BRE Centre *for* Fire Safety Engineering

Part 1. An extended travelling fire method framework with an OpenSees-based integrated tool SIFBuilder (PhD work)

Xu Dai

Authors: Xu Dai, Stephen Welch, Asif Usmani

Part 2. The analysis of the Tisova travelling fire test data (PDRA work)

Xu Dai

Authors: David Rush, Xu Dai, David Lange

THE UNIVERSITY *of* EDINBURGH
United Kingdom

Motivation

BRE Centre *for* Fire Safety Engineering

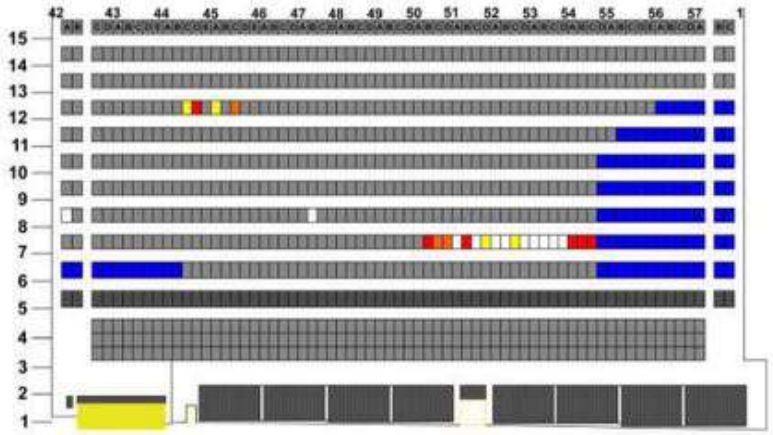
Fire uncertainties to large spaces architecture for structural design?

World Trade Center Tower 1
in New York City in 2001

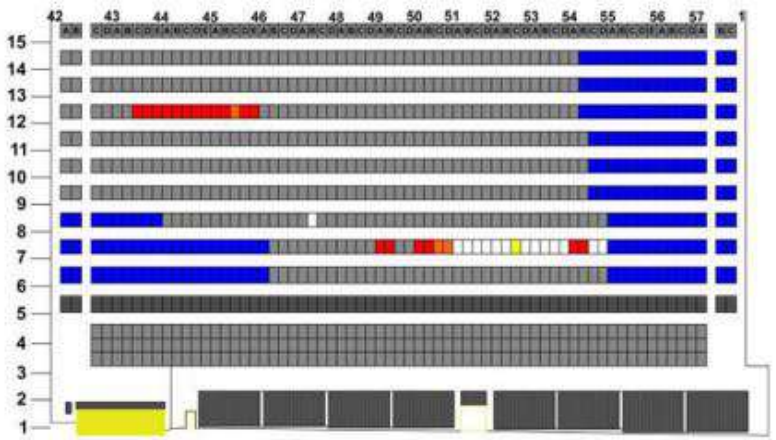
(source: https://www.metabunk.org/)

WTC 7

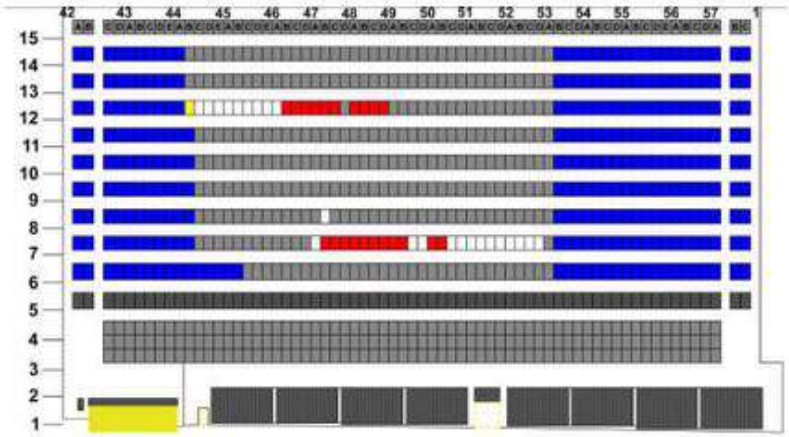
Window glass intact | Window open | Fire visible inside | Not visible



