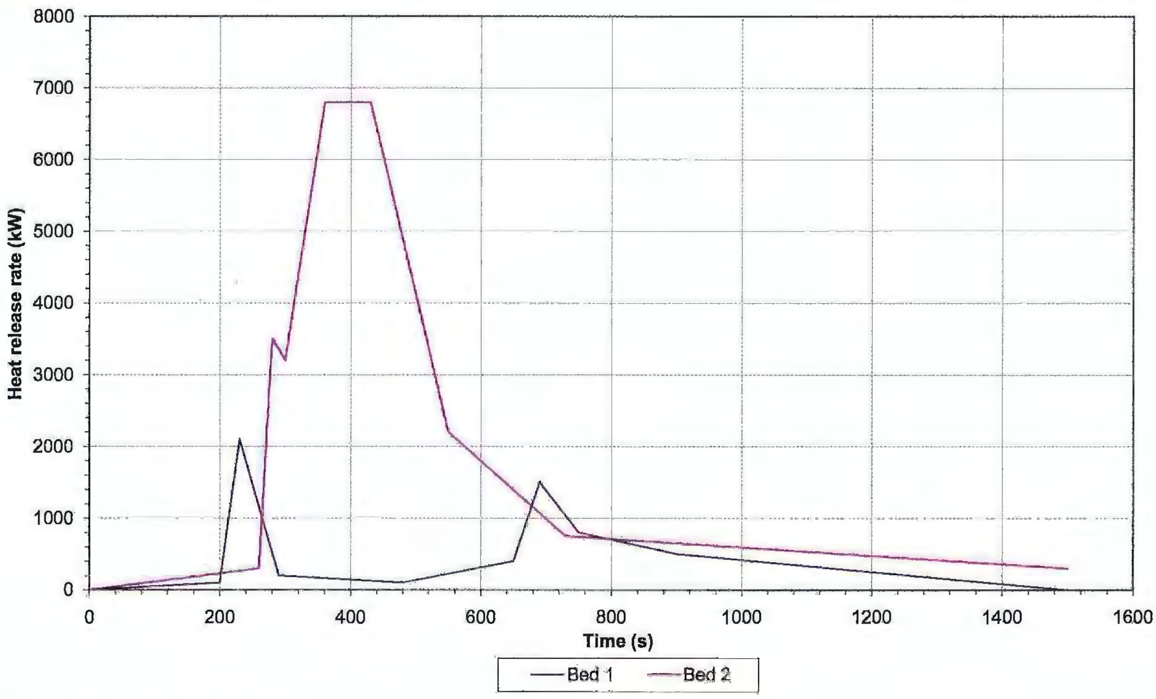
### FIRE DESIGN PARAMETERS

| Bed | α (kW/s²) | Heat of combustion (J/kg) |
|---|---|---|
| 1 | 2.22 for $0< t \leq 360$ s | 18100 |
| 2 | 0.82 for $0< t \leq 230$ s | 18100 |

### REFERENCES

Spearpoint M. FireBaseXML database. Version 1.34. New Zealand, University of Canterbury, 2007. Visit http://www.civil.canterbury.ac.nz/spearpoint/HRR_Database/HRR_Database.xml

### HEAT RELEASE RATE DATA




Total heat release rate of a double bed, bedding and night table

# 7.2 Boxes

## TEST TYPE

Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 $m^2$ coverage per head and 5 mm/min/$m^2$ delivered water density.

## FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| Corrugated cardboard boxes (610 mm × 610 mm × 480 mm) filled with packing materials, mainly polystyrene chips and expanded foam mouldings. 16 boxes per stack each on a wooden pallet with 6 stacks in total | 353 | 96 |

## MEASUREMENTS TAKEN

Heat release rate (total and convective), temperatures, optical density, mass flow rate and radiant heat

## PEAK MEASURED PARAMETERS

| | Optical density (OD/m) | Mass flow rate (kg/s) |
|---|---|---|
| Unsprinklered (Test terminated at 880 s) | 4.00* (625) | 3.71 (880) |
| Sprinklered (First sprinkler activated at 1200 s, Test terminated at 1600 s) | 3.07 (1470) | 3.03 (1355) |

*Limit of measuring range for instrument

Numbers in parentheses = time to peak parameters in seconds

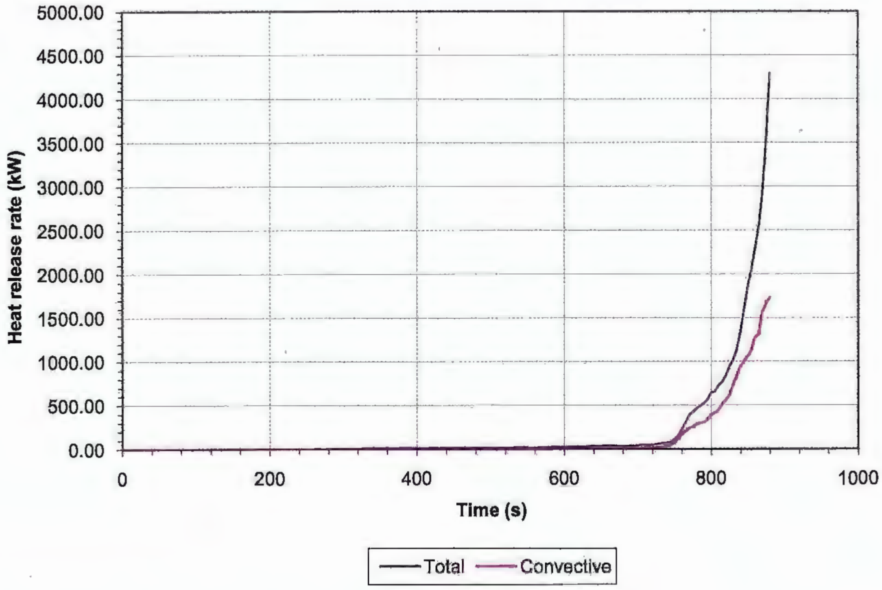
## FIRE DESIGN PARAMETER

For $0 < t \leq 880$ s, $\alpha = 0.0362$ kW/$s^2$ (unsprinklered)

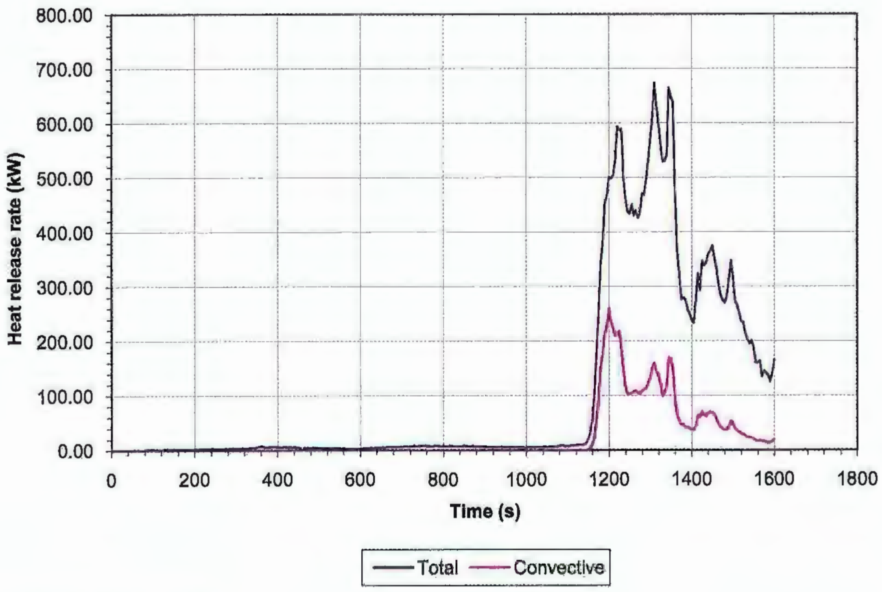
## REFERENCE

Garrad G & Smith DA. Characterisation of fires for design. Interflam 1999. Proceedings of 8th Conference, Volume 1. London, Interscience Communications, 1999. p 555

## HEAT RELEASE RATE DATA




Heat release rate of unsprinklered boxes




Heat release rate of sprinklered boxes

# 7.3 Buses

## TEST TYPE

A single free-burn experiment to simulate a fire in the rear luggage compartment

## FIRE LOAD

**Description**

- A 13 m single-deck Volvo coach with 49 passenger seats. The bus was used for development purposes and was never used in public traffic. Gear box fitted with a retarder. Fire ignited in the rear luggage compartment using a propane burner. Calorimeter placed to measure heat release rate from rear two-thirds of the bus length.

