Heat Transfer to the Structure During the Fire

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The Dalmarnock Fire Tests: Experiments and Modelling

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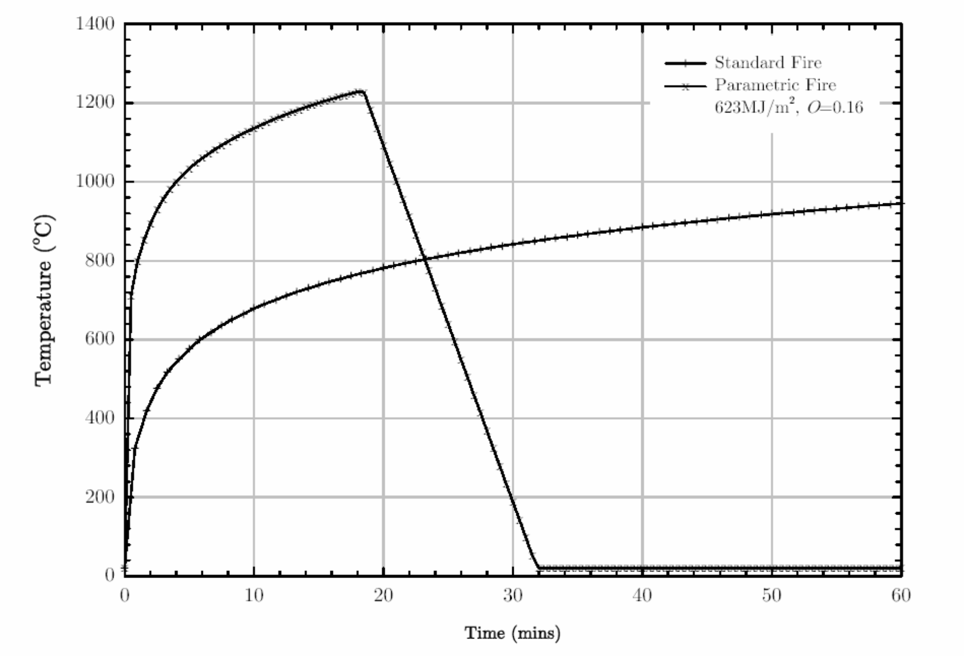
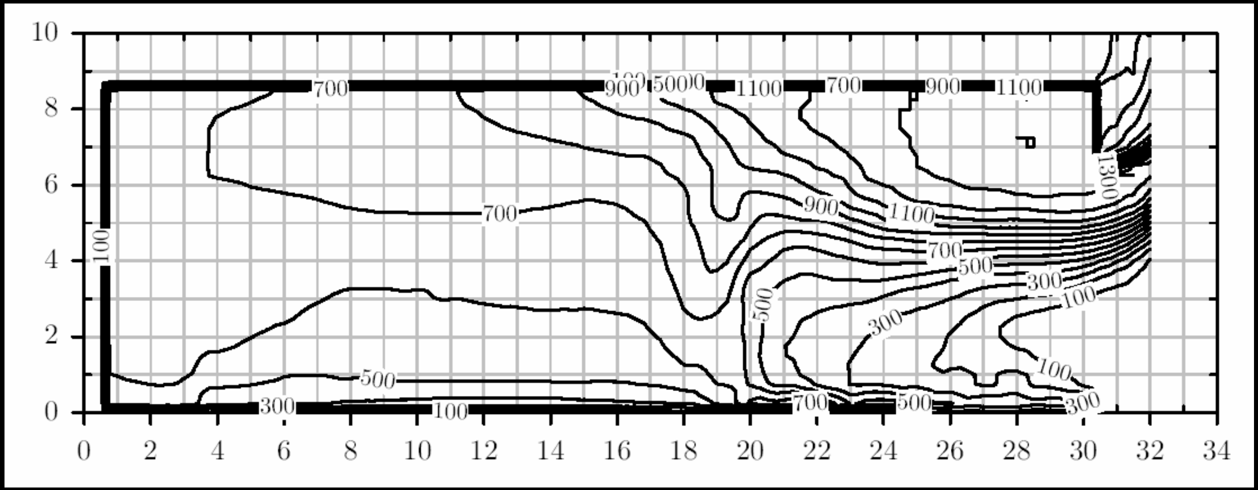
Introduction

- Modern quantitative structural fire engineering
  - Using emerging tools within a comprehensive analysis format
- Methodology for analysis
- Focus on heat transfer to structural elements
  - New tool to evaluate to structural heat fluxes using compartment fire models
- Application to the post-flashover Dalmarnock Fire Test
  - Time varying heat flux distributions

Background

- Average compartment temperature
- Single element testing
  - Fire ratings / fire protection
- Modern methods
- Full spatial resolution





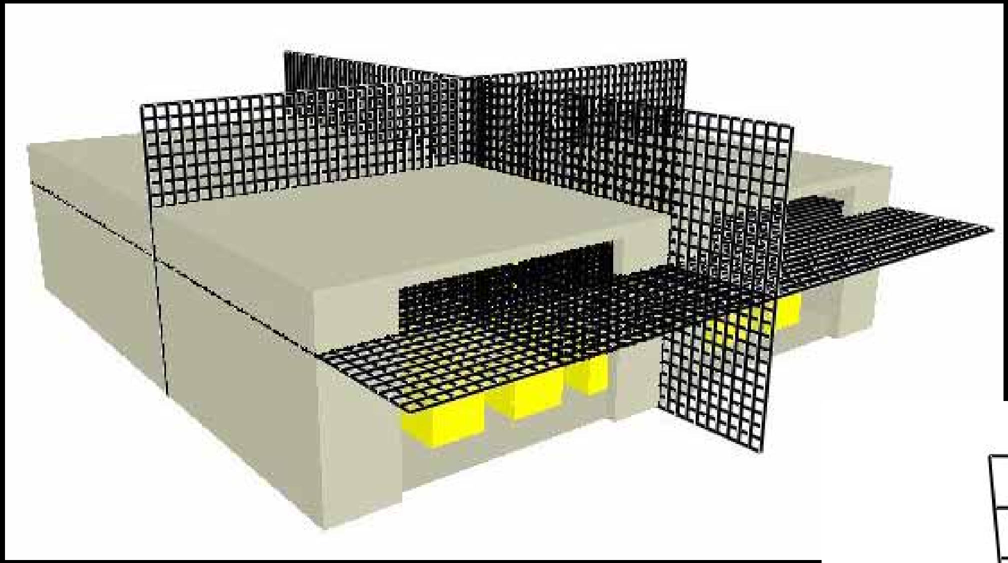
Heat Transfer to Structural Elements

- Post-processing tool for any CFD model
- Evaluates **total** surface heat fluxes based on localised gas conditions
  - **Radiation** – smoke layer properties
    - Directionality
    - Extinction coefficient
    - Temperature
  - **Convection**
    - Velocity of gas and its direction
    - Length-scale