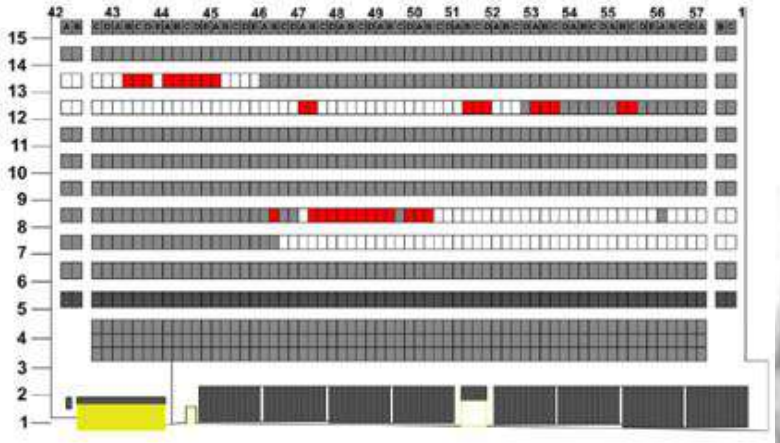
2:57 p.m.



3:05 p.m.



3:13 p.m.



3:44 p.m.

Facade map summarizing observations of fire spread and window breakage on the north face of WTC 7

(source: NIST NCSTAR 1-9, Structural Fire Response and Probable Collapse Sequence of World Trade Centre Building 7, 2008)

BRE Centre *for* Fire Safety Engineering

Introduction

What is a travelling fire?

Large compartment fires that burn locally and tend to move across floor plates over a period of time.

It is a way of approximating fire impact on structures in large open-plan spaces for structural design.

Alternative names:

moving fires, spreading fires, real fires, natural fires, non-uniform fires…

Travelling fire analytical models

BRE Centre *for* Fire Safety Engineering

Extended Travelling Fire Method (ETFM) framework

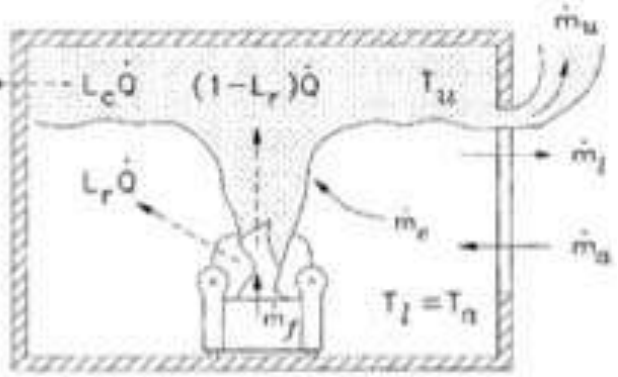
e.g. - Hasemi's localized fire model:

Based on M. Janssens' book, 2000

$$\dot{h} = 136300 - 1210$$

$$\dot{h} = 15000y^{-3.7}$$

e.g. - FIRM zone model:



heat flux

0

'Combination' of localized fire model & zone model

Ceiling

Smoke layer depth d = *d (t)*

Steel Beam

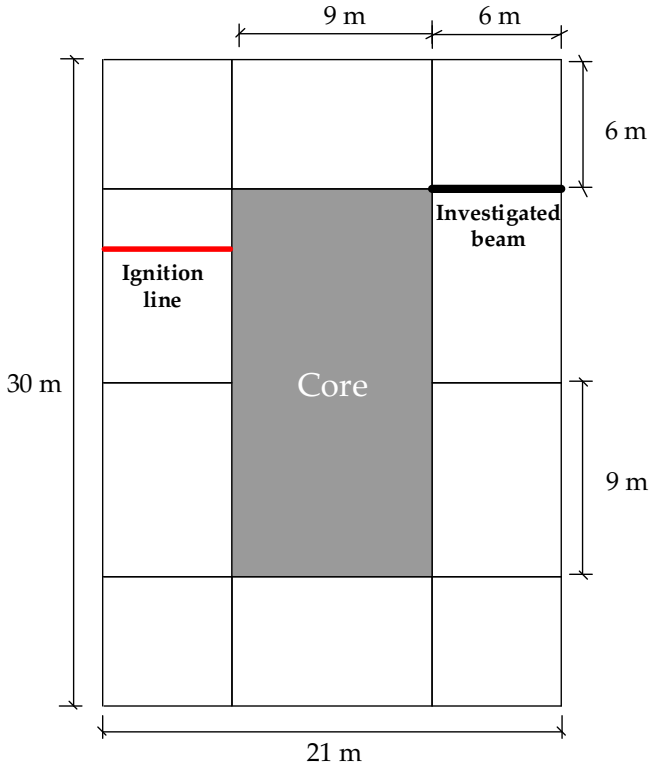
local fire

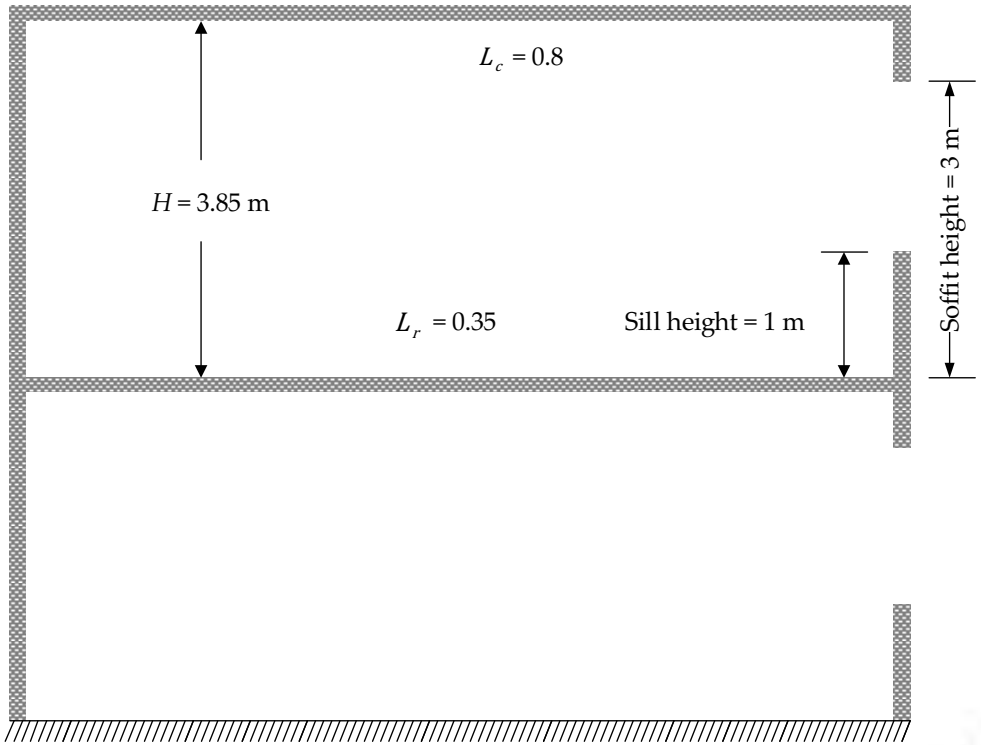
Pre-heating | *Direct exposure* | *Post-heating*

Case study using ETFM framework

BRE Centre *for* Fire Safety Engineering

An idealised steel composite building with a core





Large compartment dimensions:

Building dimensions:

x direction: 6m – 9m – 6m

y direction: 9m – 9m

z direction: 6m – 9m – 6m

Net floor area: 6m × 9m = 54 m²

Total vent width: 28 m

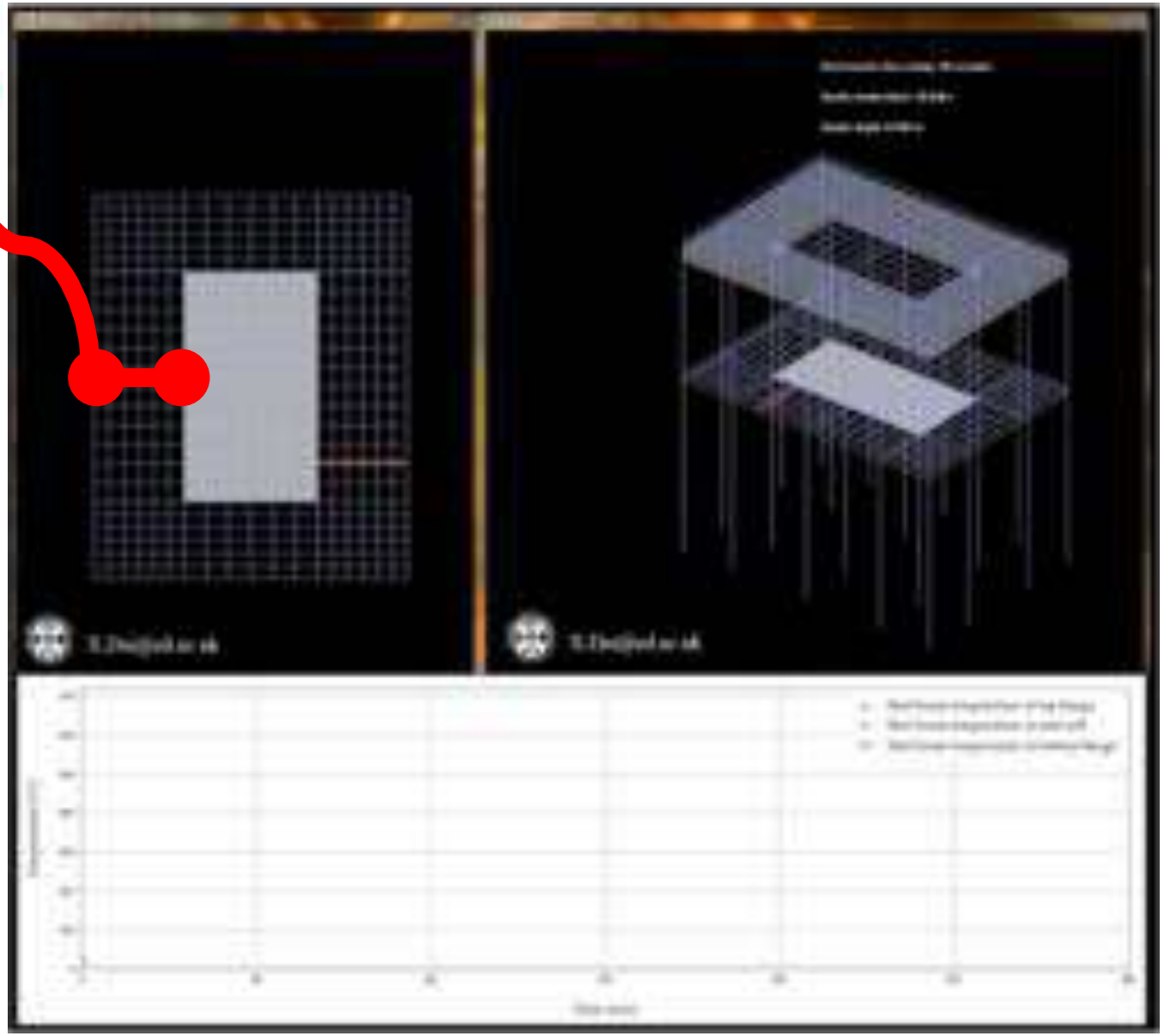
Floor height: 3.85 m

Sill height: 1 m

Soffit height: 3 m

Case study using ETFM framework

BRE Centre *for* Fire Safety Engineering



Fire scenario:

Fire starts on:
the first floor

Fire spread rate:
5 mm/s

HRR per area:
300 kW/m²

Fuel load density:
570 MJ/m²

Visualization output of OpenSees-SIFBuilder during heat transfer analysis

Case study using ETFM framework

BRE Centre *for* Fire Safety Engineering

Two key input variables for ETFM: fire spread rates, and fuel load densities

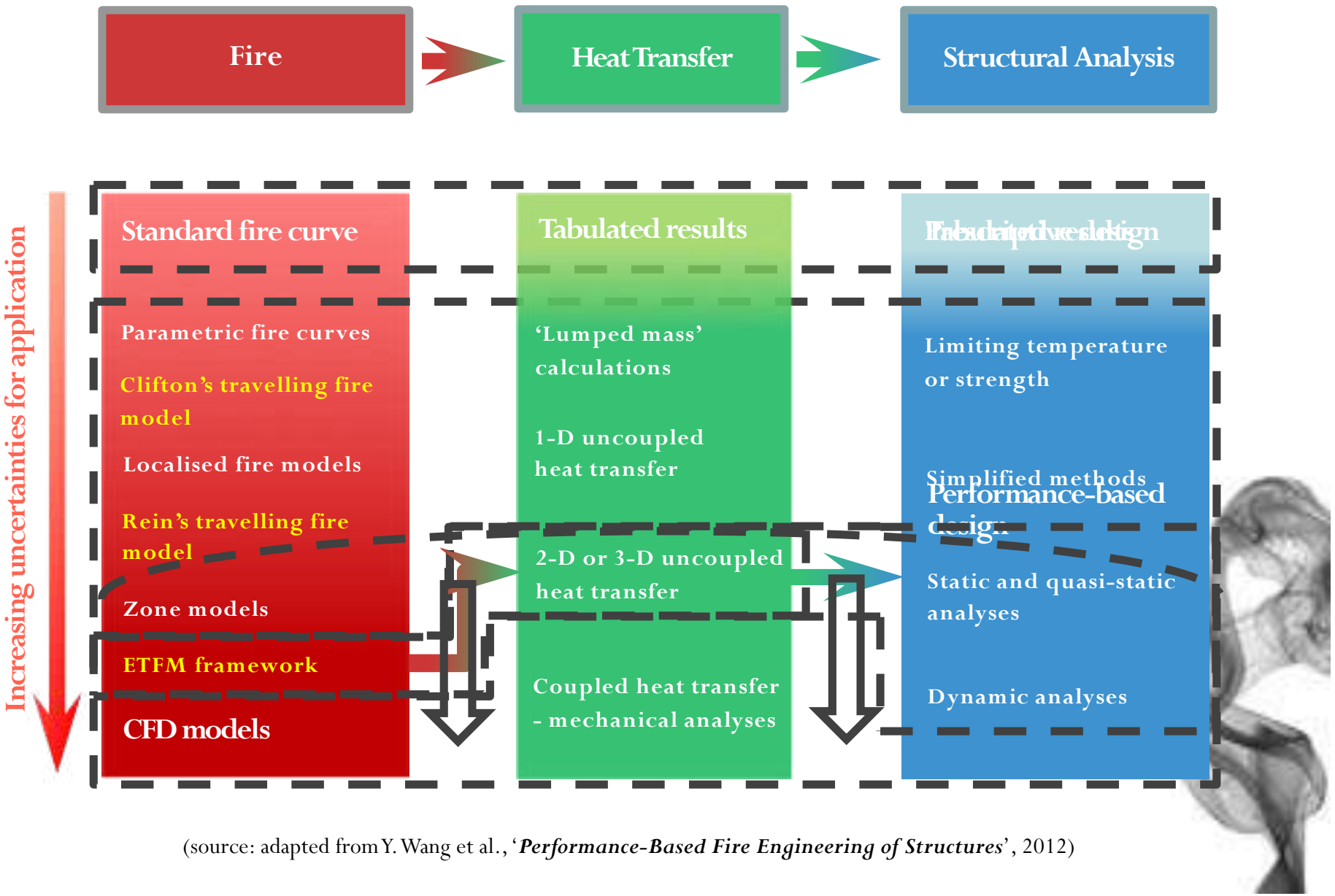
Travelling fires with changing fuel load densities