## MEASUREMENTS TAKEN

Heat release rate (total), temperatures, visibility, CO, $CO_2$, HCl, HCN, HF, HBr, $SO_2$, NOa and $NO_2$ concentrations

Photos courtesy of Björn Sundström, SP Technical Research Institute of Sweden

## PEAK MEASURED PARAMETERS (inside passenger compartment after 8 minutes)

| CO (ppm) | $CO_2$ (ppm) | HCl (ppm) | HCN (ppm) | HF (ppm) | HBr (ppm) | $SO_2$ (ppm) | NOa (ppm) | $NO_2$ (ppm) |
|---|---|---|---|---|---|---|---|---|
| 3030 | 1710 | 51 | 65 | <5 | <10 | <10 | <15 | <5 |

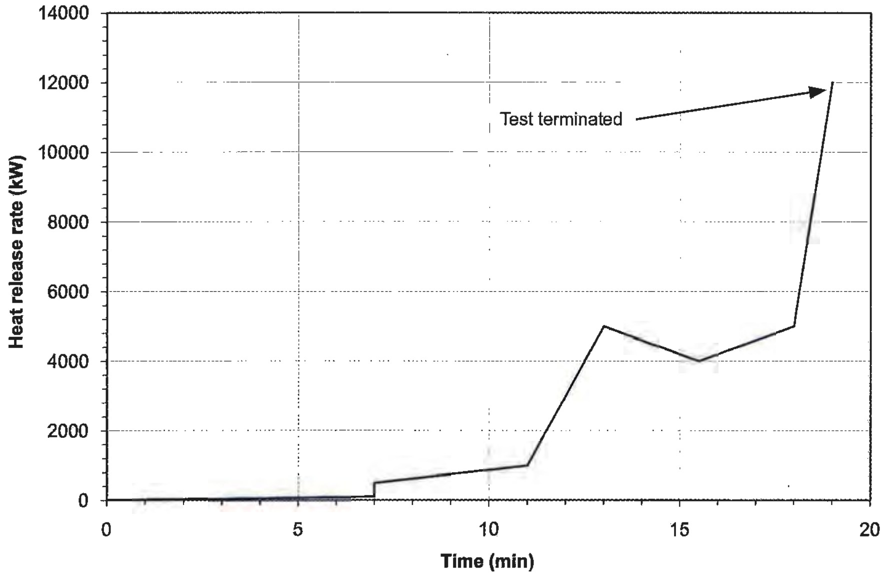
## FIRE DESIGN PARAMETER

For $0 < t \leq 1140$ s, $\alpha = 0.009$ kW/s$^2$

## REFERENCE

Hammarström R, Axelsson J, Försth M et al. Bus fire safety. SP report 2008:41. Boras, Technical Research Institute of Sweden, 2008. Available as a pdf from: www-v2.sp.se

## HEAT RELEASE RATE DATA




Total heat release rate of a bus (fire in luggage compartment)

# 7.4 Cars

## TEST TYPE

Four free-burn experiments:

- Small family car
  - fire originating in the passenger compartment (windows and doors closed)
  - fire originating in the engine compartment
- MPV
  - fire originating in the passenger compartment (windows and doors closed)
  - fire originating in the engine compartment

## MEASUREMENTS TAKEN

Heat release rate, temperatures, smoke production, volume flow rate, carbon dioxide, carbon monoxide, oxygen depletion

## FIRE LOAD

| Experiment no. | Description |
|---|---|
| 1 | 2002 5-Door medium-sized hatchback: Fire originating in the passenger compartment, ignition using a No. 7 crib, 20 litres of fuel in tank |
| 2 | 2000 MPV: Fire originating in the passenger compartment, ignition using a No. 7 crib 20 litres of fuel in tank |
| 3 | 2002 5-Door medium-sized hatchback: Fire originating in the engine bay, ignition using an IMS-soaked fibreboard, 20 litres of fuel in tank |
| 4 | 2000 MPV: Fire originating in the engine bay, ignition using an IMS-soaked fibreboard 20 litres of fuel in tank |

*Note:* Experiment nos 1 and 3 self-extinguished and were terminated respectively due to the lack of available air.

## PEAK MEASURED PARAMETERS

| | Smoke production ($m^3/s$) | Volume flow rate ($m^3/s$) | $CO_2$ (%) | CO (%) |
|---|---|---|---|---|
| Experiment 1 | 0.095 (510) | 15.386 (0 to 2217) | 0.057 (0 to 2163) | 0.004 (1959) |
| Experiment 2 | 0.492 (1413) | 18.069 (0 to 1300) | 0.050 (0 to 1800) | 0.022 (78) |
| Experiment 3 | 91.164 (2940) | 19.378 (0 to 4836) | 1.334 (2650) | 0.046 (2800) |
| Experiment 4 | 81.183 (2529) | 19.539 (0 to 3504) | 1.181 (3546) | 0.044 (3078) |

Numbers in parentheses = time to peak parameters in seconds

## FIRE DESIGN PARAMETERS

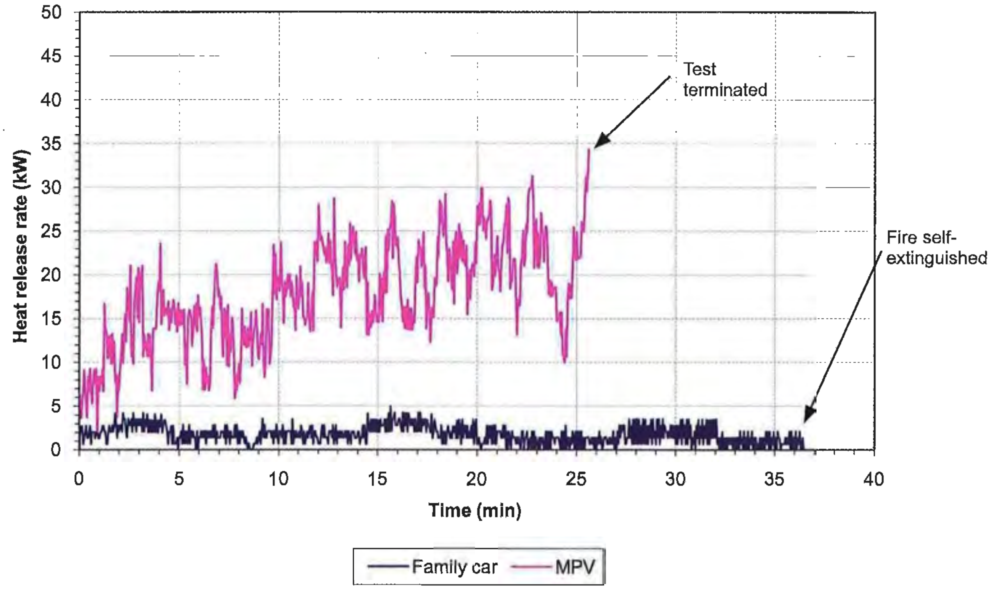
For $750 < t \leq 930$ s, $\alpha = 0.06$ kW/s² in Experiment 3

For $300 < t \leq 750$ s, $\alpha = 0.0098$ kW/s² in Experiment 4

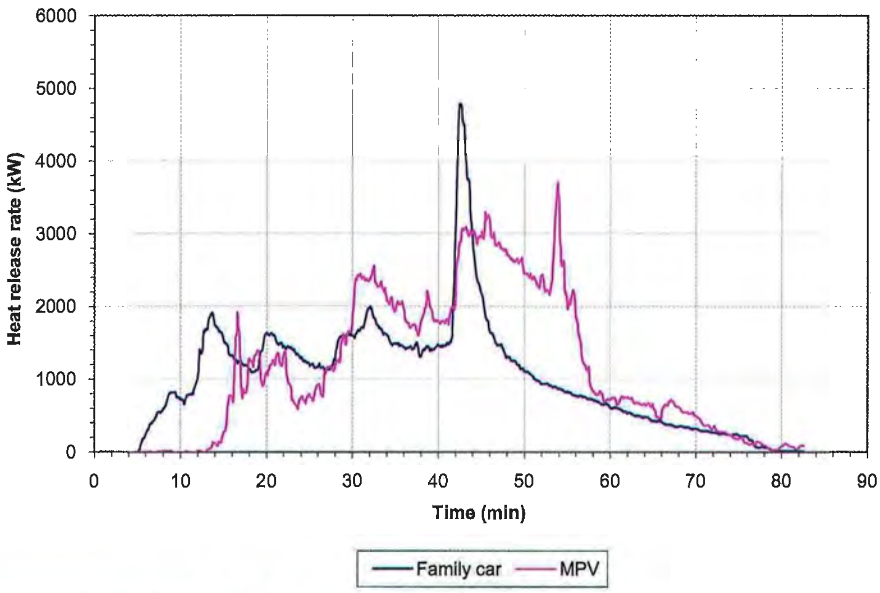
## REFERENCE

Shipp M, Fraser-Mitchell J, Chitty R et al. Fire spread in car parks. A summary of the CLG/BRE research programme and findings. 2009. Available at www.info4fire.com/in-depth-content/full/fire-spread-in-car-parks

## HEAT RELEASE RATE DATA




Total heat release rate of a family car and MPV (fire originating in passenger compartment with windows and doors closed)




Total heat release rate of a family car and MPV (fire originating in engine compartment)

# 7.5 Chairs

## FIRE LOAD

| Experiment no. | Description | Mass (kg) | No. of items |
|---|---|---|---|
| 1 | Stacked chairs constructed from foam and cellulosic material | 40.00 | 16 |
| 2 | Wood-frame easy chair, polyeurathane cushions, polyolefin fabric[A] | 28.34 | 1 |
| 3 | Wood-frame easy chair, cotton padding, polyolefin fabric[B] | 31.20 | 1 |
| 4 | Love seat, metal frame, four solid polyurethane foam-filled cushions covered in plastic-coated fabric[C] | – | 1 |

## MEASUREMENTS TAKEN

Heat release rate (total)

## FIRE DESIGN PARAMETERS

| Chairs | $\alpha$ (kW/s²) | Heat of combustion (J/kg) |
|---|---|---|
| 1 | 0.255 for $0 < t \leq 84$ s | 15000 |
| 2 | 0.017 for $0 < t \leq 350$ s | – |
| 3 | 0.0075 for $0 < t \leq 365$ s | 16800 |
| 4 | 0.0012 for $0 < t \leq 500$ s | – |

## REFERENCES

Spearpoint M. FireBaseXML database. Version 1.34. New Zealand, University of Canterbury, 2007. Visit http://www.civil.canterbury.ac.nz/spearpoint/HRR_Database/HRR_Database.xml

**Chair[A]**

Williamson RB & Dembsey NA. Advances in assessment methods for fire safety. Interflam 1990. Proceedings of 5th Conference. London, Interscience Communications, 2001. p

