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Fire Dynamics Simulator vs. Parametric fire curves

A quantitative comparison with compartment fire test data

Introduction

- Parametric methods still used for global compartment temperature predictions
- However, use of CFD analysis in the fire engineering industry is almost ubiquitous
- Most CFD validation carried out on plumes
- Large-scale predictions coupled with unknown accuracy levels is dangerous
- Need a quantitative comparison of parametric and field modelling methods

Parametric 1: EC1 method

- The temperature-time curve in the heating phase is given by

$$Q_g = 20 + 1325\left(1 - 0.324e^{-0.2t^*} - 0.204e^{-1.7t^*} - 0.472e^{-19t^*}\right)$$

- Until t_{max} is reached and then another curve is applied for cooling period

$$Q_g = Q_{max} - 250\left(3 - t^*_{max}\right)\left(t^* - t^*_{max} \times x\right)$$

One of 3 cooling curves depending on the value of t_{max}

Parametric 2: BFD curve

- Barnett's basic concept: Newton's law of cooling, (cooling down process plots as a curve)
- Barnett analyses various test data to produce an empirically based curve

$$T = T_a + T_m e^{-z} \quad \text{where} \quad z = (\ln t - \ln t_m)^2 / s_c$$

- Empirical data fitting from Cardington, Kawagoe, Odeen, JFRO, EBS, CIB, CTICM, and others produced BFD curve

FDS: Introduction

- Fire Dynamics Simulator: LES code
  - Much validation for plume modelling
  - Need for validation of compartment fires
- Cardington compartment
- Input conditions
- Grid resolution
- Output data

FDS

- Many validation exercises only provide a qualitative assessment of FDS
- ‘FDS predicts temperatures to an accuracy of 5% to 20% compared to experimental measurements, depending on the fidelity of the underlying grid’ - NIST
- As such, a quantitative statistical analysis of the FDS output data is required

BRE, Cardington

- Eight full fire tests (NFSC)
- Post flashover temperature profiles of interest
  - Fire growth and spread not an issue
- Three parameters investigated
  - Ventilation
  - Linings
  - Fuel load
- Not specifically carried out for CFD validation
  - Full temperature data

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Cardington compartment

- Stand-alone concrete compartment

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Cardington compartment

- 12m x 12m on plan, 3.4m in height

Cardington compartment

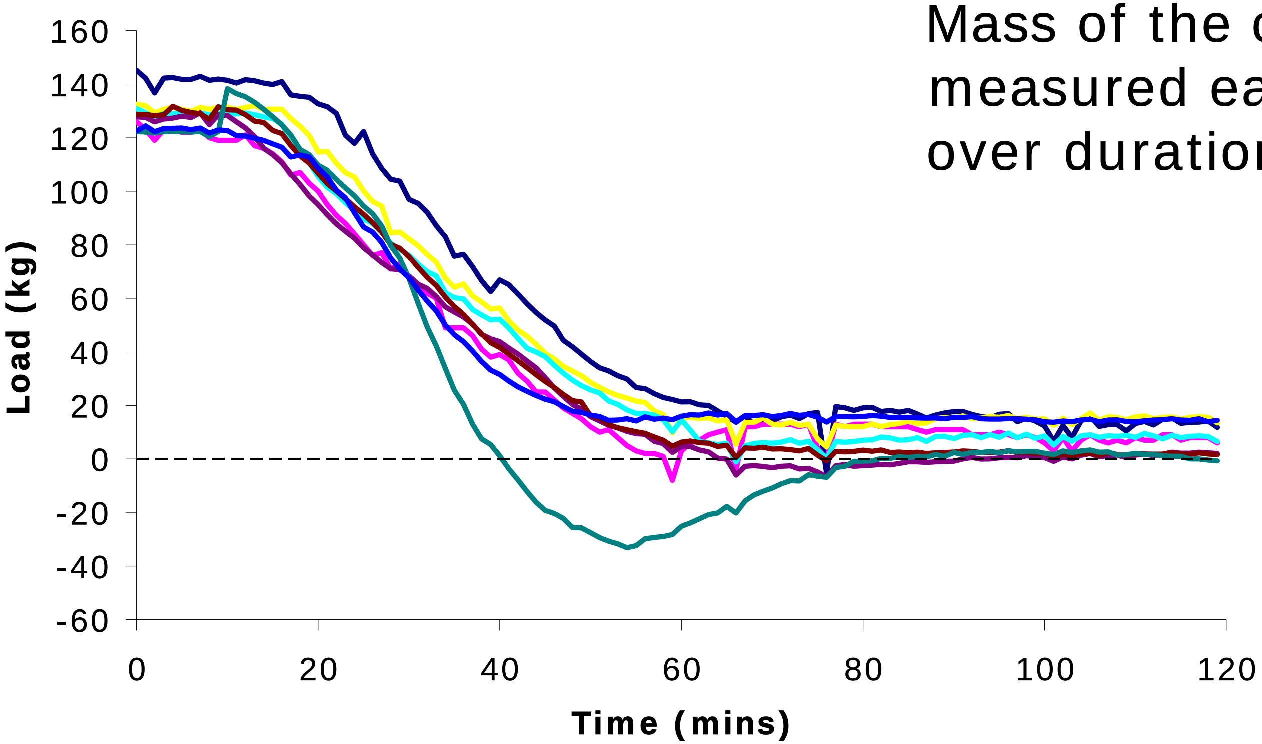
- 49 cribs, fuel content varied between tests