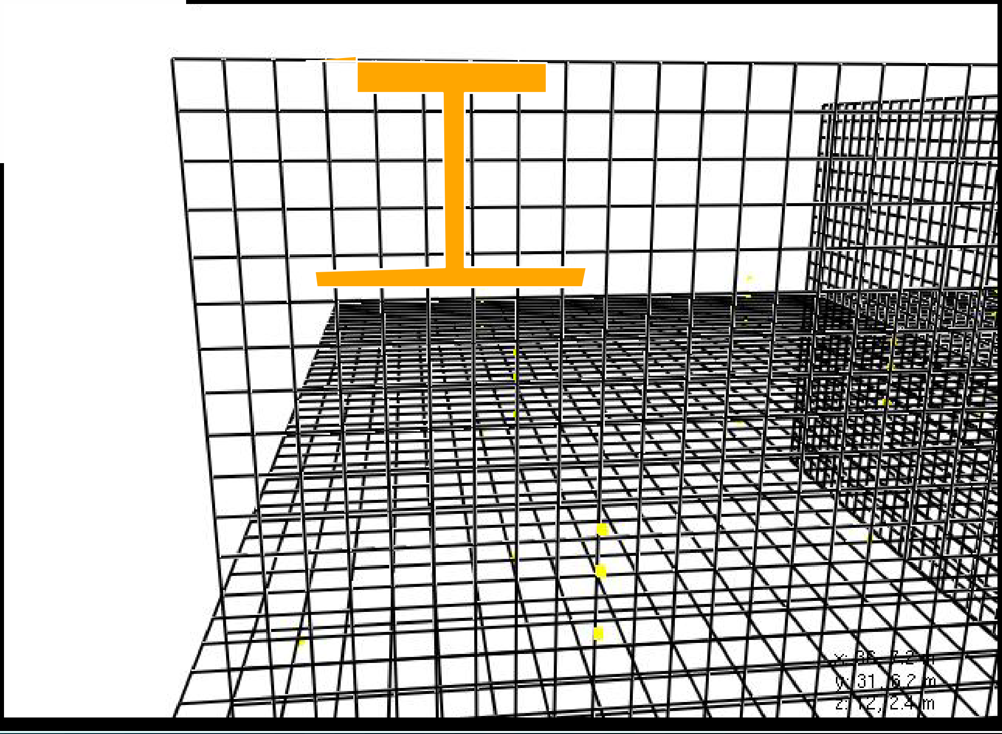
Heat Transfer to Structural Elements

- Simplicity allows any structural geometry to be modelled
- Heat fluxes evaluated considering: -
  - Characteristic heating time-scales
    - Different material behaviour
- Full resolution can be captured
- Heat flux vs. time curves to be passed to a member conduction analysis and / or a mechanical analysis
  - Uncoupled process, but remains simplified

Heat Transfer to Structural Elements



Problems associated with grid size and structural elements



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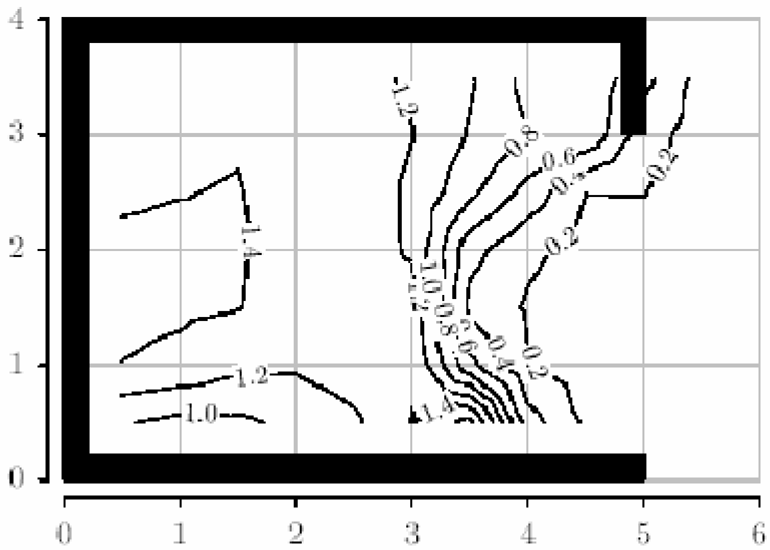
Radiation Within the Model

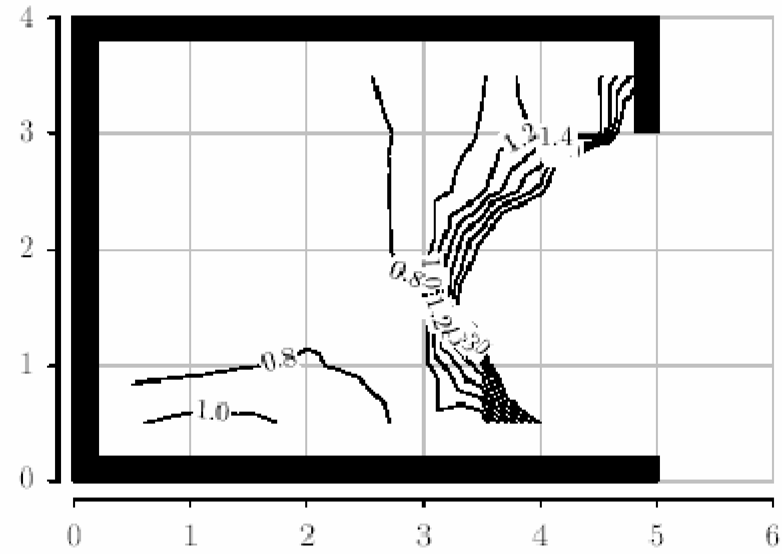
- Defined by optical limits within the smoke (post-flashover)