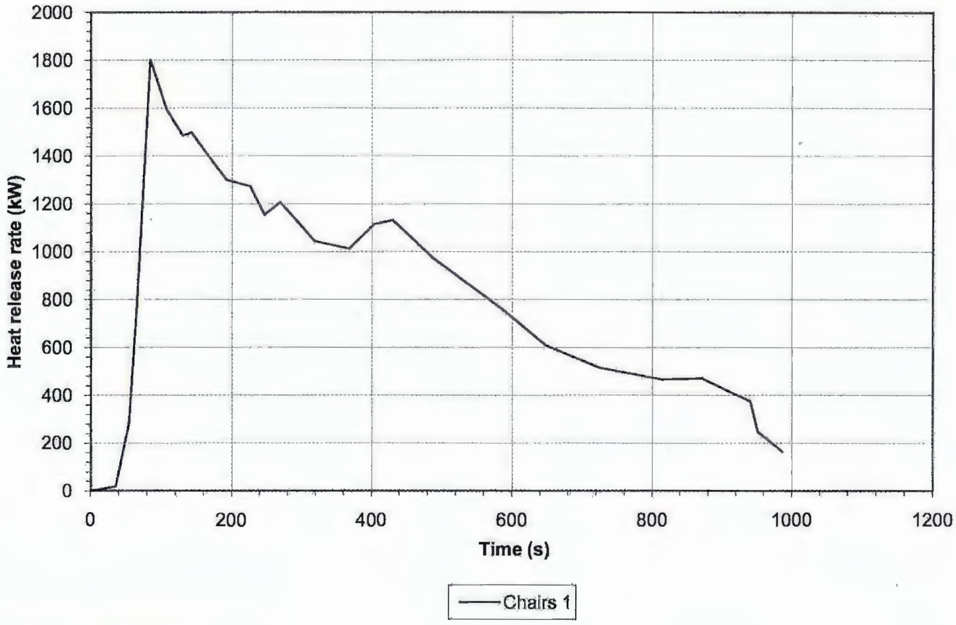
**Chair[B]**

Lawson JR, Walton WD & Twilley WH. Fire performance of furnishings as measured in the NBS furniture calorimeter. Part I. NBSIR 83-2787. 1984. Available at http://fire.nist.gov/bfrlpubs/fire84/art002.html

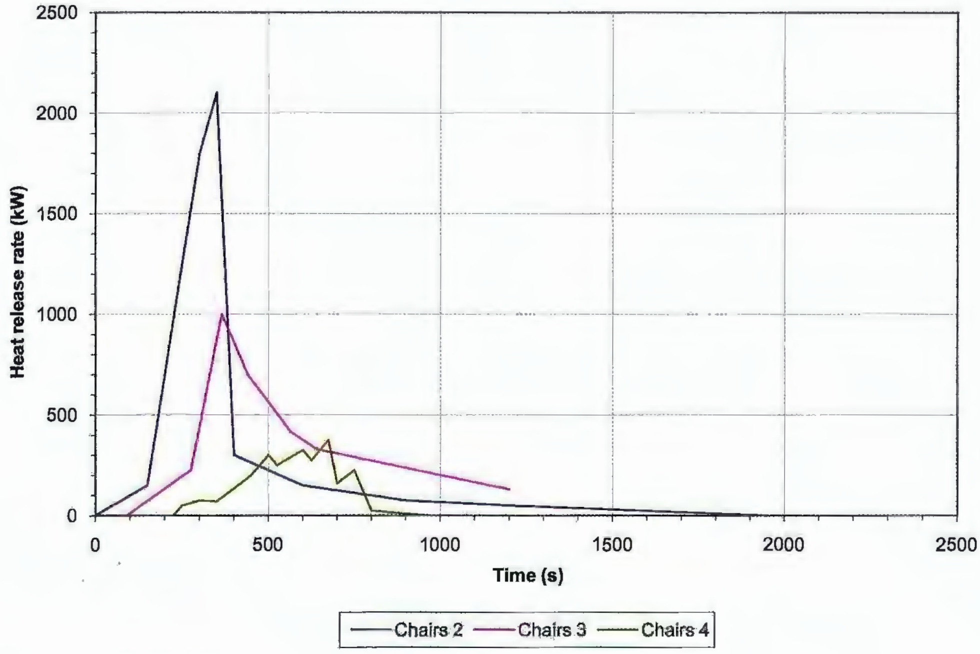
**Chair[C]**

Babrauskas V, Lawson J R, Walton W D & Twilley WH. Upholstered furniture heat release rates measured with a furniture calorimeter. NBSIR 82-2604. 1982. Available at http://fire.nist.gov/bfrlpubs/fire82/art007.html

## HEAT RELEASE RATE DATA




Total heat release rate of 16 stacked chairs




Total heat release rate of single chairs

# 7.6 Christmas trees

## FIRE LOAD

| Experiment no. | Description | Mass (kg) | No. of items |
|---|---|---|---|
| 1 | Height 2.6 m, width at widest point 1.7 m, moisture content 30% Conditioned at 23 °C, 50% RH for 3 weeks. Ignition by electric match | 17.2 | 1 |
| 2 | Height 2.7 m, width at widest point 1.3 m, moisture content 27% Conditioned at 23 °C, 50% RH for 3 weeks. Ignition by electric match | 15.9 | 1 |
| 3 | Height 2.3 m, width at widest point 1.7 m, moisture content 30% Conditioned at 23 °C, 50% RH for 3 weeks. Ignition by electric match | 20.0 | 1 |
| 4 | Height 2.5 m, width at widest point 1.2 m, moisture content 30% Conditioned at 23 °C, 50% RH for 3 weeks. Ignition by electric match | 9.5 | 1 |
| 5 | Height 2.5 m, width at widest point 1.7 m, moisture content 28% Conditioned at 23 °C, 50% RH for 3 weeks. Ignition by electric match | 19.1 | 1 |
| 6 | Height 2.5 m, width at widest point 1.1 m, moisture content 32% Conditioned at 23 °C, 50% RH for 3 weeks. Ignition by electric match | 12.7 | 1 |
| 7 | Height 3.1 m, width at widest point 1.5 m, moisture content 25% Conditioned at 23 °C, 50% RH for 3 weeks. Ignition by electric match | 18.6 | 1 |

## MEASUREMENTS TAKEN

Heat release rate (total)

## FIRE DESIGN PARAMETERS

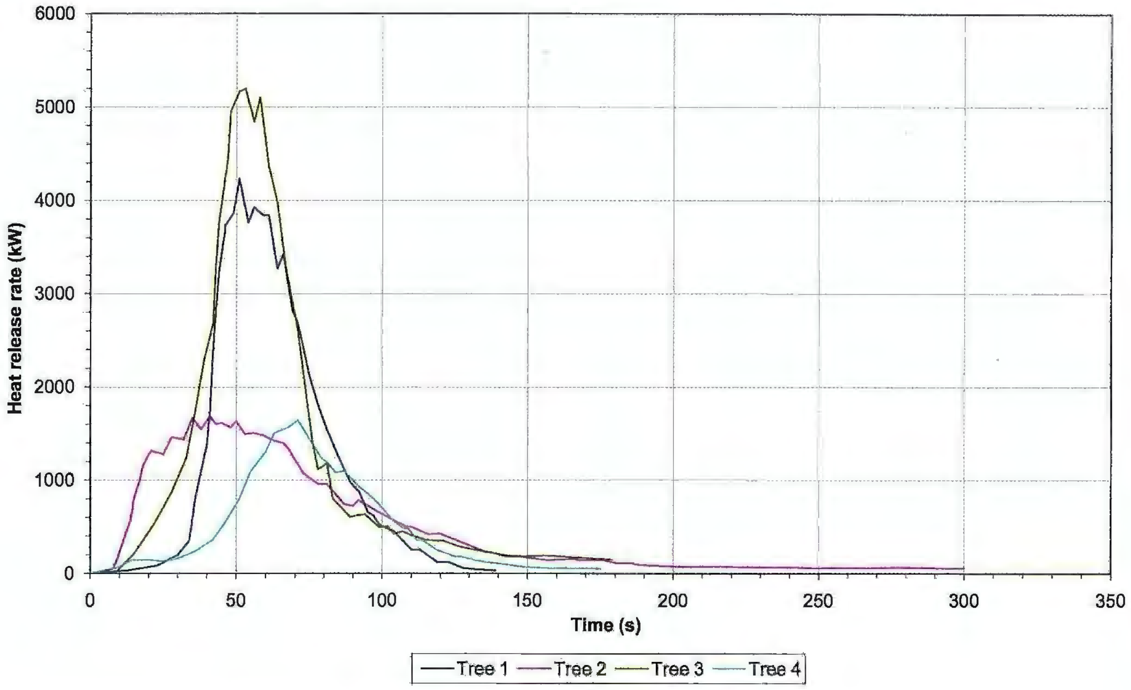
| Tree | $\alpha$ ($kW/s^2$) | Total heat release (MW) |
|---|---|---|
| 1 | 1.63 for $0 < t \leq 51$ s | 161.282 |
| 2 | 2.98 for $0 < t \leq 21$ s | 138.803 |
| 3 | 1.85 for $0 < t \leq 53$ s | 203.852 |
| 4 | 0.38 for $0 < t \leq 63$ s | 84.243 |
| 5 | 0.89 for $0 < t \leq 61$ s | 188.31 |
| 6 | 0.26 for $0 < t \leq 81$ s | 93.5425 |
| 7 | 1.63 for $0 < t \leq 44$ s | 151.42 |