Example shown here is a range of wooden cribs

Further fuel was polypropylene

FDS input – RHR

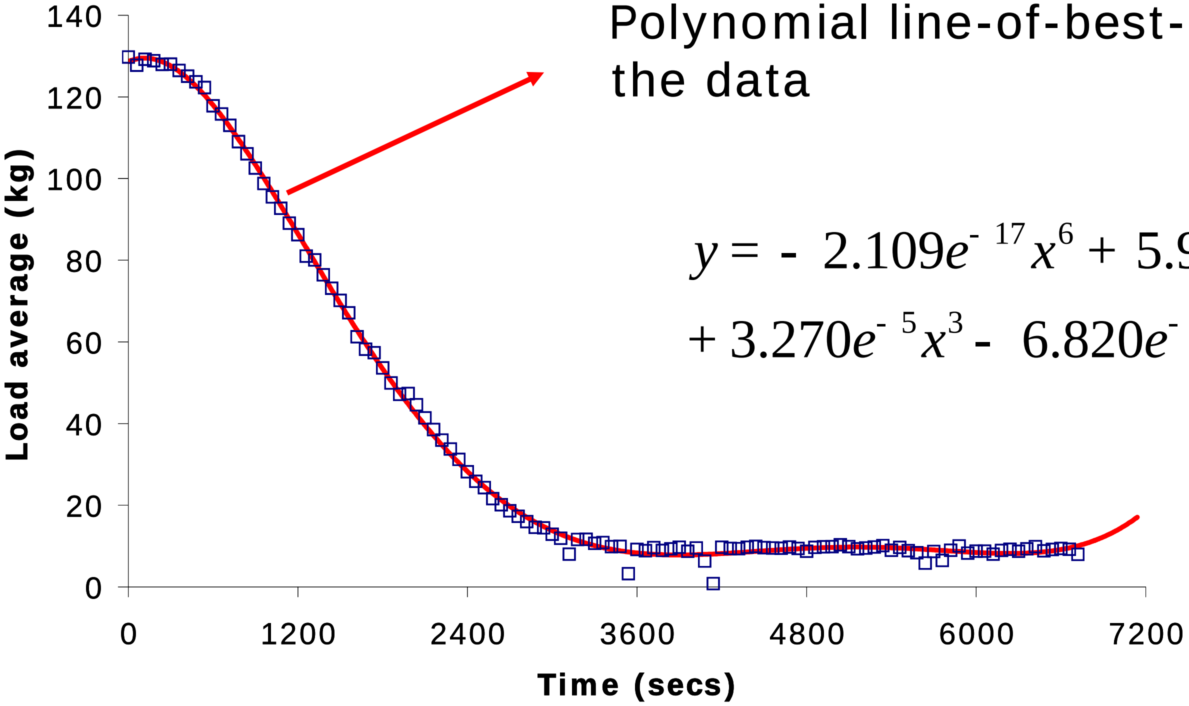
- Eight cribs set up as 'load cribs'...



Mass of the cribs measured each minute over duration of test

FDS input – RHR

- Average load of cribs calculated...

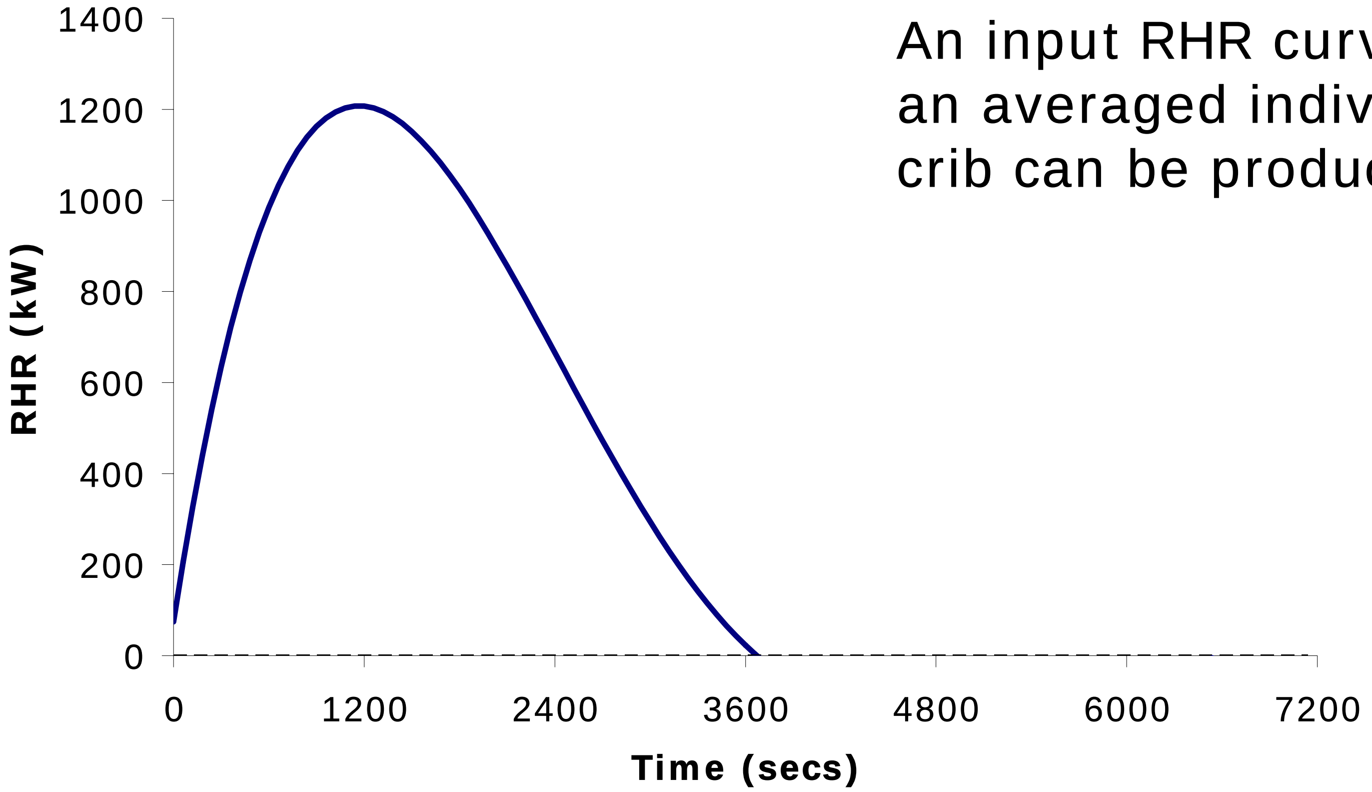


Polynomial line-of-best-fit applied to the data

$$y = -2.109e^{-17}x^6 + 5.983e^{-13}x^5 - 6.494e^{-9}x^4 + 3.270e^{-5}x^3 - 6.820e^{-2}x^2 + 3.460x + 1.290e^5$$

FDS input – RHR

- Differentiated *wrt* time and using the fuel's calorific value...