Case study using ETFM framework

BRE Centre *for* Fire Safety Engineering

Progress so far for structural design

BRE Centre *for* Fire Safety Engineering



(source: adapted from Y. Wang et al., '*Performance-Based Fire Engineering of Structures*', 2012)

Case study using ETFM framework

BRE Centre *for* Fire Safety Engineering

Fire scenario:	Fire starts on:	Fire spread rate:	HRR per area:	Fuel load density:
	the first floor	**5 mm/s**	**300 kW/m²**	**570 MJ/m²**

Fire & heat transfer analysis in SIFBuilder

Structural analysis in SIFBuilder

BRE Centre *for* Fire Safety Engineering

Part 1. An extended travelling fire method framework with an OpenSees-based integrated tool SIFBuilder (PhD work)

Xu Dai

Authors: Xu Dai, Stephen Welch, Asif Usmani

Part 2. The analysis of the Tisova travelling fire test data (PDRA work)

Xu Dai

Authors: David Rush, Xu Dai, David Lange

THE UNIVERSITY *of* EDINBURGH
United Kingdom

The Tisova Fire Test

BRE Centre *for* Fire Safety Engineering

- Jan. 2015 – Czech Republic
- SP, University of Edinburgh, Imperial College London, Luleå Technical University, and Technical University Ostrava, Majaczech, CSTB and CERIB
- Aim: to generate experimental data on:
  - Travelling fires;
  - Thermal and structural response of composite slabs, concrete slabs, and concrete columns to real fires as an input to round robin studies;
  - As a post-fire assessment of a structure after a quantified fire event

The test building

- Four storeys tall
- Original 1958 beam and post concrete construction with flat slabs
- 1980 - change of use - installation of 4 composite panels at 1st floor level

- The test was conducted on the ground floor -Total area ca. 230 m^2
- All windows opened to encourage fuel controlled fire
- Continuous fuel bed ca. 170 m^2 - 0.5 to 1 m wide path around the fuel, 680MJ/m^2