$$L_e = \frac{1}{\kappa}$$

$\kappa L >> 1$	Optically thick
$\kappa L << 1$	Optically thin



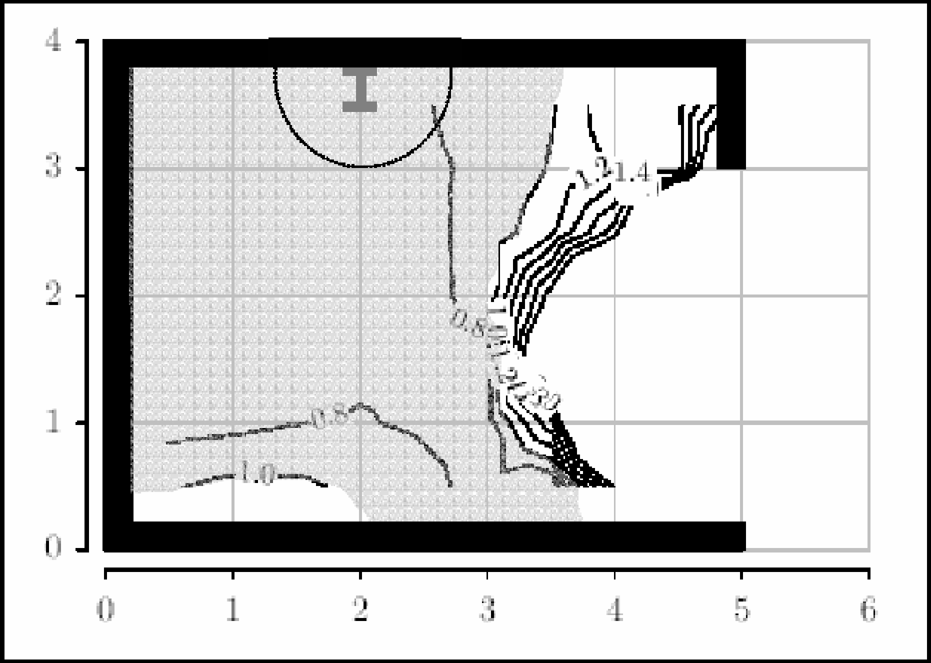
Plot of extinction coefficient κ (m^{-1})

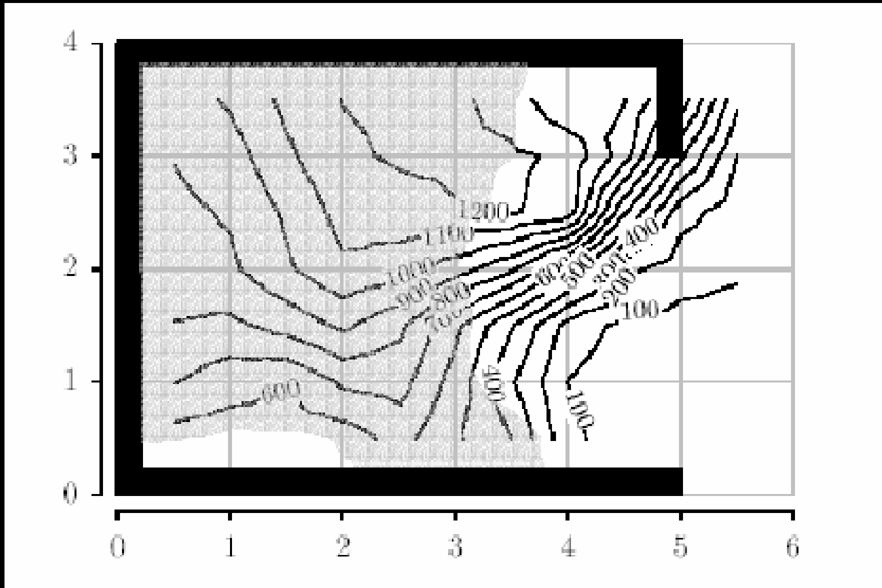


Plot of optical depth L_e (m)

Hemispherical Method

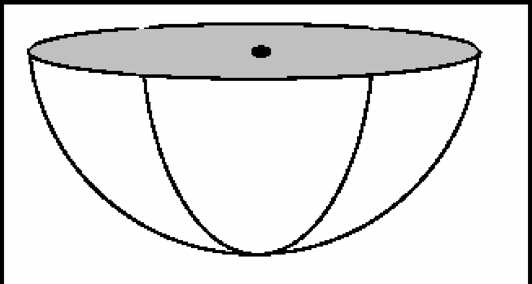
- Only a knowledge of the extinction coefficient and temperature is required to evaluate the incident radiation
- Only a certain radius needs consideration



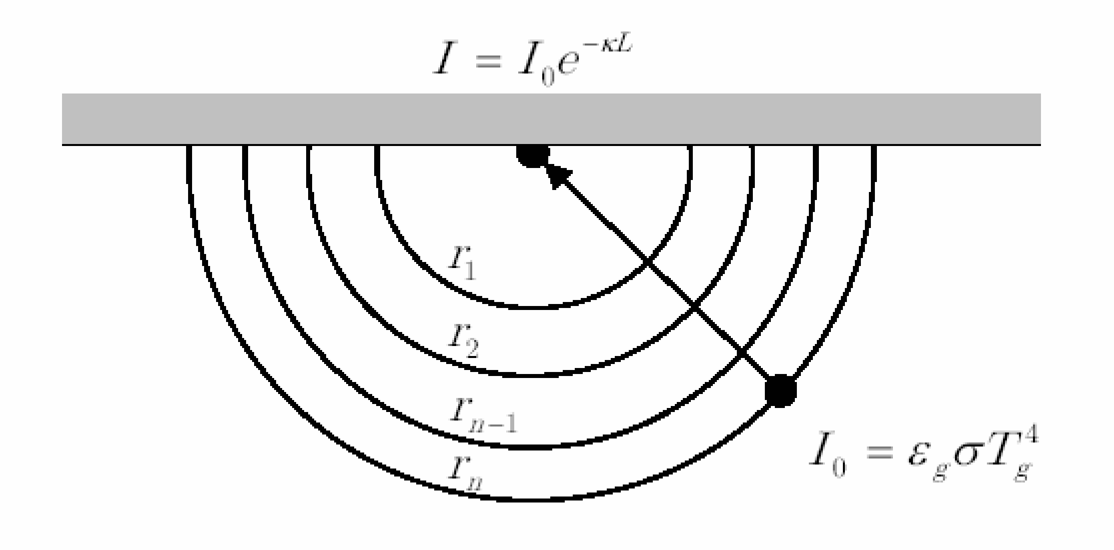


Plot of gas-phase temperature T (°C)