An input RHR curve for an averaged individual crib can be produced

FDS input – grid resolution

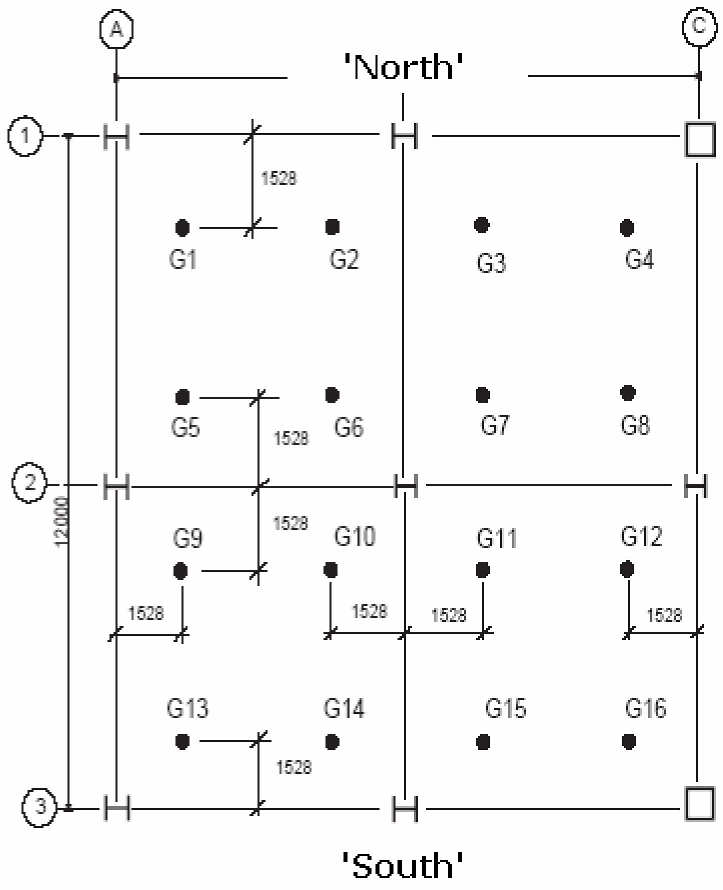
- Often debated issue in field fire modelling
- Usual LES guideline:
  - Finer grid, ‘finer’ results
- Large-scale, ‘long-scale’ modelling has different requirements than plumes
  - Spatial: metres, rather than centimetres
  - Temporal: hours rather than seconds

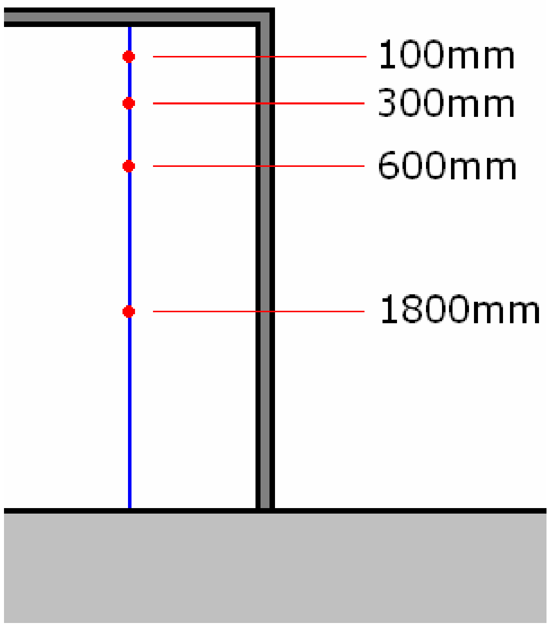
FDS simulations

- After basic sensitivity study and addressing the literature, two grid resolutions were taken:
  - $(0.2\text{m})^3$ = (~100,000 cells)
  - $(0.4\text{m})^3$ = (~12,000 cells)
- To simulate a Cardington 120 minute test fire took just over 5 CPU-hours for the coarser grid and over 110 CPU-hours for the finer grid
- Reducing the grid size further to $(0.1\text{m})^3$ would send the run-times to CPU-months