## REFERENCES

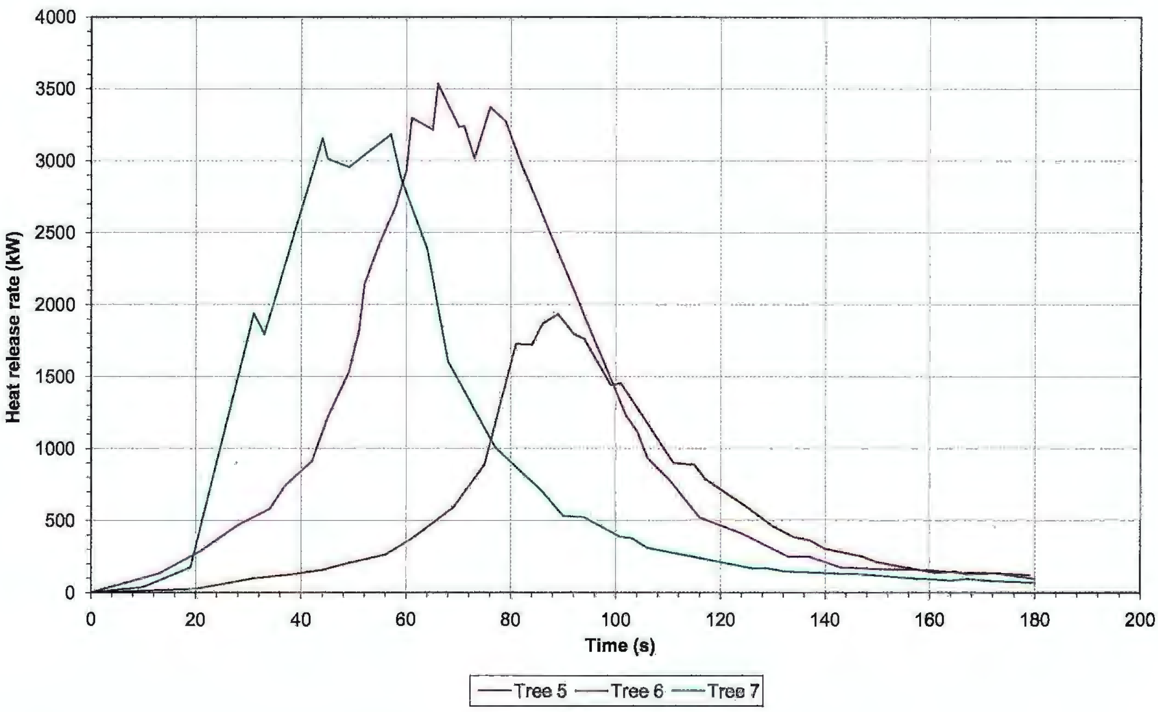
Spearpoint M. FireBaseXML database. Version 1.34. New Zealand, University of Canterbury, 2007. Visit http://www.civil.canterbury.ac.nz/spearpoint/HRR_Database/HRR_Database.xml

Stroup DW, DeLauter L, Lee J & Roadarmel G. Scotch pine Christmas tree fire tests. NIST Report FR 4010. Gaithersburg MD, Building and Fire Research Laboratory, National Institute of Standards and Technology, 1999

## HEAT RELEASE RATE DATA




Total heat release rate of Christmas trees (Trees 1–4)




Total heat release rate of Christmas trees (Trees 5–7)

# 7.7 Computers

## FIRE LOAD

| Experiment no. | Description | Mass (kg) | No. of items |
|---|---|---|---|
| 1 | Laptop computer in a corrugated cardboard box and polystyrene foam packing | 3.41 | 1 |
| 2 | Desktop computer in a single wall corrugated cardboard box and polystyrene foam packing | 5.93 | 1 |

## MEASUREMENTS TAKEN

Heat release rate (total)

## FIRE DESIGN PARAMETERS

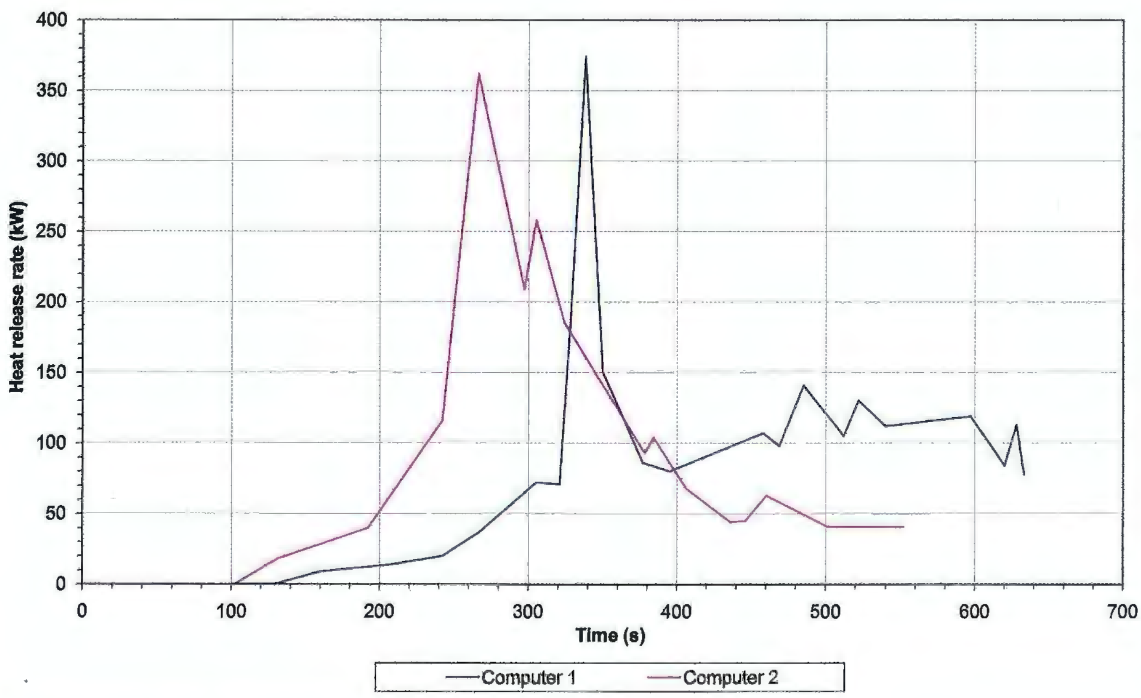
| Computer | α (kW/s²) | Total heat release (MW) |
|---|---|---|
| 1 | 0.0086 for $100 < t \leq 358$ s | 42.5 |
| 2 | 0.0135 for $100 < t \leq 266$ s | 43.7 |

## REFERENCES

Hasegawa HK, Alvares NJ & White JA. Fire tests of packaged and palletized computer products. Fire Technology 1999: 35(4): 291–307

Spearpoint M. FireBaseXML database. Version 1.34. New Zealand, University of Canterbury, 2007. Visit http://www.civil.canterbury.ac.nz/spearpoint/HRR_Database/HRR_Database.xml

## HEAT RELEASE RATE DATA




Total heat release rate of individual computers

# 7.8 Curtains

## FIRE LOAD

| Experiment no. | Description | Mass (kg) | No. of items |
|---|---|---|---|
| 1 | Mixed material curtains: 39% cotton, 16% polyester, 45% acrylic | 1.43 | 1 |
| 2 | Mixed material curtains: 39% cotton, 16% polyester, 45% acrylic | 1.43 | 1 |

## MEASUREMENTS TAKEN

Heat release rate (total)

## FIRE DESIGN PARAMETERS

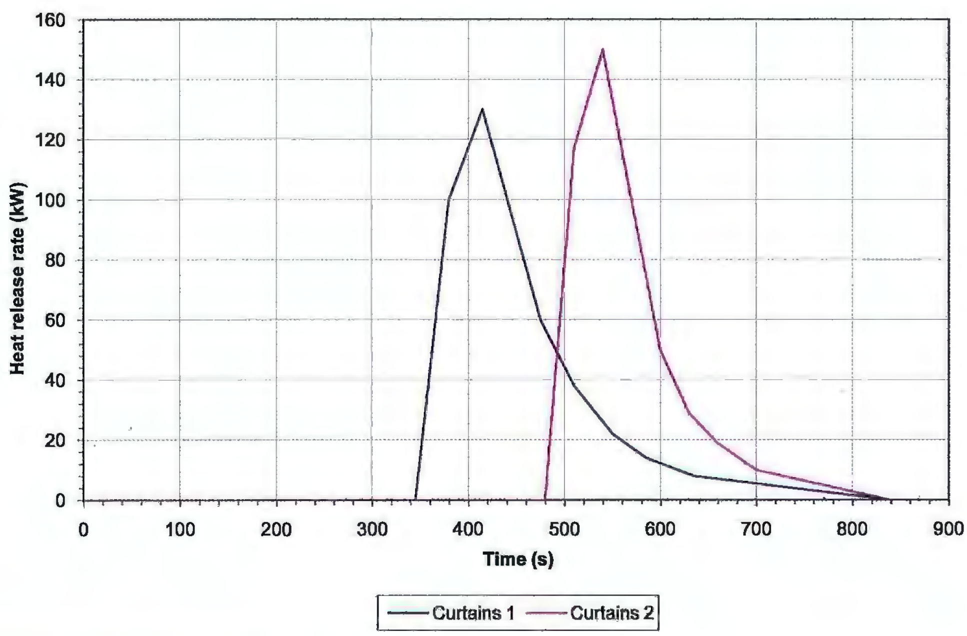
| Curtains | $\alpha$ (kW/s²) | Heat of combustion (J/kg) |
|---|---|---|
| 1 | 0.027 for $0 < t \leq 415$ s | 13000 |
| 2 | 0.042 for $0 < t \leq 540$ s | 12000 |

## REFERENCES


Gross D. Data sources for parameters used in predictive modeling of fire growth and smoke spread. NBSIR 85-3223. 1985. Available at: http://fire.nist.gov/bfrlpubs/fire85/art001.html

Spearpoint M. FireBaseXML database. Version 1.34. New Zealand, University of Canterbury, 2007. Visit http://www.civil.canterbury.ac.nz/spearpoint/HRR_Database/HRR_Database.xml


## HEAT RELEASE RATE DATA




Total heat release rate of pairs of curtains

# 7.9 Flight luggage

## FIRE LOAD

| Experiment no. | Description |
|---|---|
| 1 | Air-side airport design fire consisting of two carry-on bags burning simultaneously |
| 2 | Land-side airport design fire consisting of bags on a piled-high luggage trolley<br>The bags were filled with clothing and other representative materials |

## MEASUREMENTS TAKEN

Heat release rate (total)