Hemispherical Method



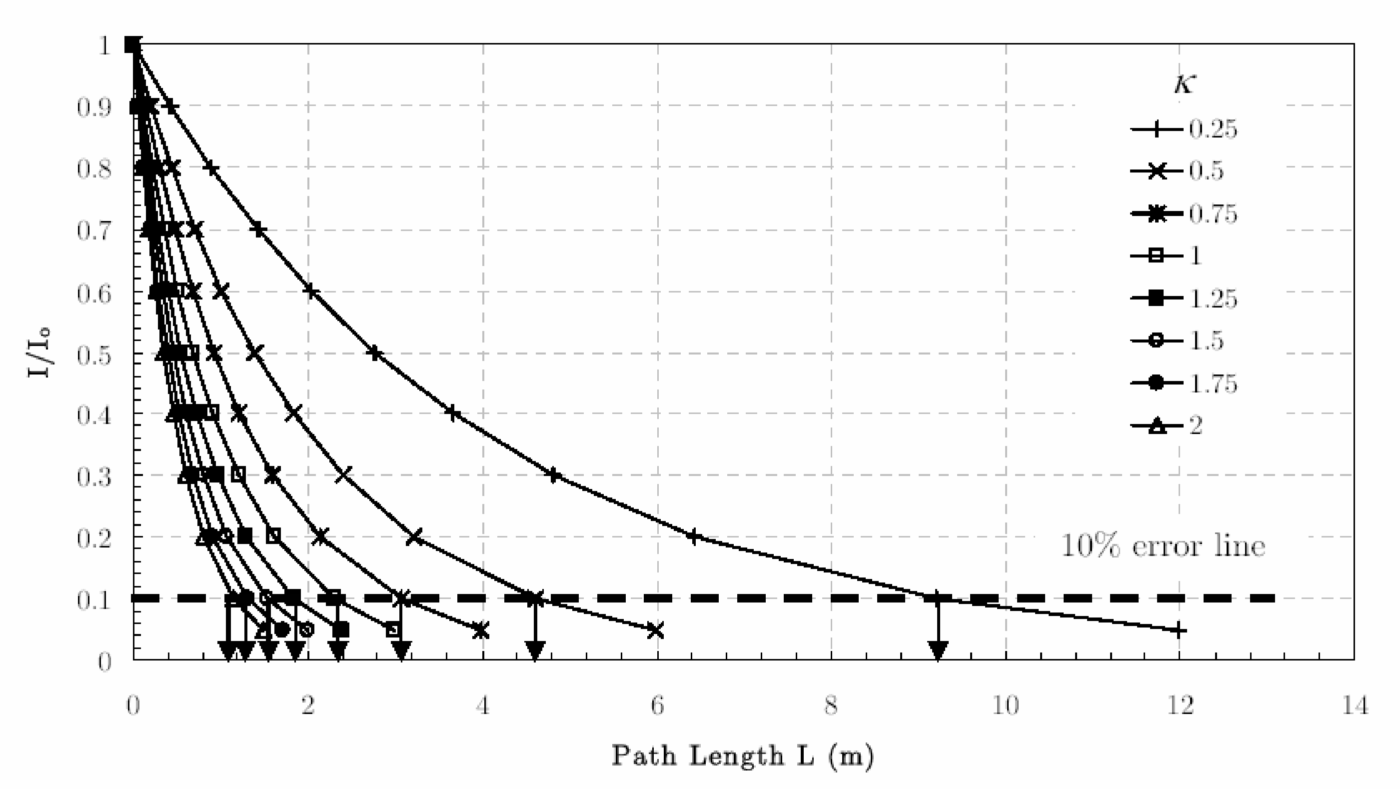
- A series of shells are analysed
- Each shell surface has a uniform extinction coefficient and temperature
- Summation of contributions from each shell defines radiative intensity



$$I = \sum_{r=1}^{n} I_{0,r} e^{-\kappa_r r} = \sum_{r=1}^{n} \varepsilon_{g,r} \sigma T_{g,r} e^{-\kappa_r r}$$

Path Length Definition

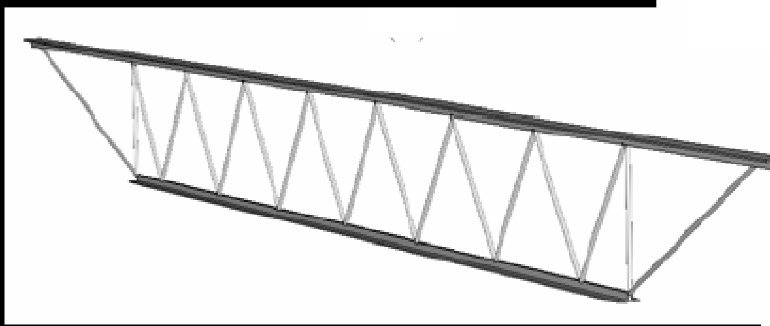
- Proposed error limit defines calculation path length