Fuel load on ground floor

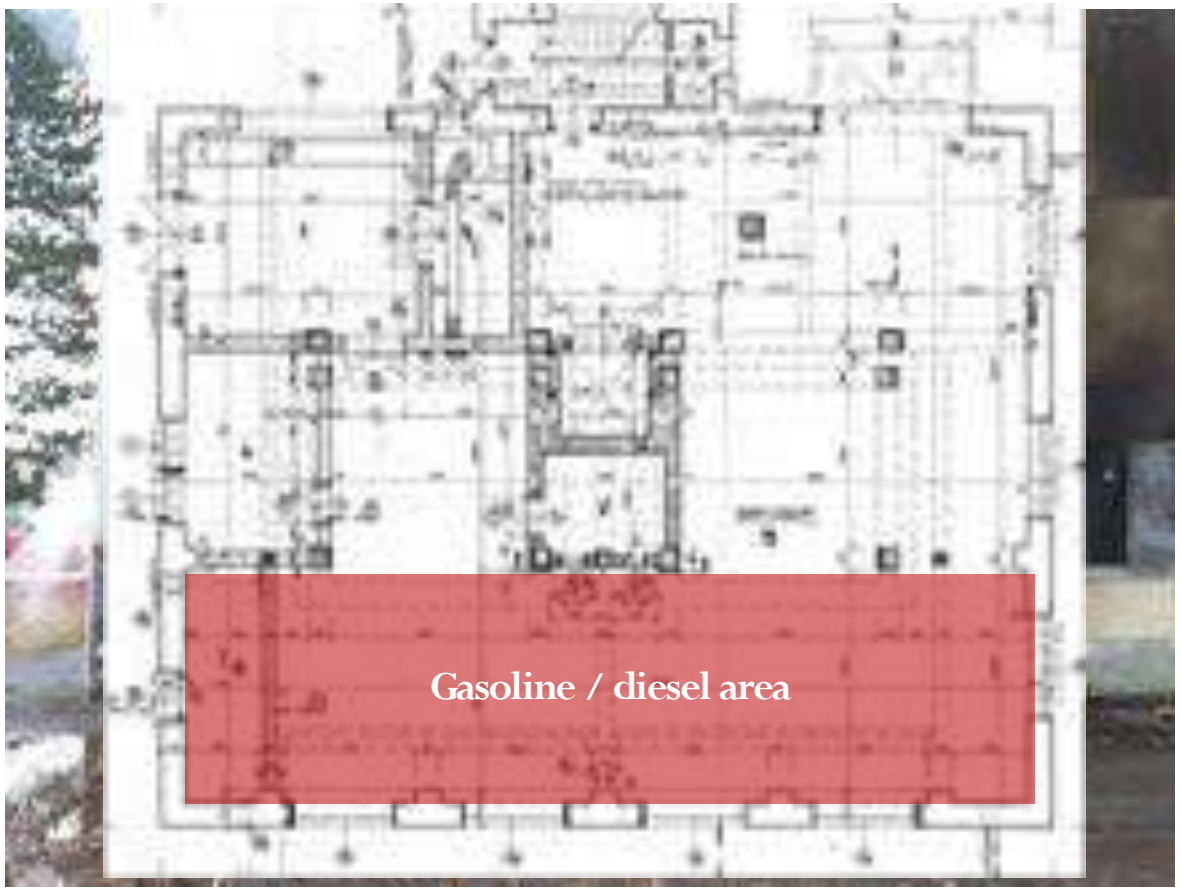
Elevation view

Plan view

BRE Centre *for* Fire Safety Engineering

Results of fire

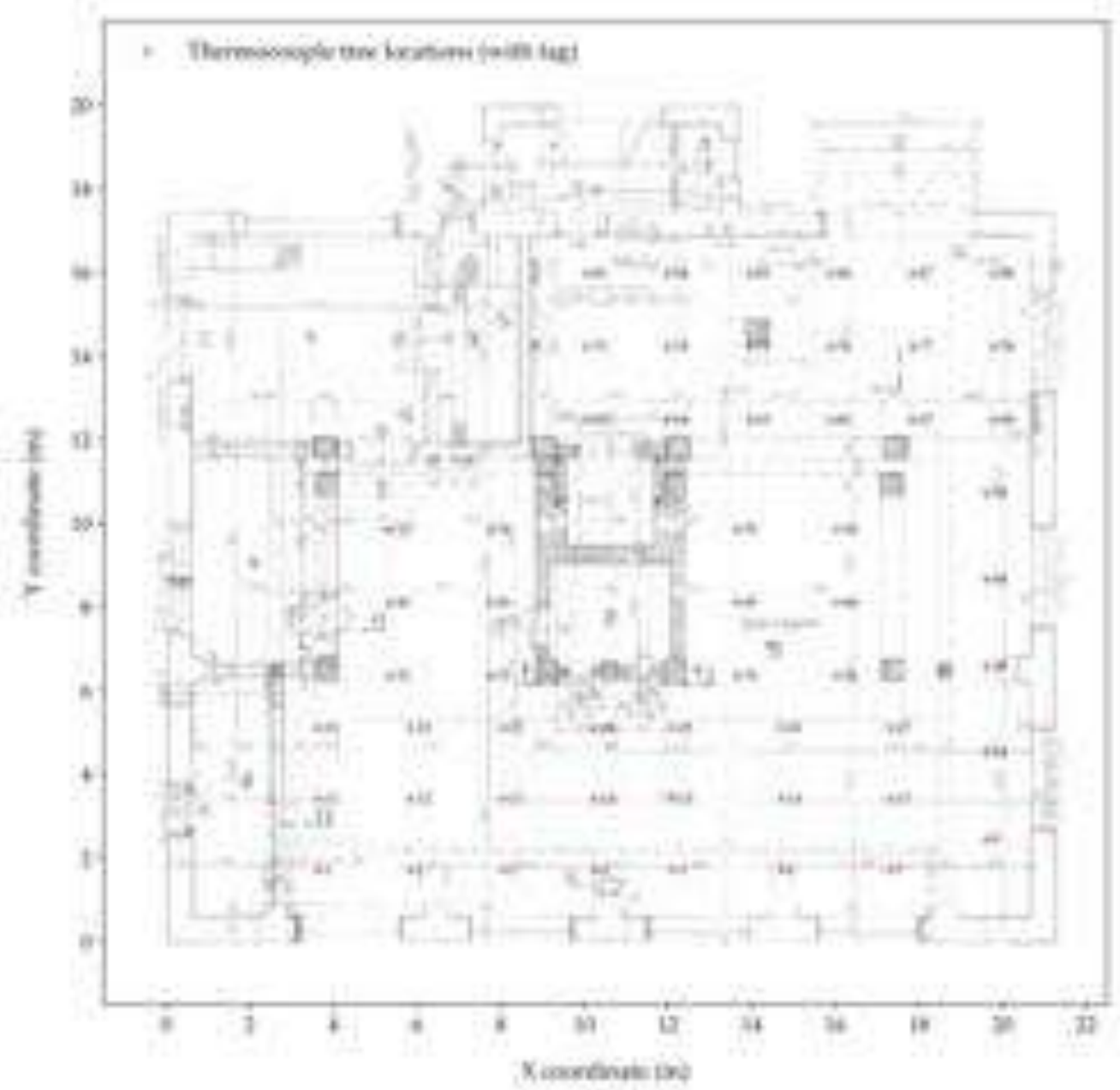
- Didn't burn as ferociously as we would have liked