## FIRE DESIGN PARAMETERS

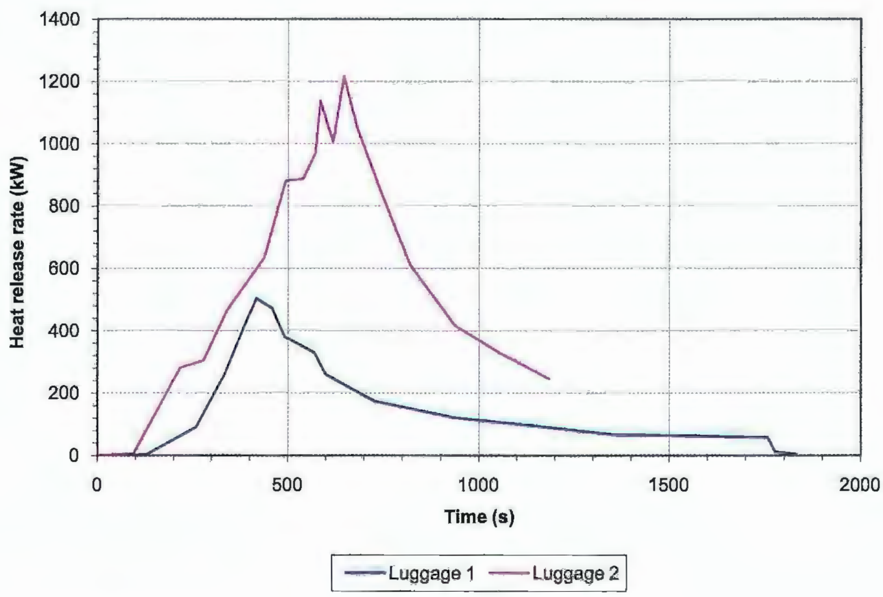
| Luggage | α (kW/s²) |
|---|---|
| 1 | 0.006 for $128 < t \leq 419$ s |
| 2 | 0.003 for $94 < t \leq 1218$ s |

## REFERENCES


Morgan H & De Smedt J-C. Prescription in flight. Fire Engineers Journal and Fire Prevention 2002: July

Spearpoint M. FireBaseXML database. Version 1.34. New Zealand, University of Canterbury, 2007. Visit http://www.civil.canterbury.ac.nz/spearpoint/HRR_Database/HRR_Database.xml


## HEAT RELEASE RATE DATA




Total heat release rate of flight luggage

# 7.10 Hand cart

## TEST TYPE

Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION

Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 $m^2$ coverage per head and 5 mm/min/$m^2$ delivered water density.

## FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| Synthetic flowers constructed of manmade fibres, mainly polyester petals with polypropylene covered wire stems. Handcart was constructed of MDF with a polycotton canopy | 13.1 | 100+ |

## MEASUREMENTS TAKEN

Heat release rate (total & convective), temperatures, optical density, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETER

| | Optical density (OD/m) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|
| Unsprinklered (Test terminated at 600 s) | 3.52 (268) | 48939 (423) | 630 (413) |
| Sprinklered (First sprinkler activated at 1300 s, Test terminated at 1500 s) | 1.91 (1290) | 17965 (1305) | 403 (1300) |

Numbers in parentheses = time to peak parameters in seconds

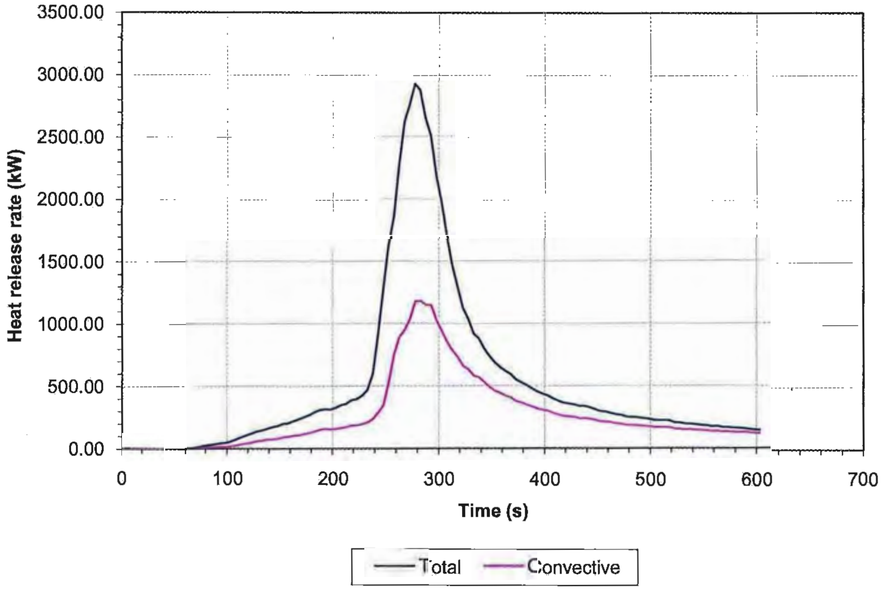
## FIRE DESIGN PARAMETER

$\alpha = 0.038$ kW/$s^2$ (unsprinklered time to peak heat release rate = 276 s)

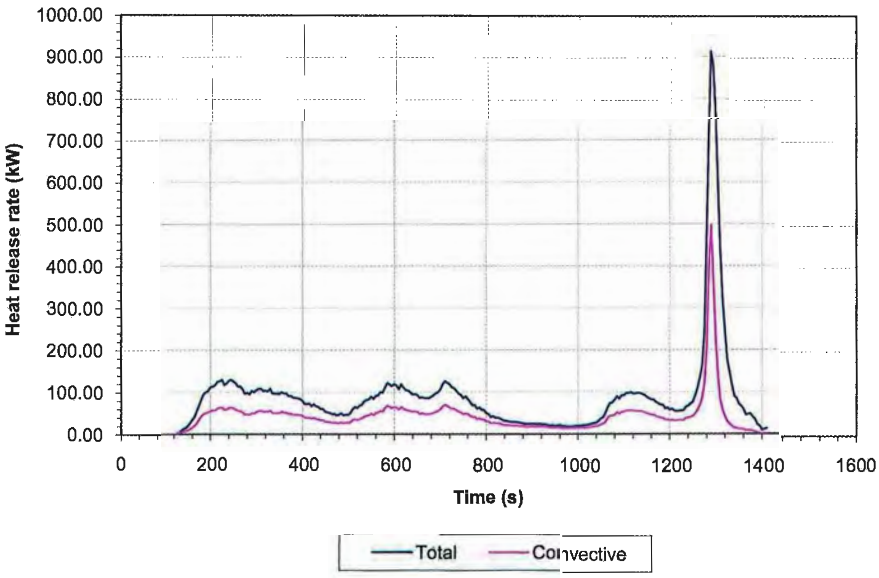
## REFERENCE

Clarke P & Smith DA. Characterisation of fires for design purposes: a database for fire safety engineers. Interflam 2001. Proceedings of 9th Conference, Volume 1. London, Interscience Communications, 2001. p 1157

## HEAT RELEASE RATE DATA




Heat release rate of an unsprinklered hand cart




Heat release rate of an sprinklered hand cart

# 7.11 Pallets

## TEST TYPE
Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION
Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 m² coverage per head and 5 mm/min/m² delivered water density.


## FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| Wooden pallets 1200 mm × 1200 mm stacked between 1.15 m and 1.17 m high<br>Moisture content between 10 to 20% | 500+ | 40 |

## MEASUREMENTS TAKEN
Heat release rate (total and convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

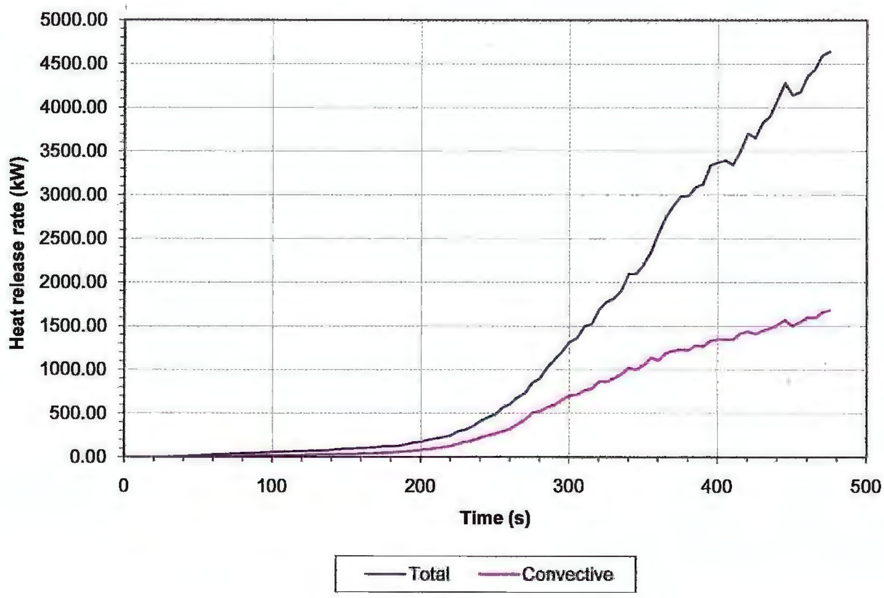
| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 480 s) | 1.48 (870) | 3.22 (830) | 22850 (690) | 4344 (535) |
| Sprinklered (First sprinkler activated at 240 s, Test terminated at 1200 s) | 1.91 (475) | 3.93 (448) | 84103 (475) | 701 (270) |

Numbers in parentheses = time to peak parameters in seconds

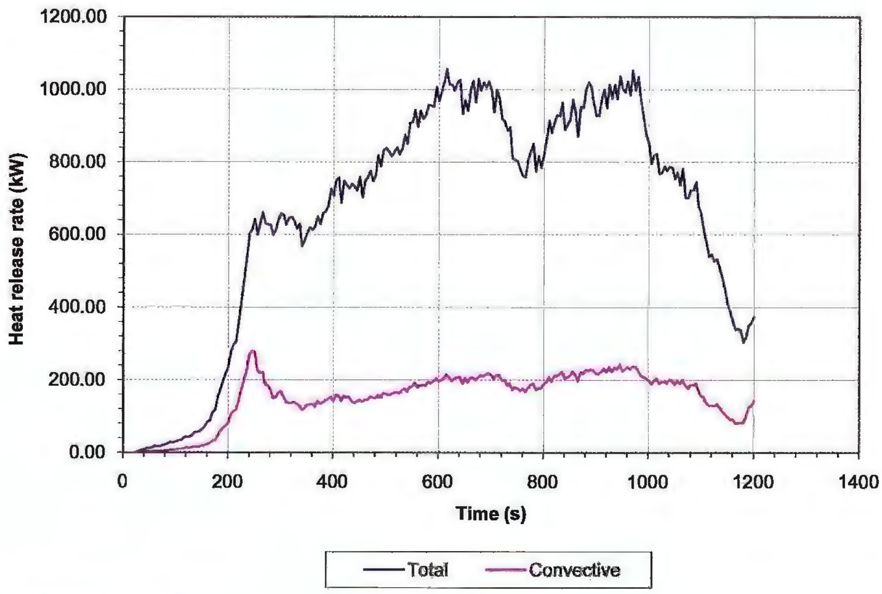
## FIRE DESIGN PARAMETER
For $0 < t \leq 240$ s, $\alpha = 0.0104$ kW/s² (unsprinklered)