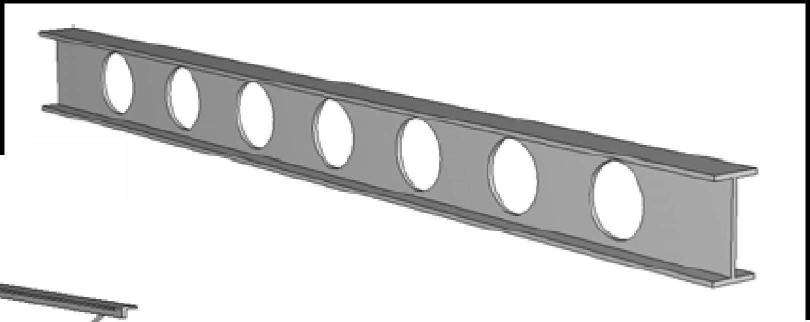


$$I = I_0 e^{-\kappa r}$$

$$r = \frac{-\ln\left(\frac{I}{I_0}\right)}{\kappa}$$

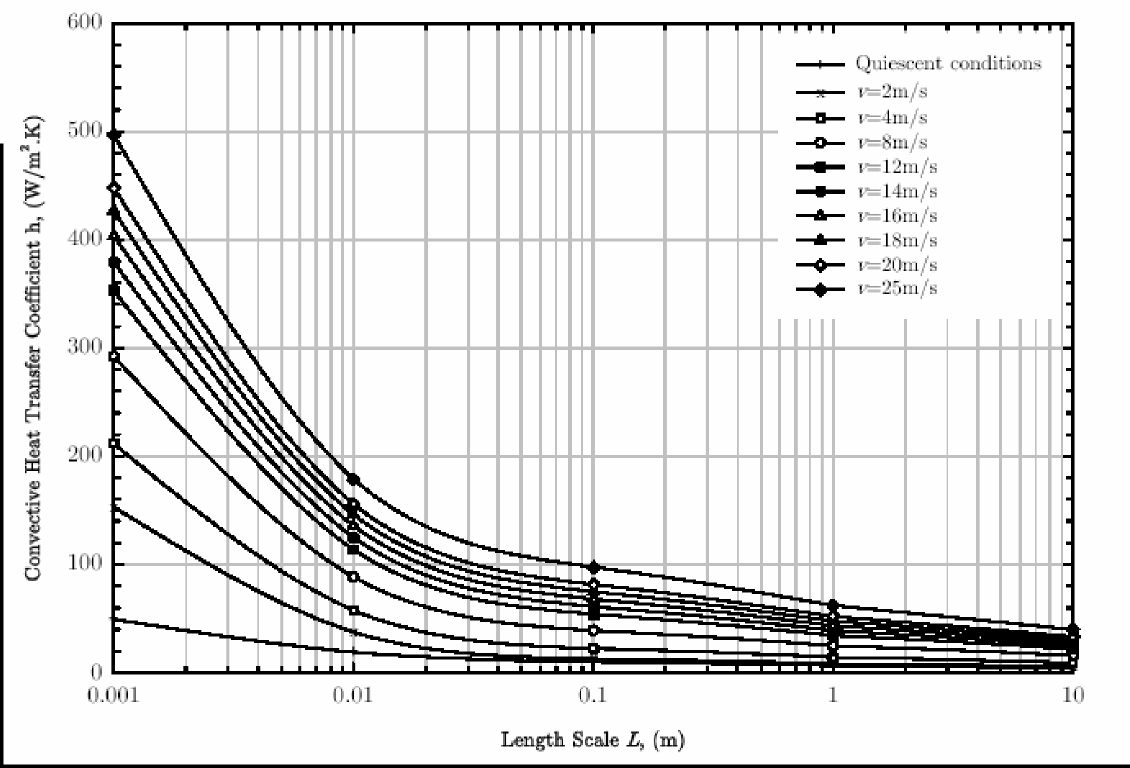
Convection Within the Model



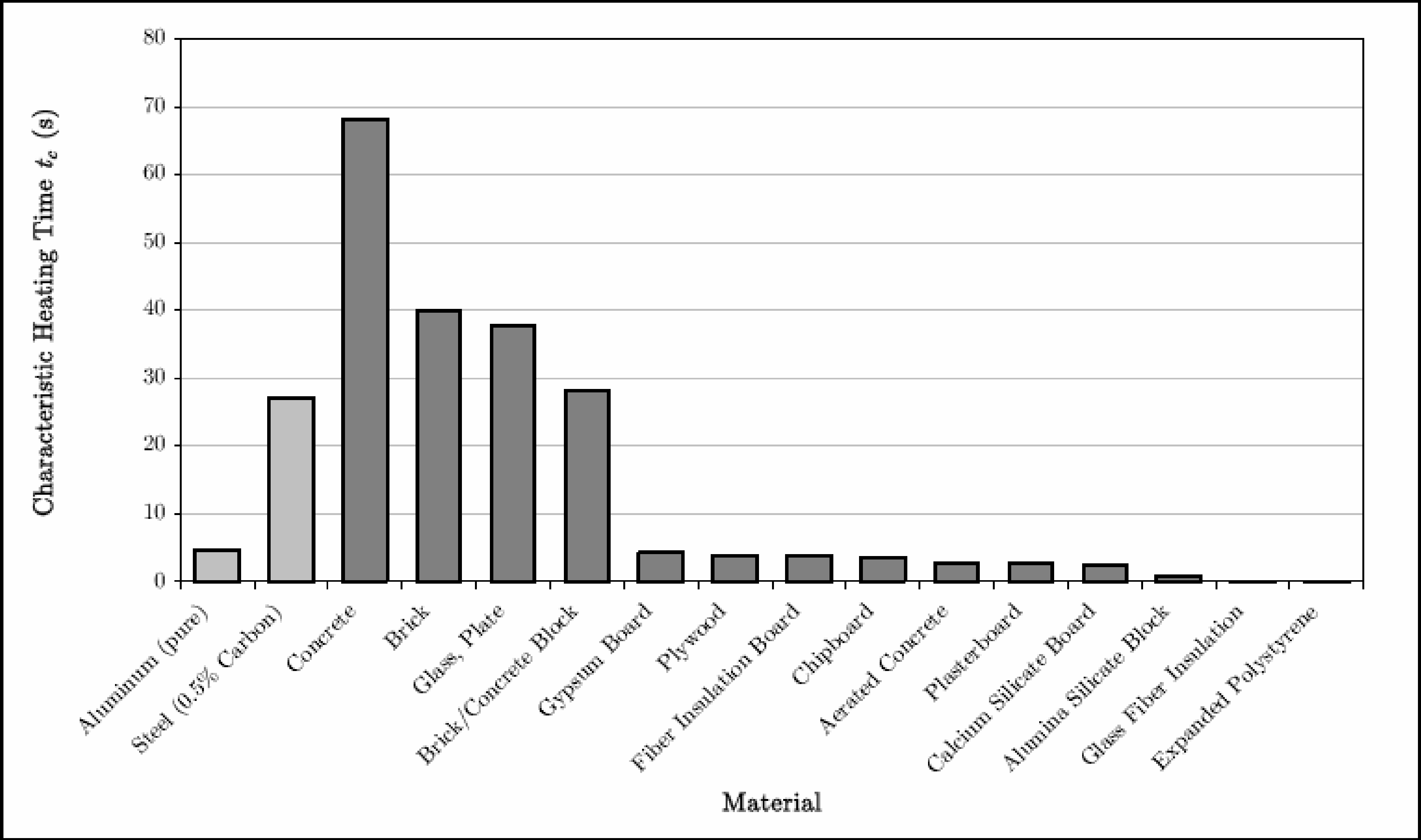


$$q''_c = hT_g$$

- Important for members with small length-scale complex geometries
- Definition of the heat transfer coefficient



Characteristic Heating Times



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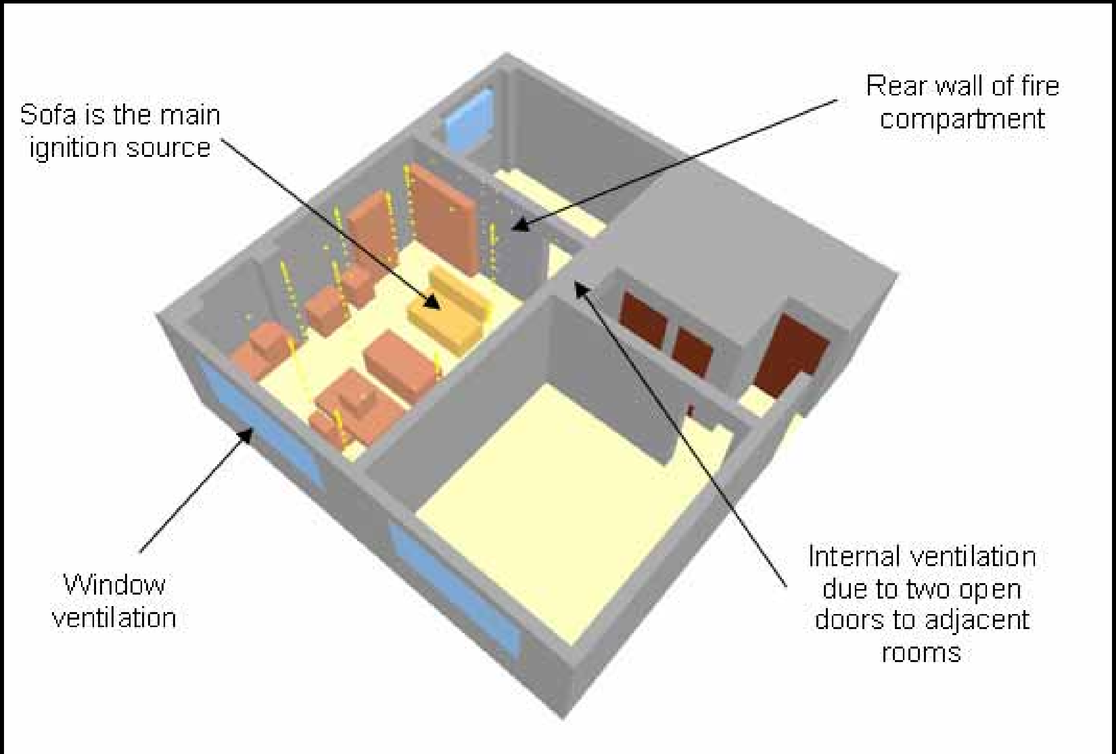
Dalmarnock Fire Tests