- The fire spread rate was initially very slow so we closed the window openings and added 10 litres of a 1:1 mix of gasoline / diesel at the red rectangular area



Plan view

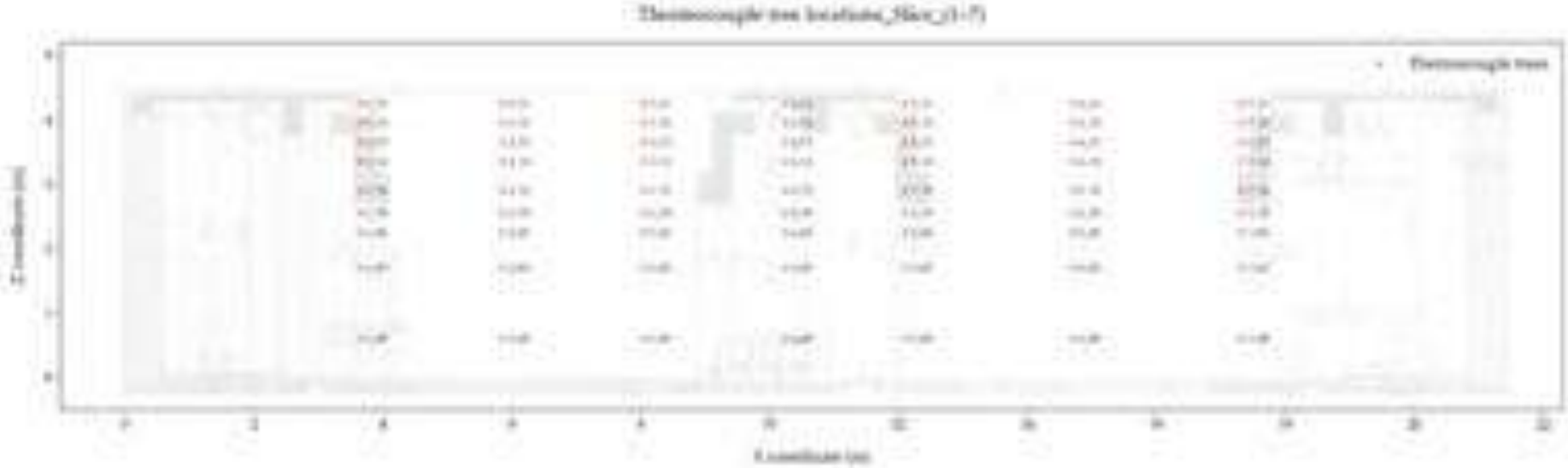
Test building floor plan with TC tree locations