## REFERENCE
Garrad G & Smith DA. Characterisation of fires for design. Interflam 1999. Proceedings of 8th Conference, Volume 1. London, Interscience Communications, 1999. p 555

## HEAT RELEASE RATE DATA




Heat release rate of unsprinklered pallets




Heat release rate of sprinklered pallets

# 7.12 Pool fires

## TEST TYPE

Twelve free-burn experiments incorporating industrial methylated spirit (IMS) and kerosene fuel

## FIRE LOAD

| Test | Location | Fuel | Tray size (Length × width × height) (m) | Mass of fuel (kg) | Nominal fire size (kW) |
|---|---|---|---|---|---|
| 1 | Centre of a room | IMS99 | 0.75 × 0.75 × 0.15 | 24 | 400 |
| 2 | Centre of a room | IMS99 | 0.75 × 0.75 × 0.15 | 24 | 400 |
| 3 | Against a wall | IMS99 | 0.75 × 0.75 × 0.15 | 24 | 400 |
| 4 | Against a wall | IMS99 | 0.75 × 0.75 × 0.15 | 24 | 400 |
| 5 | In a corner | IMS99 | 0.75 × 0.75 × 0.15 | 24 | 400 |
| 6 | In a corner | IMS99 | 0.75 × 0.75 × 0.15 | 24 | 400 |
| 7 | In a corner | IMS99 | 1.55 × 1.55 × 0.15 | 128 | 2000 |
| 8 | In a corner | IMS99 | 1.55 × 1.55 × 0.15 | 128 | 2000 |
| 9 | In a corner | Kerosine | 1.1 × 1.1 × 0.15 | 60 | 2000 |
| 10 | In a corner | Kerosine | 1.1 × 1.1 × 0.15 | 60 | 2000 |
| 11 | In a corner | Kerosine | 1.55 × 1.55 × 0.15 | 160 | 5000 |
| 12 | In a corner | Kerosine | 1.55 × 1.55 × 0.15 | 160 | 5000 |

## MEASUREMENTS TAKEN

Heat release rate (total), flame height, temperatures, optical density, mass flow rate, radiant heat, oxygen depletion, $CO_2$ and CO concentrations

## FIRE DESIGN PARAMETERS

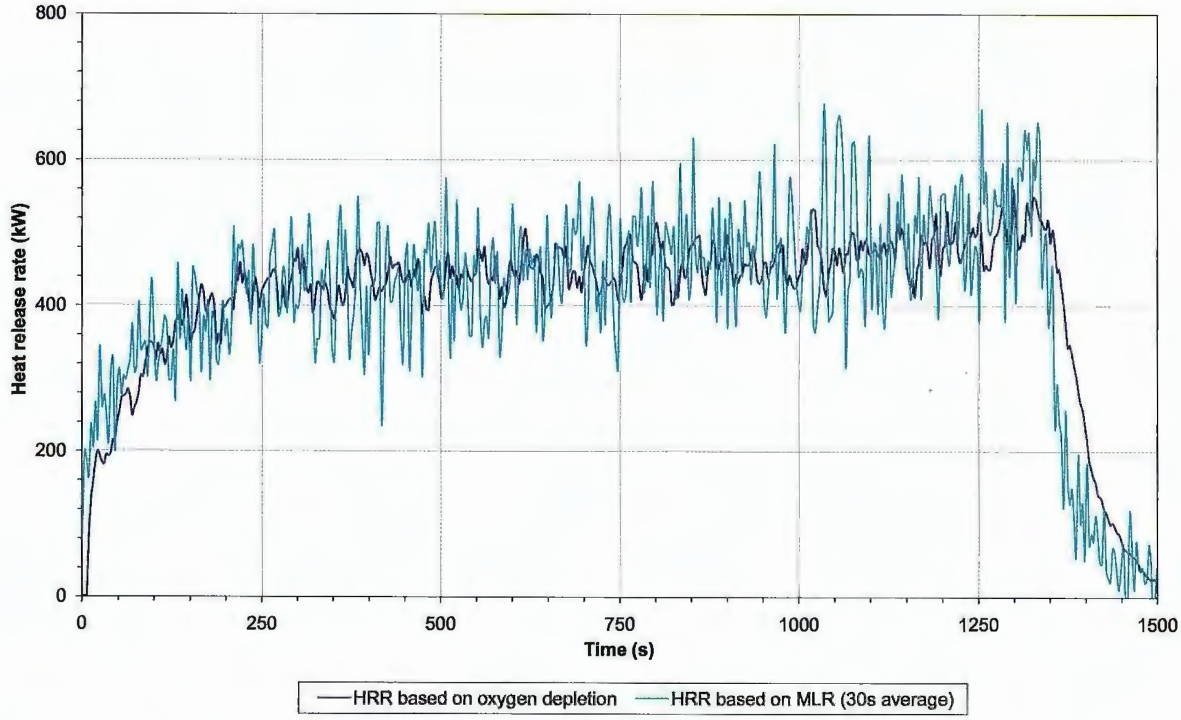
| Test | Maximum HRR (kW) | Average HRR at SS (kW) | Total HR (MJ) | Peak CO ($m^3/s$) | Peak $CO_2$ ($m^3/s$) | Peak rate of smoke production ($m^2/s$) | Flame height (m) |
|---|---|---|---|---|---|---|---|
| 1/2 | 560 | 461.5 | 611 | – | 0.0219 (1323) | – | 2.2 |
| 3/4 | 497 | 401.1 | 591 | – | 0.0194 (1341) | – | 2.2 |
| 5/6 | 512 | 403.9 | 620 | – | 0.0196 (1467) | – | 2.2 |
| 7/8 | 2685 | 2093.8 | 3089 | – | 0.0971 (1313) | – | 4.2 |
| 9/10 | 2806 | 2165.0 | 2408 | 0.00201 (684) | 0.0891 (1011) | 140.6 (1030) | 4.2 |
| 11/12 | 6961 | 5510.0 | 6659 | 0.00391 (1026) | 0.2073 (639) | – | 5.9 |

Numbers in parentheses = time to peak parameters in seconds

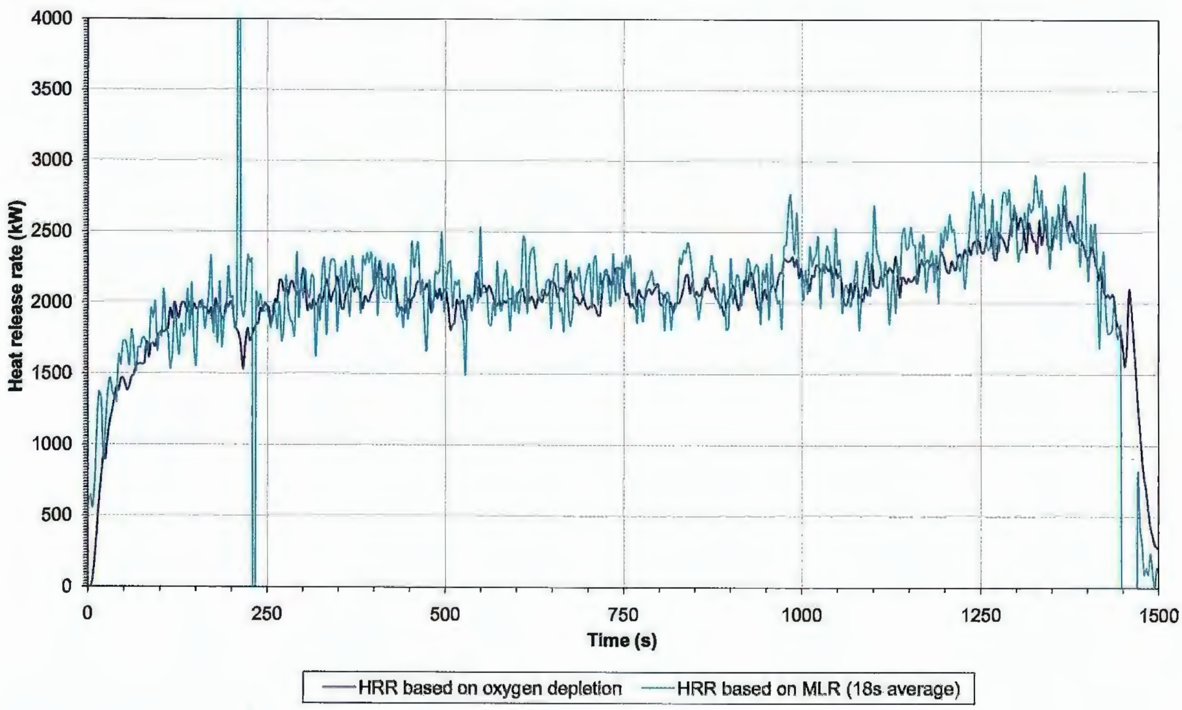
## REFERENCE

Marshall N. Evaluation of fire models for fire hazard assessment in buildings. Part 1: Experimental programme. Private communication, 1999