- Typical office fire load
- Detailed fire environment measurements taken
- Sustained post-flashover period

CFD Modelling of the Dalmarnock Tests

- FDS used as the CFD model

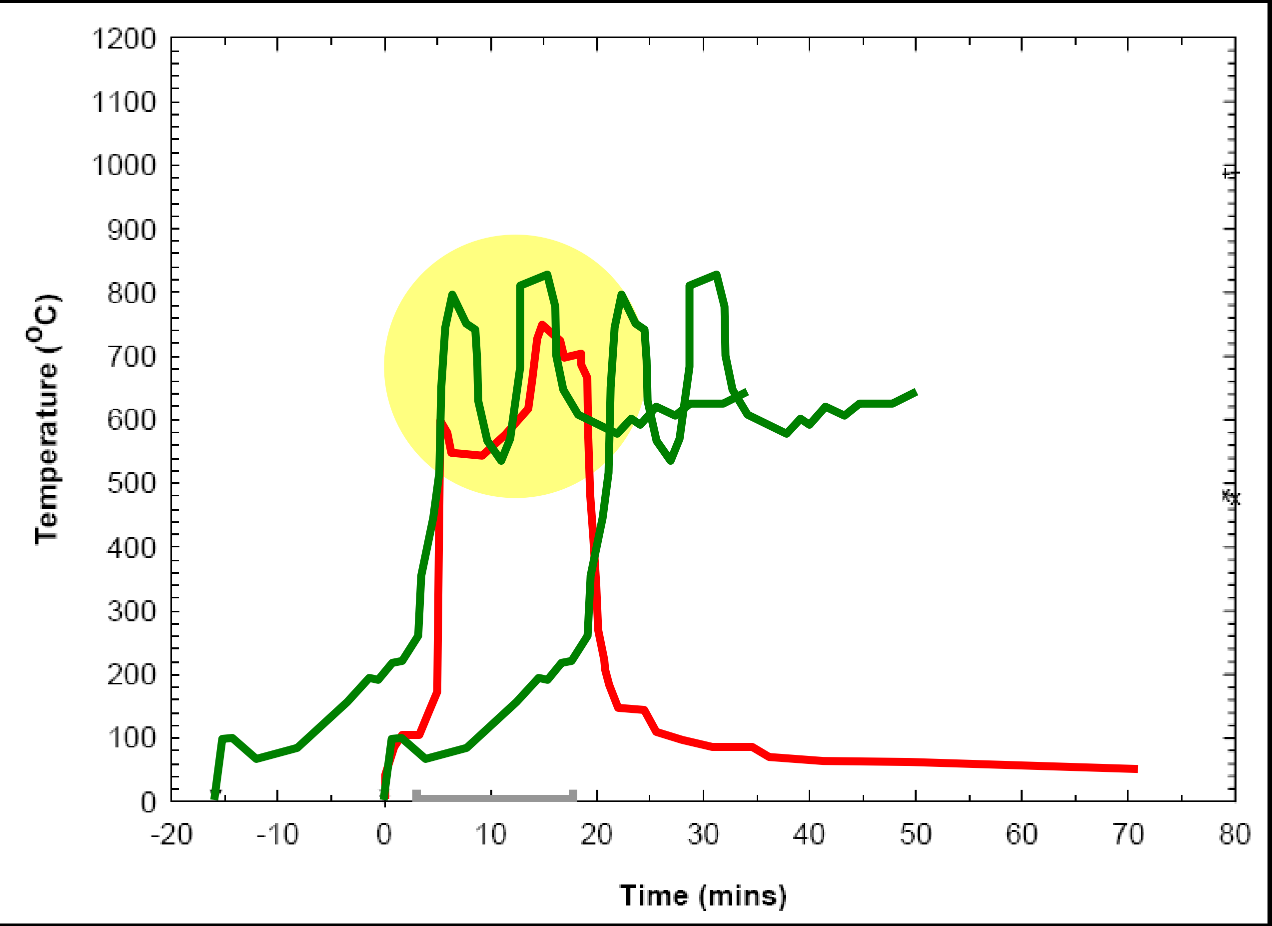
Compartment layout



- Not a validation of FDS!
- Simplified HRR applied to the sofa
- Flame spread definition
  - Ignition heat flux of 20kW/m^2
  - Representative HRR

Matching Results for Post-Flashover

Average compartment gas temperature (°C)