Cardington output

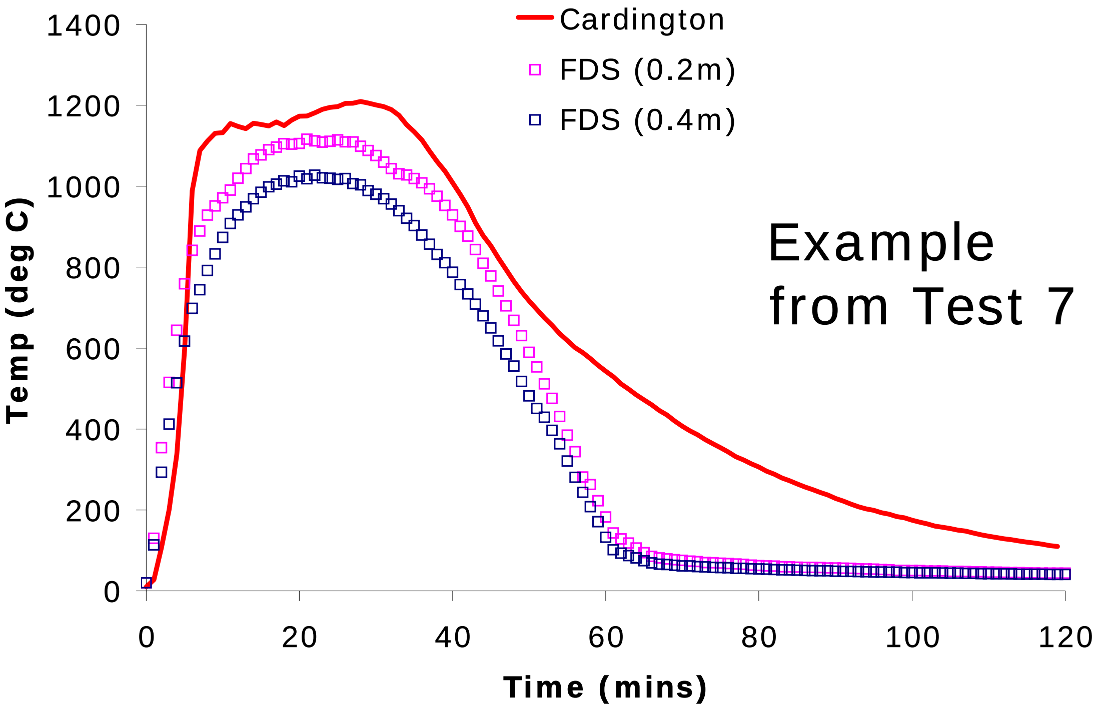
- Output data from 64 thermocouples





FDS output

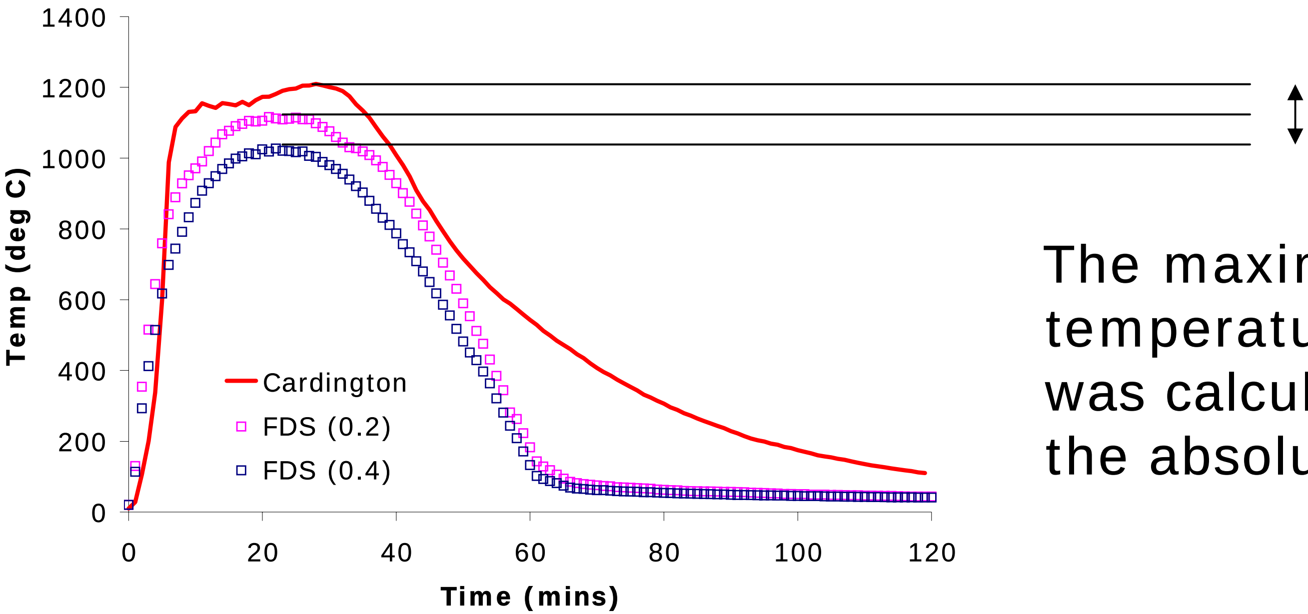
In order to gain some comparative data from FDS, the average compartment temperature was taken



Example from Test 7

Quantitative comparison 1

- The maximum temperature reached in a fire compartment is often of significance to the integrity of the structure
- Averaging the compartment temperatures across the FDS predictions allows a direct, non-spatially specific, parameter for analysis against the parametric data
- The equivalent parameter is easily generated using parametrics