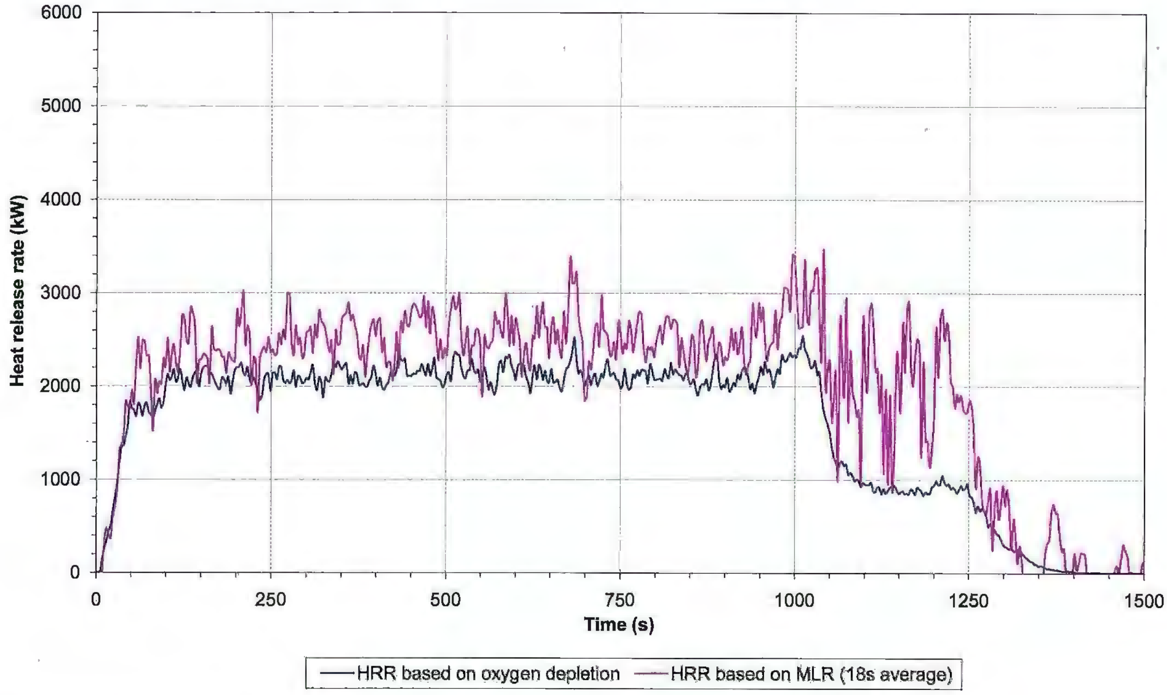
## HEAT RELEASE RATE DATA



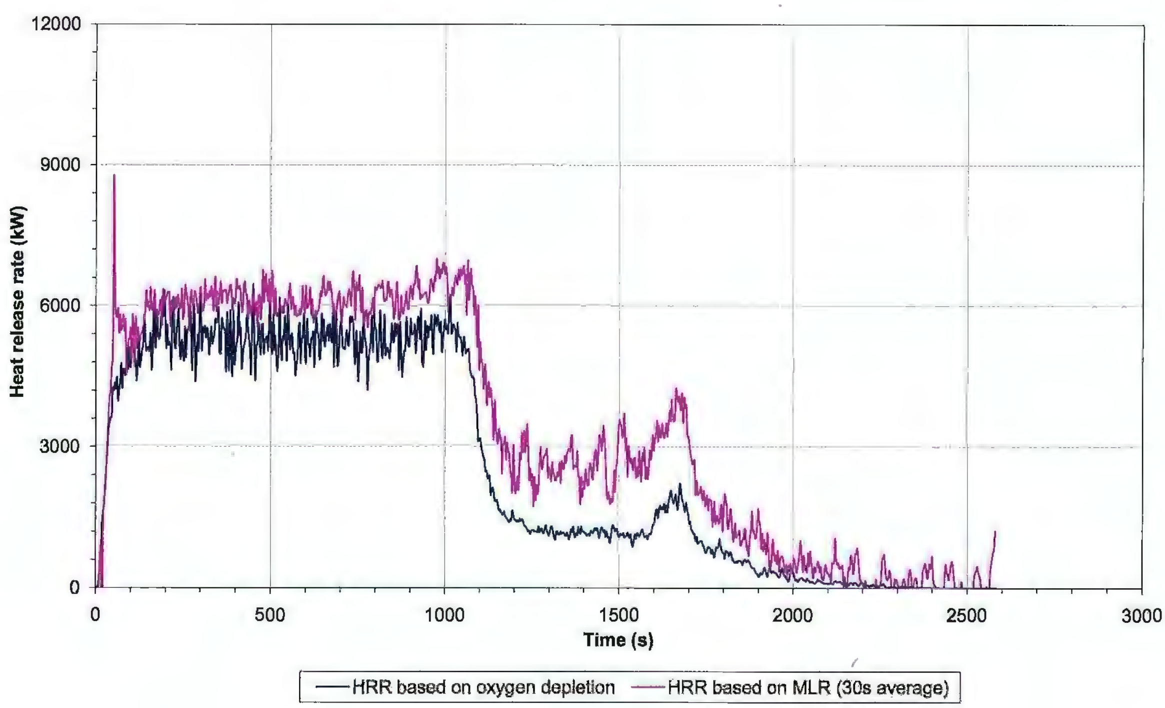

Heat release rate for a 0.75 × 0.75 m² IMS pool fire
MLR = mass loss rate




Heat release rate for a 1.55 × 1.55 m² IMS pool fire




Heat release rate for a 1.1 × 1.1 $m^2$ kerosine pool fire




Heat release rate for a 1.55 × 1.55 $m^2$ kerosine pool fire

# 7.13 Soft toys

## TEST TYPE
Two free-burn experiments (with and without sprinklers)

## SPRINKLER SPECIFICATION
Four standard-response sprinklers (unless stated) operated manually. Total combined flow rate of 270 l/min and with a pressure of 0.6 bar at the sprinkler heads. This gave at least a 12 $m^2$ coverage per head and 5 mm/min/$m^2$ delivered water density.

## FIRE LOAD

| Description | Mass (kg) | No. of items |
|---|---|---|
| Toys: mainly manmade fibres, described as hollow-fibre fillings with plush coverings. Wall-mounted items were made of an undetermined plastic and were contained in blister packs with a cardboard backing. | 62 | 383 |

## MEASUREMENTS TAKEN
Heat release rate (total and convective), temperatures, optical density, mass flow rate, radiant heat, $CO_2$ and CO concentrations

## PEAK MEASURED PARAMETERS

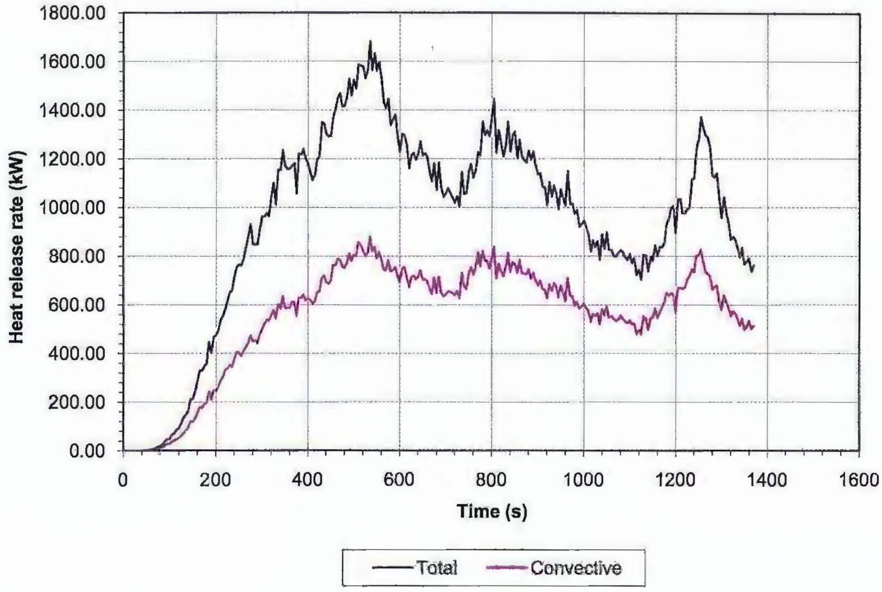
| | Optical density (OD/m) | Mass flow rate (kg/s) | $CO_2$ (ppm) | CO (ppm) |
|---|---|---|---|---|
| Unsprinklered (Test terminated at 1380 s) | 2.40 (285) | 4.34 (965) | 27092 (540) | 739 (1140) |
| Sprinklered (First sprinkler activated at 300 s, Test terminated at 420 s) | 1.84 (265) | 3.70 (300) | 22320 (315) | 400 (310) |

Numbers in parentheses = time to peak parameters in seconds

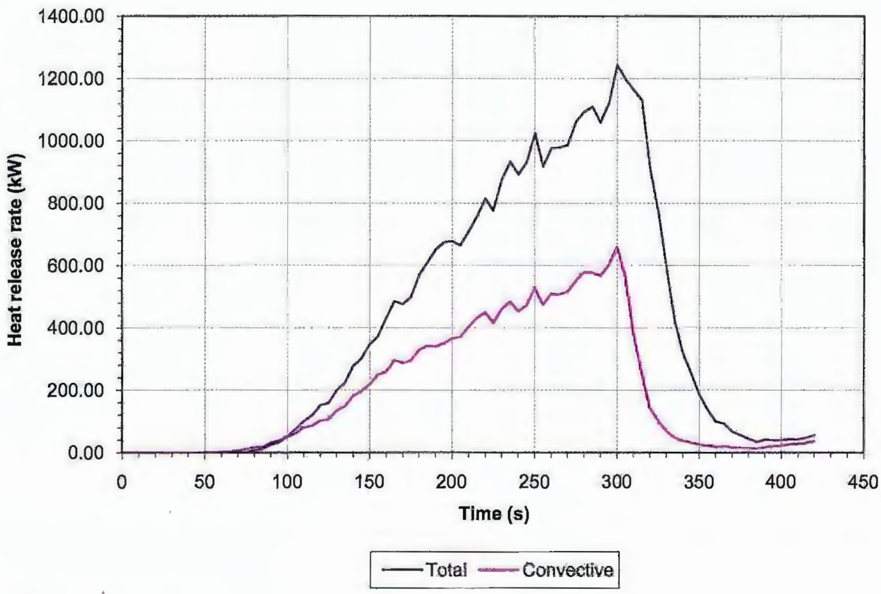
## FIRE DESIGN PARAMETER
For $0 < t \leq 535$ s, $\alpha = 0.006$ kW/$s^2$ (unsprinklered)