Average temperature can hide important variations in fire severity

- Misleading results

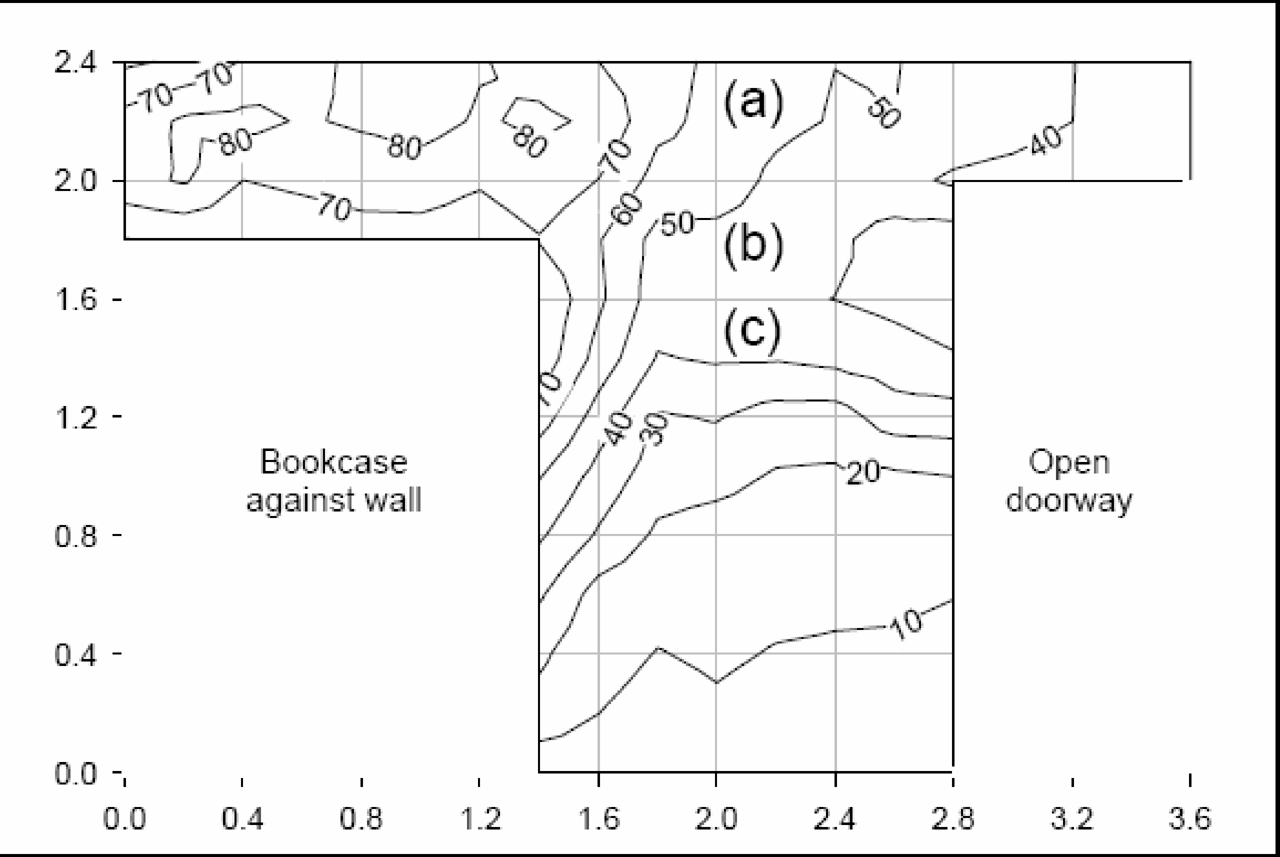
Total Heat Flux on the Rear Wall

Highest heat fluxes above the book case

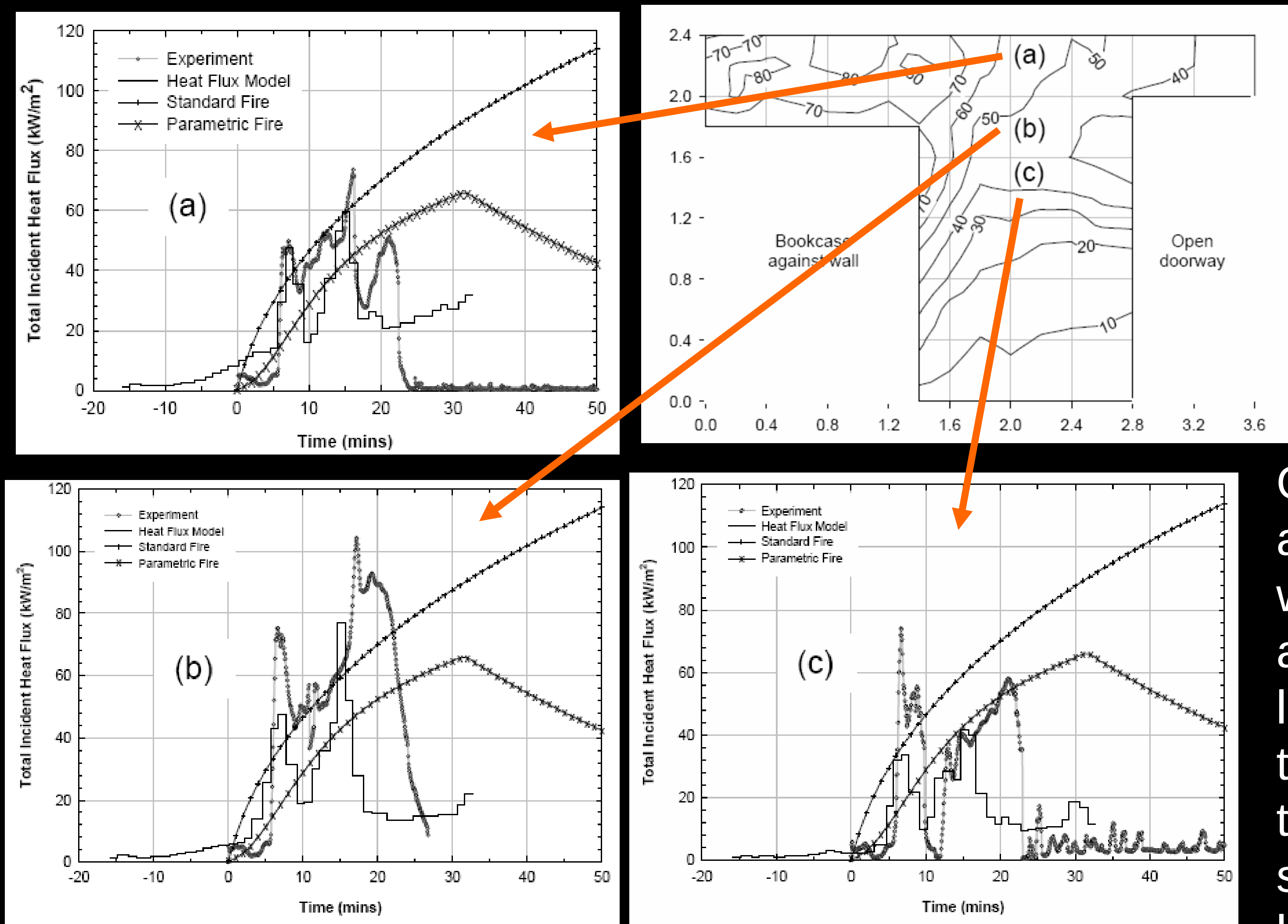
Severe fluxes due to the fire forced into the upper left corner of the room