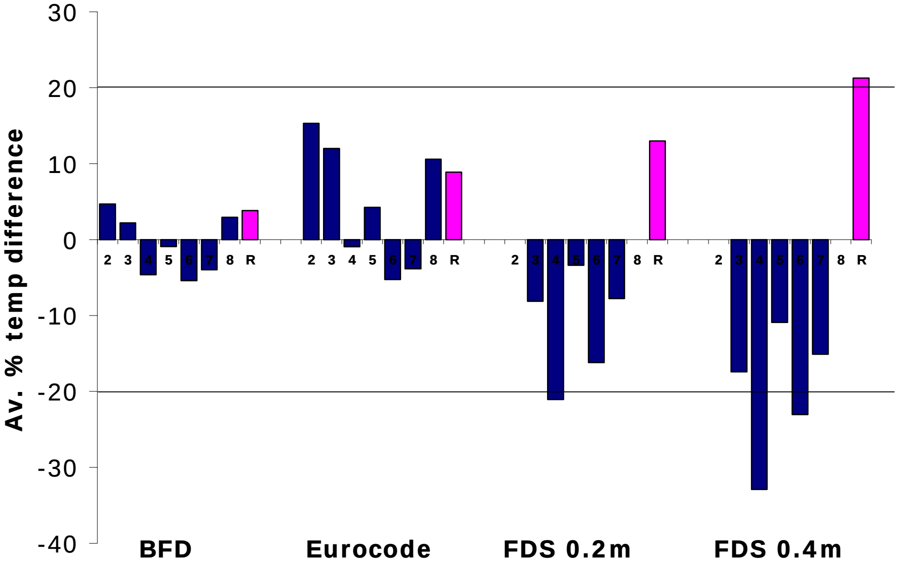


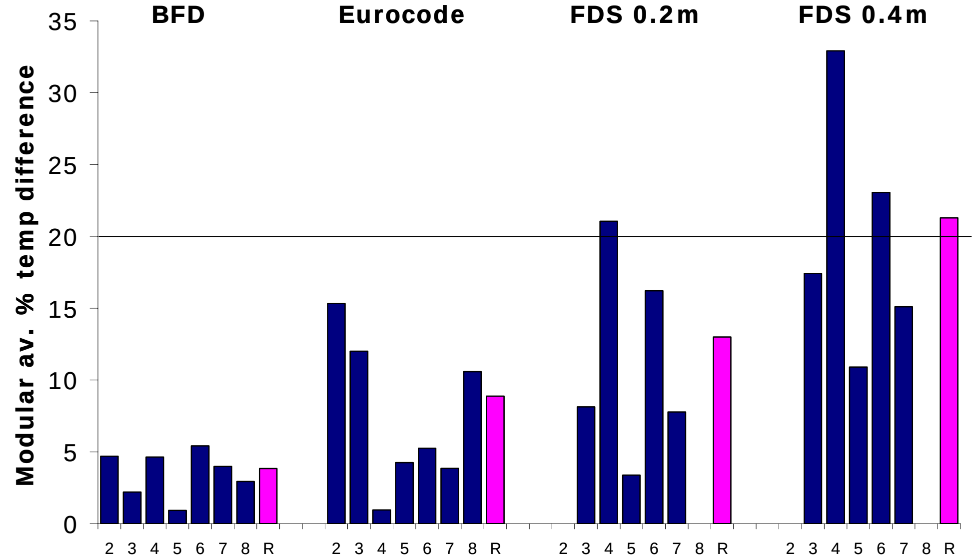
The maximum temperature difference was calculated as a % of the absolute temperature

(E.g. Test 7, above)

QC1: maximum temperatures

- The difference in measured and predicted maximum average compartment temperatures are shown





- Both parametric methods are ‘better’ at predicting the maximum compartment temperature than the FDS tool
- Of key note: the FDS predictions are all *under*-predictions of maximum gas temps

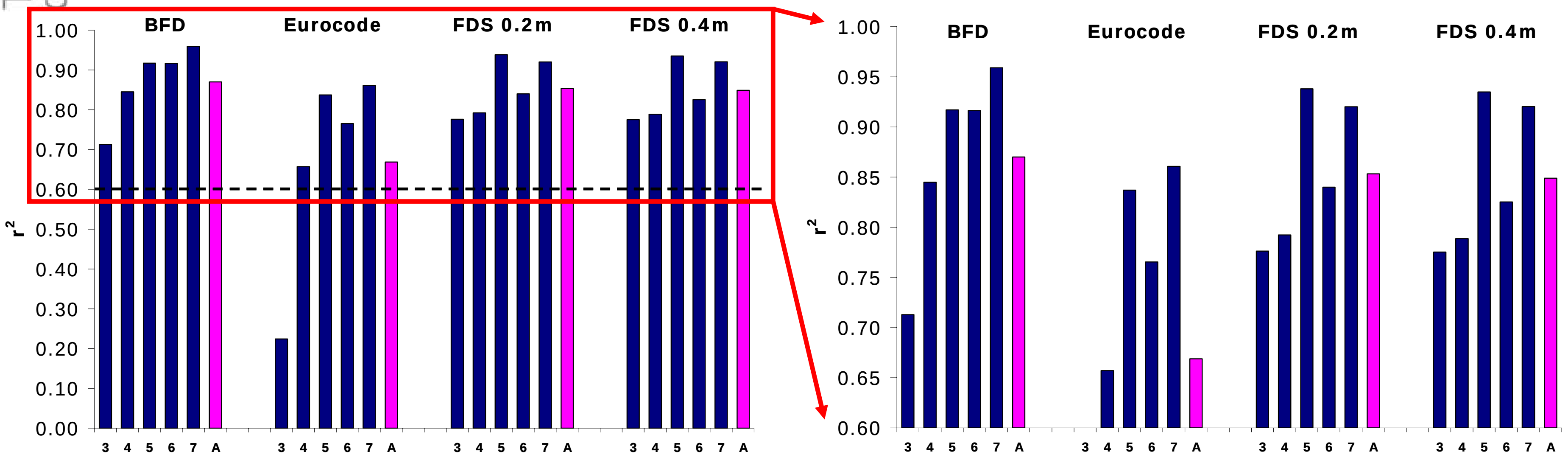
Quantitative comparison 2

- The square of the product moment correlation coefficient, r^2, value is a measure of measure of the degree of correlation of the predicted values against observed test values

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{(n - 1) s_x s_y}$$

- Essentially, the higher the value of r^2, the better the correlation

QC2: r^2 comparison



- BFD produces the best correlation
- FDS produces a better correlation than the EC1 method, which itself is notably poor in its predictions

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EC1 example: Test 4

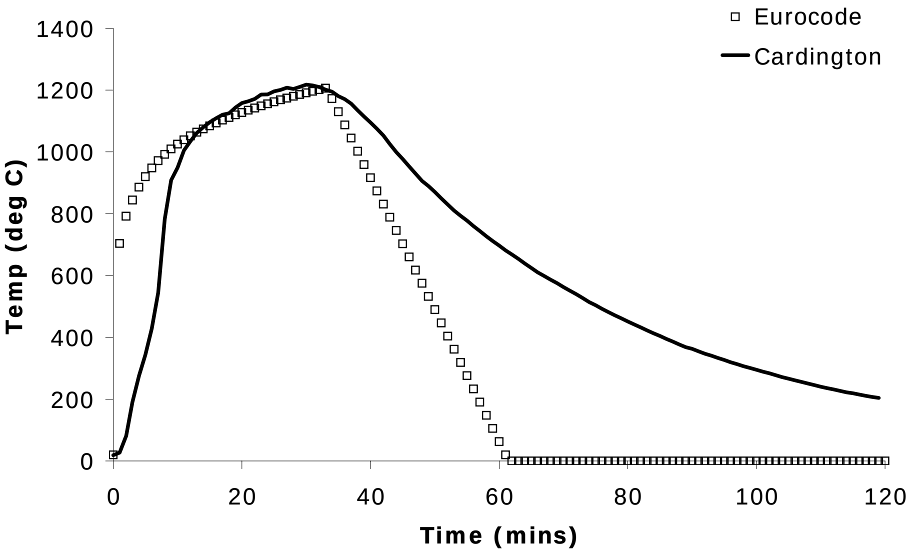
Test 4, max temp:

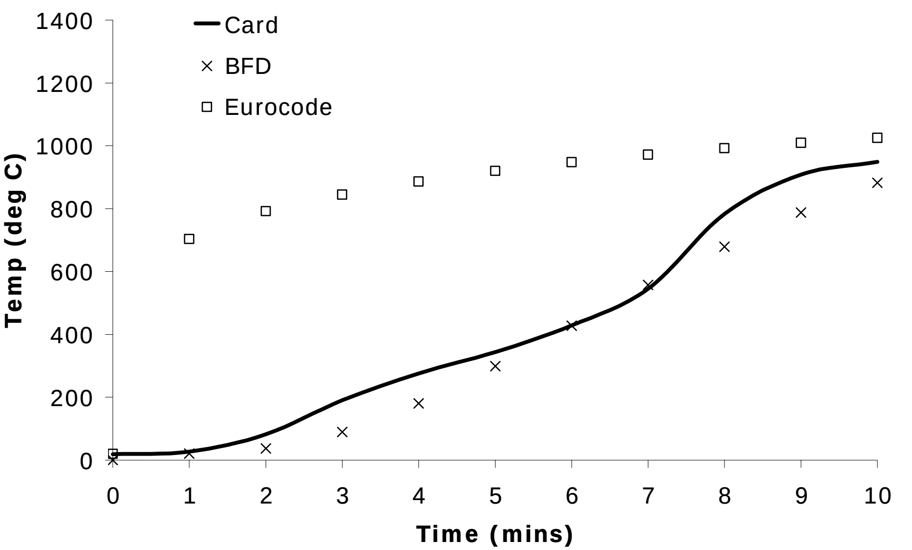
Predicted: 1201°C

Measured: 1217°C

The linear decay phase is highly unlikely to mirror any temperature decay in reality

The extremely sharp growth period reaches 700°C within a minute





Output comparison

- FDS consistently under-predicts global compartment gas temperatures
  - Important distinction for obvious reasons
- However, the indication is there that for a fine enough grid, the solution may converge more accurately
- Averaged data only gives average conclusions
- Full analysis of the individual temperature profiles more reliable

FDS Test 5 analysis

- One of the main attributes of field models is their ability for spatially specific predictions
- The quantitative comparison needed an averaging procedure in order to compare field model predictions with parametric predictions
- Taking NFSC 5 as the test case …

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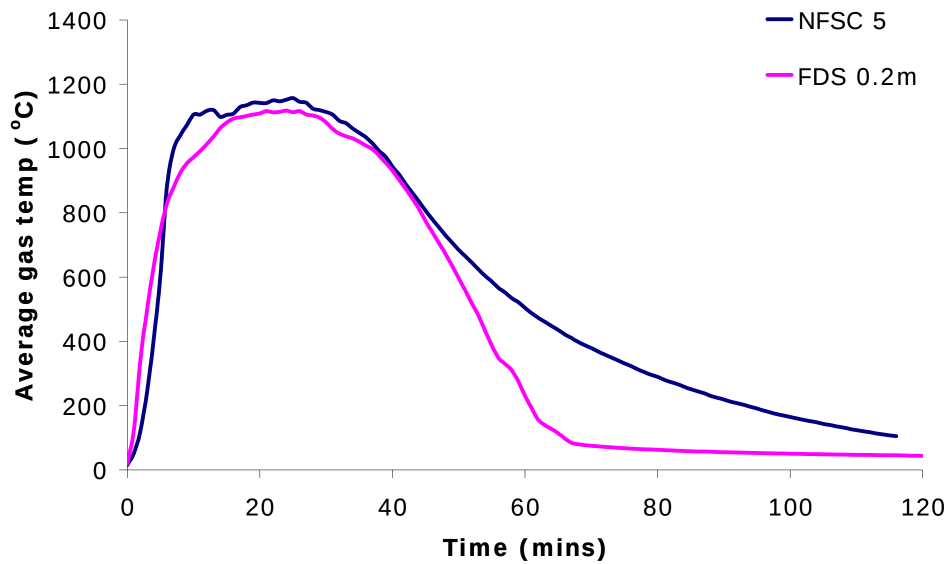
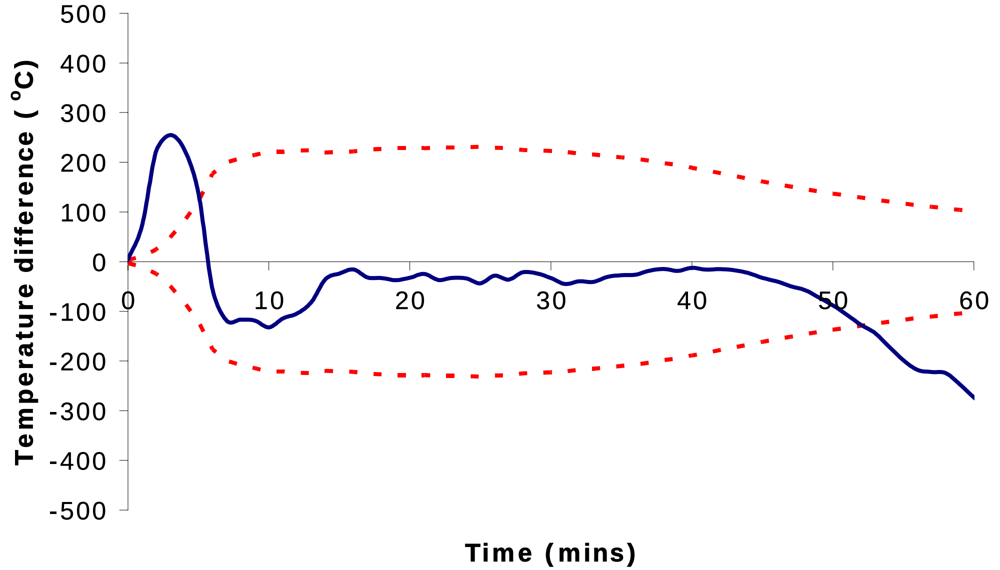
FDS Test 5 analysis