## REFERENCE
Garrad G & Smith DA. Characterisation of fires for design. Interflam 1999. Proceedings of 8th Conference, Volume 1. London, Interscience Communications, 1999. p 555

## HEAT RELEASE RATE DATA




Heat release rate of unsprinklered soft toys




Heat release rate of sprinklered soft toys

# 7.14 Televisions

## FIRE LOAD

| Experiment no. | Description | Mass (kg) | No. of items |
|---|---|---|---|
| 1 | 28 inch TV in a plastic case. Ignition with a 1 kW propane gas flame | 31.83 | 1 |
| 2 | 25 inch TV in a plastic case. Ignition with a 1 kW propane gas flame | 24.42 | 1 |
| 3 | 28 inch TV in a plastic case. Ignition with a 1 kW propane gas flame | 30.53 | 1 |

## MEASUREMENTS TAKEN

Heat release rate (total)

## FIRE DESIGN PARAMETERS

| Television | α (kW/s²) | Heat of combustion (J/kg) |
|---|---|---|
| 1 | 0.057 for 77 < t ≤ 147 s | 31900 |
| 2 | 0.009 for 0 < t ≤ 162 s | 28200 |
| 3 | 0.0087 for 84 < t ≤ 238 s | 28600 |

## REFERENCES

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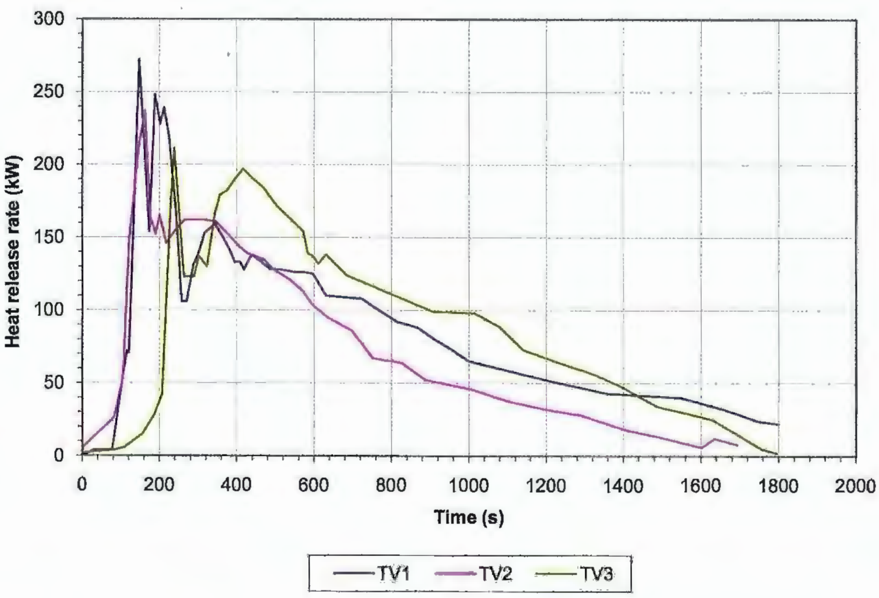
## HEAT RELEASE RATE DATA




Total heat release rate for single televisions

# 7.15 Upholstered furniture

## FIRE LOAD

| Experiment no. | Description: Design | Filling | Wrap | Cover |
|---|---|---|---|---|
| 1 | Fully upholstered 3-seater sofa with loose seat and back cushions | Polyether foam seat/ polyester interior back | Polyester fibre to seat cushion | 100% polyester ground cloth/ polyacrylic pile |
| 2 | Fully upholstered 3-seater sofa with loose seat and back cushions | CMHR foam seat/ shredded foam interior back | – | FR-treated cotton |
| 3 | As for Experiment 1 but 2-seater sofa | | | |
| 4 | As for Experiment 2 but single-seat chair | | | |
| 5 | Fully upholstered chair with loose seat and back cushions | CMHR foam seat/ FR polyester interior and back | FR polyester fibre | 100% Polyacrylic pile fabric/ FR back coated/cellulosic ground |
| 6 | Fully upholstered chair with loose seat and back cushions | HR foam | – | Leather |

FR = fire retardant, HR = high resilient, CMHR = combustion-modified high resilient

## MEASUREMENTS TAKEN

Heat release rate (total), smoke production rate, HCN, HCl, HBr and CO concentrations

## FIRE DESIGN PARAMETERS

| Experiment | Peak HRR (kW) | Total HR (MJ) | Peak smoke production rate ($m^2/s$) | Peak HCN (g/s) | Peak HCL (g/s) | Peak CO (g/s) |
|---|---|---|---|---|---|---|
| 1 | 2154 | 704.4 | 33 | – | – | – |
| 2 | 1946 | 520.4 | 14 | 0.31 | 0.28 | 1.96 |
| 3 | 2285 | 658.4 | 28 | – | – | – |
| 4 | 784 | 368.4 | 4 | 0.14 | 0.3 | 0.83 |
| 5 | 742 | 463.3 | 12 | 0.18 | 0.26 | 1.7 |
| 6 | 1158 | 412.8 | 8 | 0.02 | 0.07 | 0.56 |

## REFERENCE

Sundström B (Ed). Fire safety of upholstered furniture: the final report on the CBUF research programme. Report EUR 16477 EN. Brussels, European Commission Measurements and Testing. For information, visit http://www.sp.se/en/index/research/cbuf/sidor/default.aspx

# 7.16 Wardrobe

## FIRE LOAD

| Experiment no. | Description | Mass (kg) | No. of items |
|---|---|---|---|
| 1 | 12.7 mm thick Douglas-fir plywood. Two hinged doors on front. Unfinished surfaces. Contained 1.93 kg of clothing and paper | 68 | 1 |
| 2 | 3.2 mm mahogany veneer plywood and hardboard on 19 × 40 mm hardwood frame. Top, bottom and back were hardboard with plywood sides and doors. Two rolling doors provided access to the interior. A 384 mm deep shelf extended across the width. Contained 1.93 kg clothing and paper | 36 | 1 |

## MEASUREMENTS TAKEN

Heat release rate (total)

## FIRE DESIGN PARAMETERS

| Wardrobe | α (kW/s²) | Heat of combustion (J/kg) |
|---|---|---|
| 1 | 0.29 for 0 < t ≤ 110 s | 14900 |
| 2 | 0.28 for 0 < t ≤ 150 s | 16900 |

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Lawson JR, Walton WD & Twilley WH. Fire performance of furnishings as measured in the NBS furniture calorimeter. Part I. NBSIR 83-2787. 1984. Available at http://fire.nist.gov/bfrlpubs/fire84/art002.html

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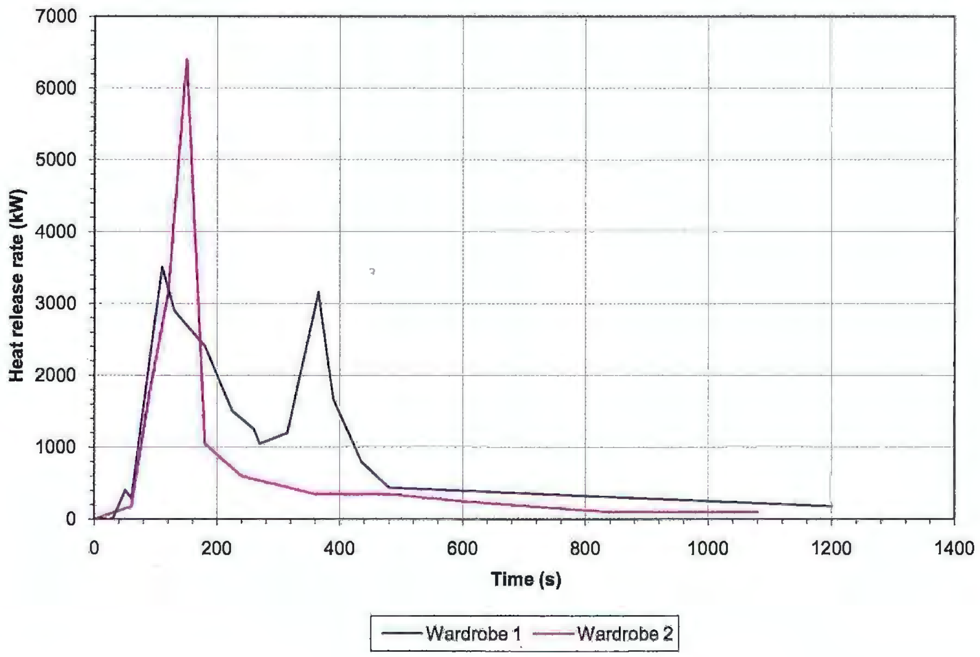
## HEAT RELEASE RATE DATA




Total heat release rate of a wardobe

# 7 Notes

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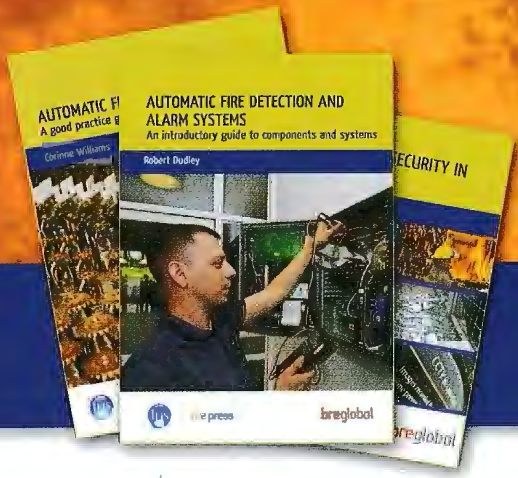


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