- Ventilation conditions
- Effects of wind

Total incident heat flux kW/m^2 at t = 15 minutes



Total Heat Flux Histories – Rear Wall

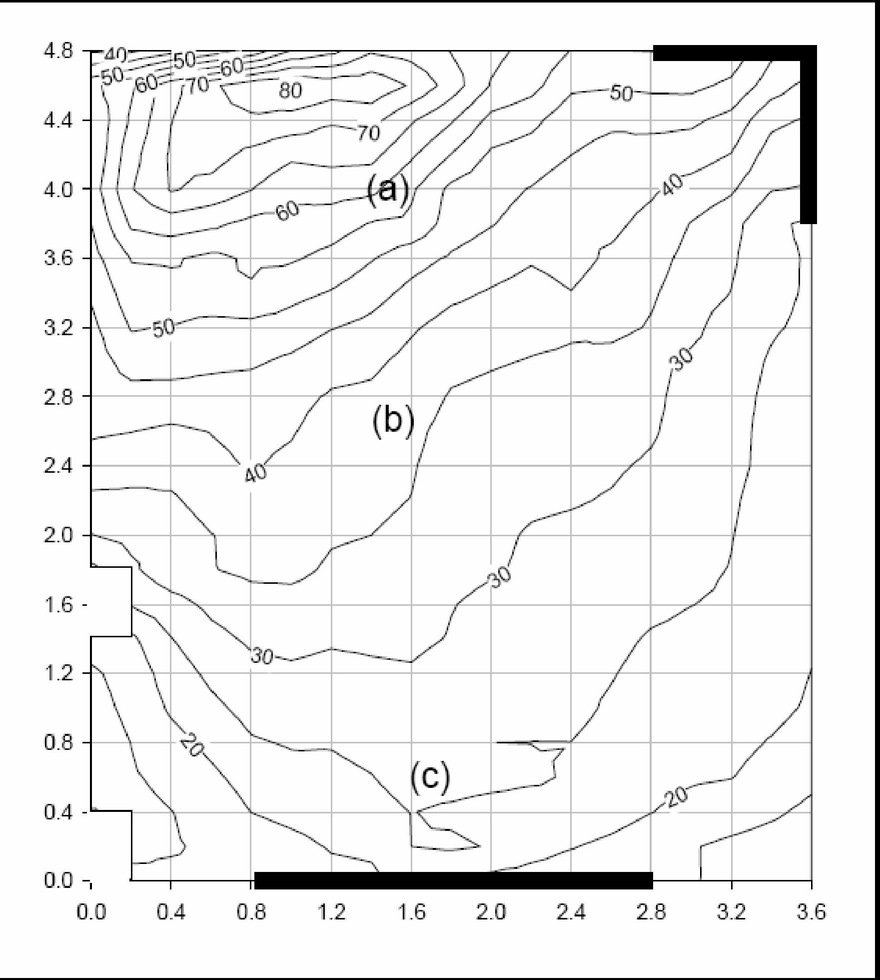


Good agreement with test data at higher locations on the wall due to the dense smoke in this location

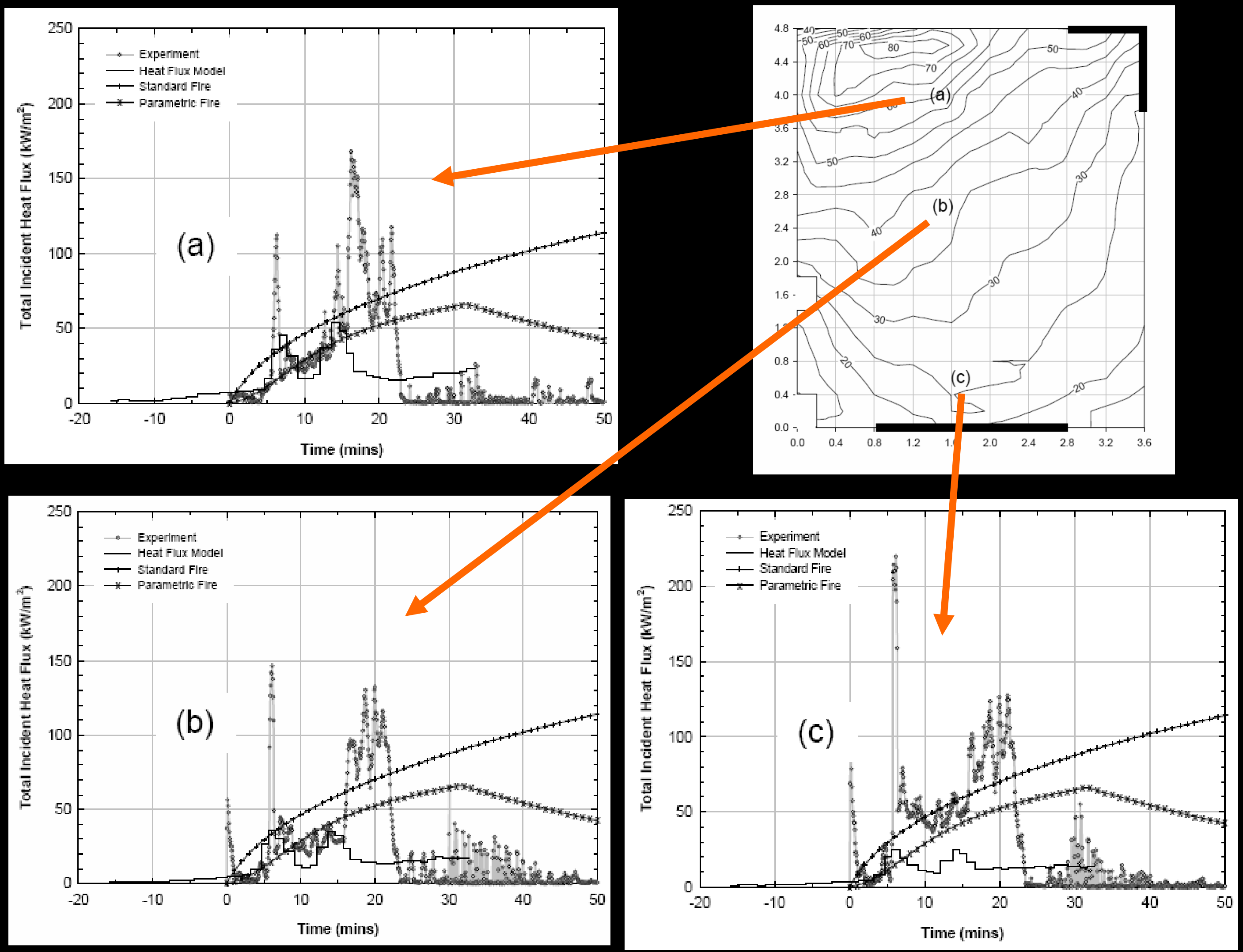
Total Heat Flux on the Ceiling

- Large gradient in total heat flux from front to rear of compartment
- Combination of ventilation and burning objects resulting in the fire localising at the rear left corner

Total incident heat flux kW/m^2 at t = 15 minutes



Total Heat Flux Histories – Ceiling



Good agreement with test data at the rear of the compartment due to effects of ventilation

Summary

- Model to define total heat flux to a structural element based on CFD simulations
  - Radiative and convective contributions
  - Member geometry
  - Material of the element
- Application of the model to the Dalmarnock Fire Test
  - Validation against test data – good agreement for post-flashover
  - Structural fire design applications
- Large spatial and temporal distributions demonstrated within a fully-developed fire
  - Applicability of a single temperature-time curve?