The average temp-time plot prediction by FDS is impressive

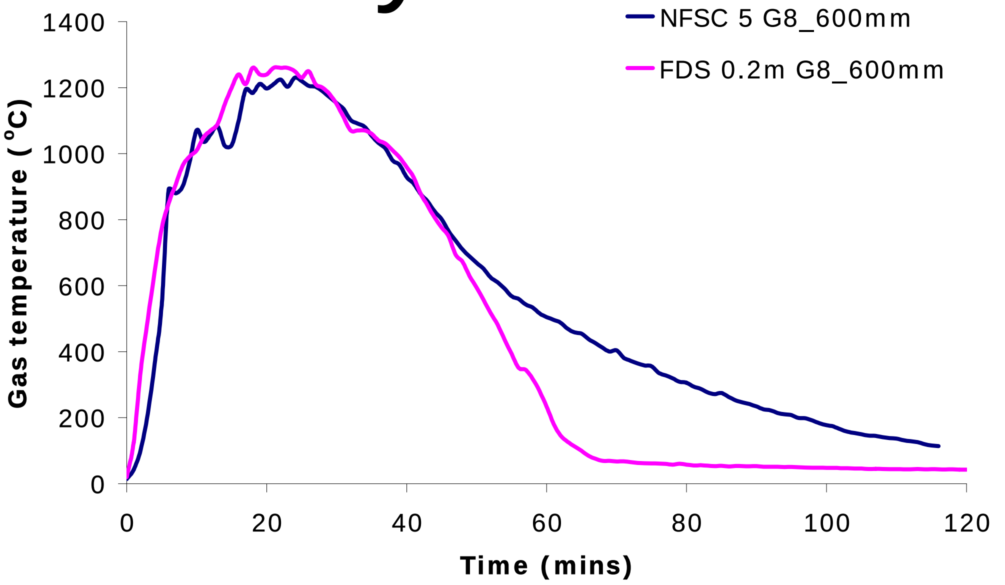
A 20% error bound can be produced at each measured data point

As expected from the temp-time plot, the difference in predicted and measured temperature falls within the 20% error bound

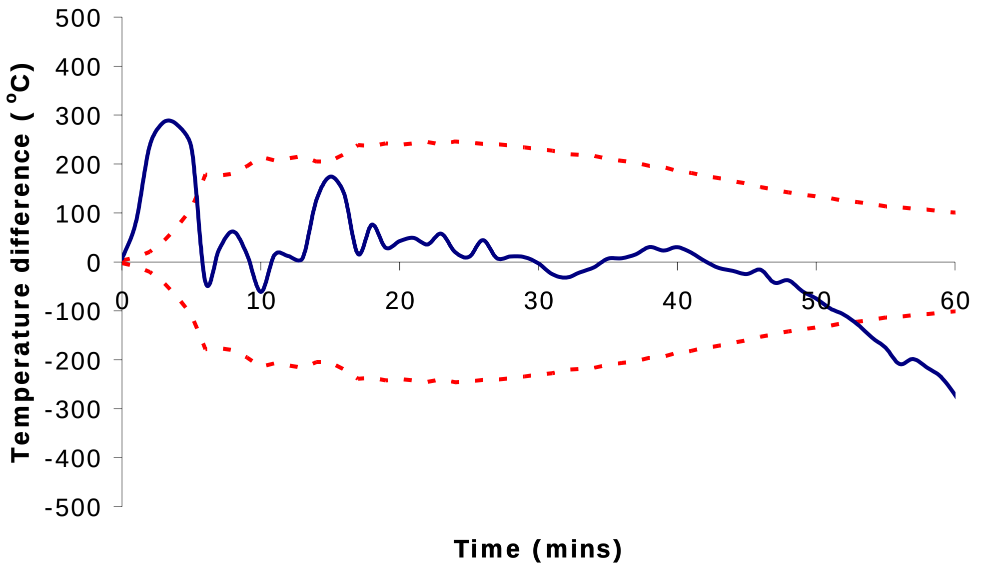




FDS Test 5 analysis



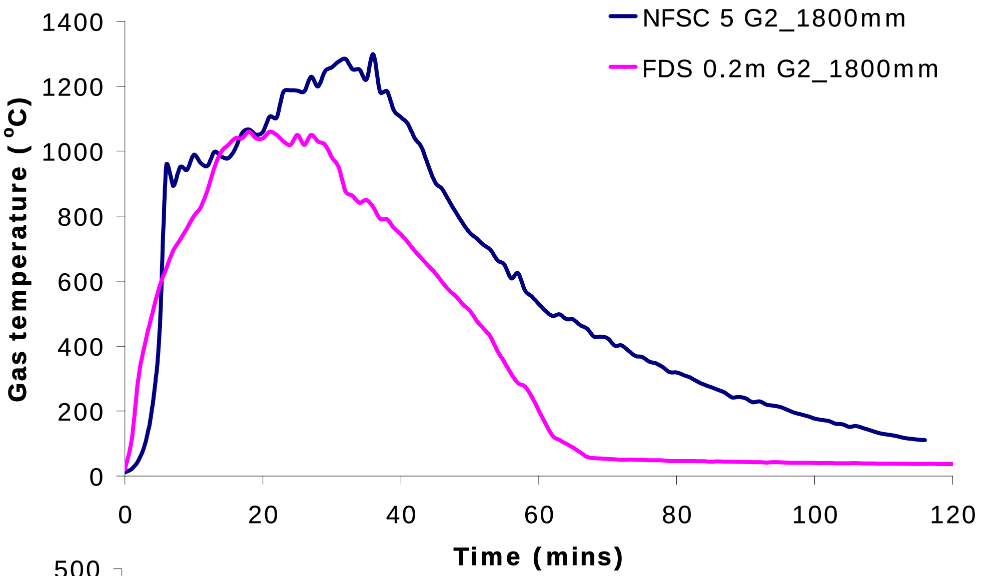
Location within the domain where the predictions are very accurate

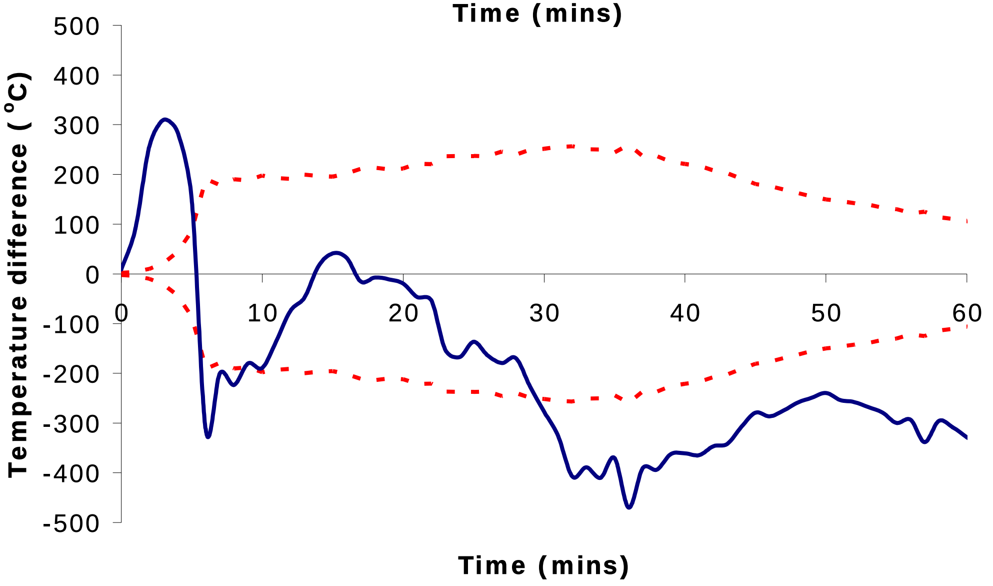


FDS Test 5 analysis

However, several locations where predictions are far less accurate

It should be noted, this is one location within the domain of the 0.2m grid resolution (NFSC 5) – the most accurate of the FDS simulations





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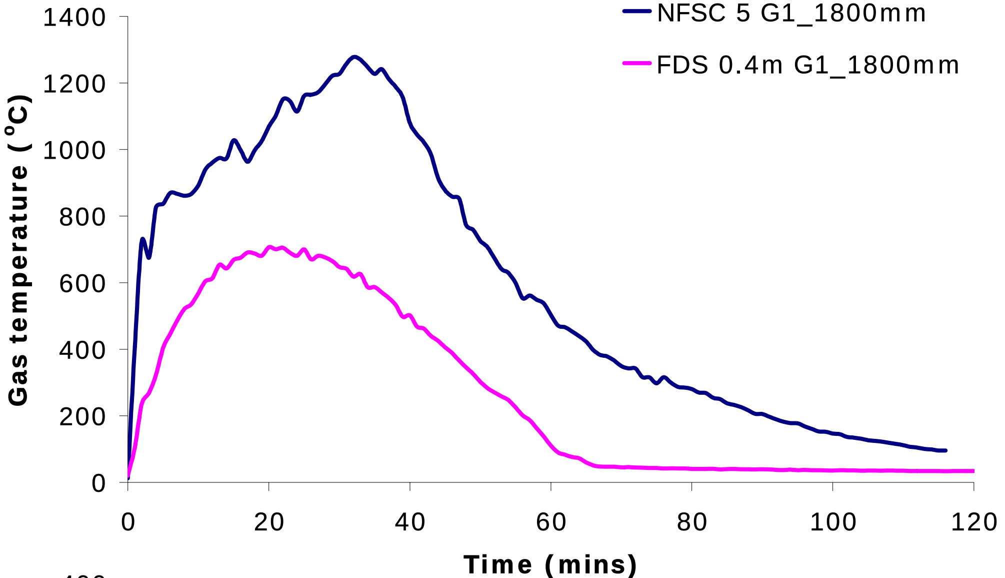
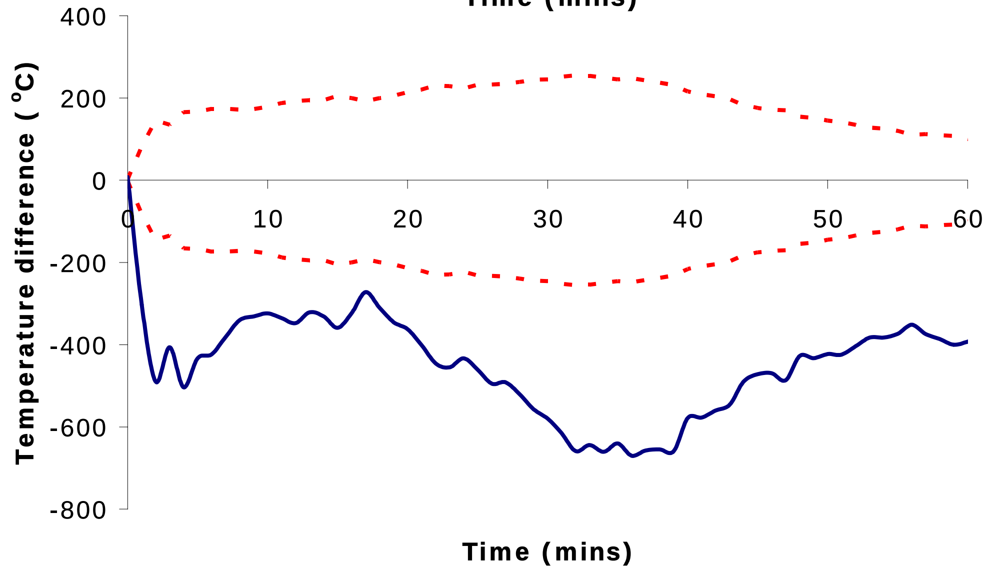
FDS Test 5 analysis: 0.4m

Taking the coarser grid for Test 5, and looking at a spatially specific prediction highlights the differences



At no point is the predicted temperature within 20% of the measured temperature at that location



Conclusions: Test 5 analysis

- Dangerous to rely on CFD predictions, even when seem to be modelling reality
  - For any given simulation carried out, there is no way of telling whether any spatially-specific predictions are over- or under-predictions, and by how much
- If the averaged predictions are significantly inaccurate, is it safe to use CFD to predict specific flows and patterns?
- More validation and calibration work
- Potential is there, harnessing the power safely

Conclusions: comparison

- The max temp predictions and correlation analysis suggests for the compartment tests modelled, the global temp predictions of BFD are more accurate than both EC1 and FDS
- For the main use of CFD, i.e. spatially-specific predictions, the user must be aware of limitations and inaccuracies

Thank you

for

listening

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