BRE Centre *for* Fire Safety Engineering



Test building elevation with TC tree locations

BRE Centre *for* Fire Safety Engineering



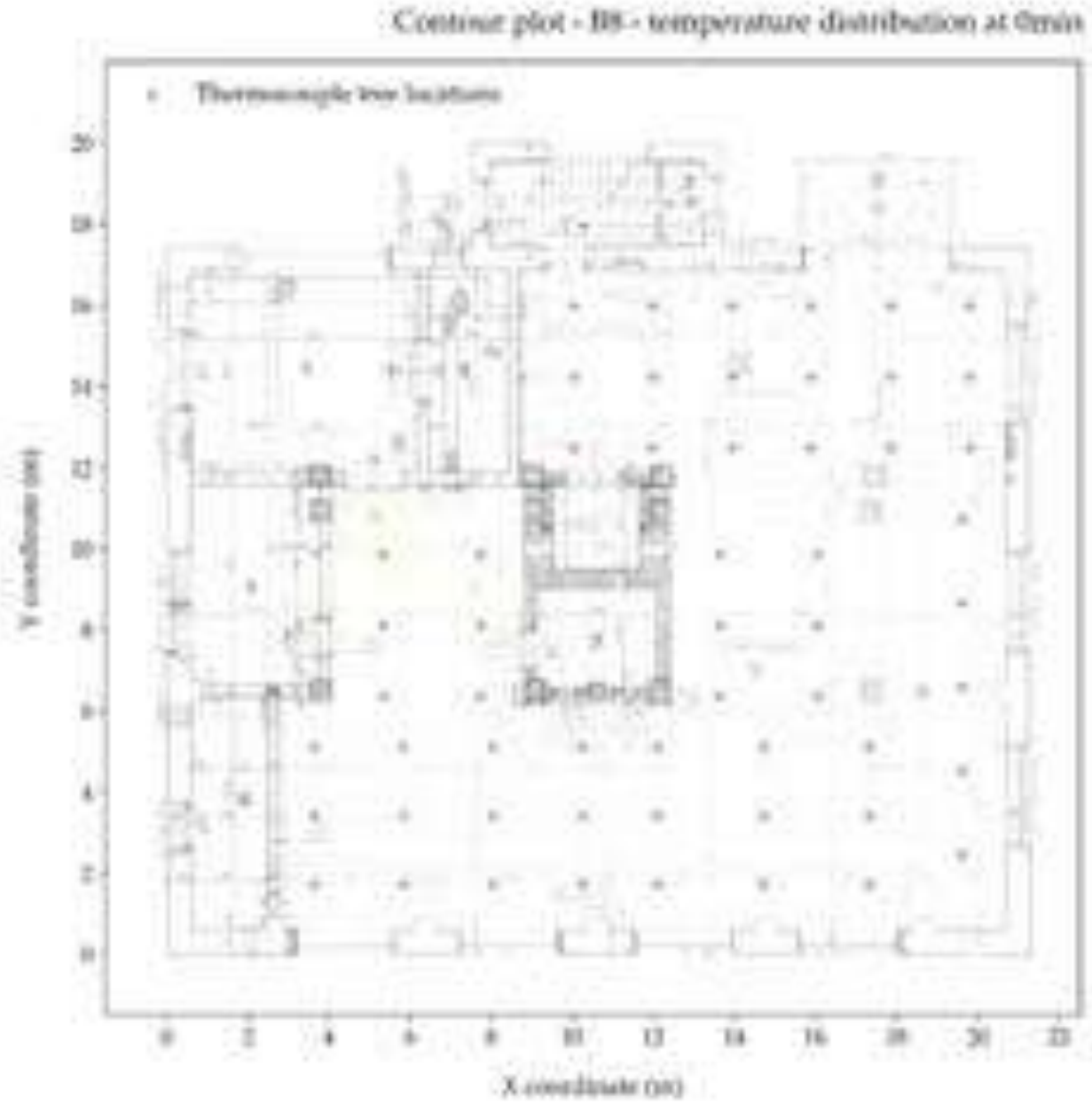
Test floor - front view (from drawings in 1958)

BRE Centre *for* Fire Safety Engineering

TEMPERATURE DISTRIBUTION AT B8

Temperature distribution B8 - Video

BRE Centre *for* Fire Safety Engineering

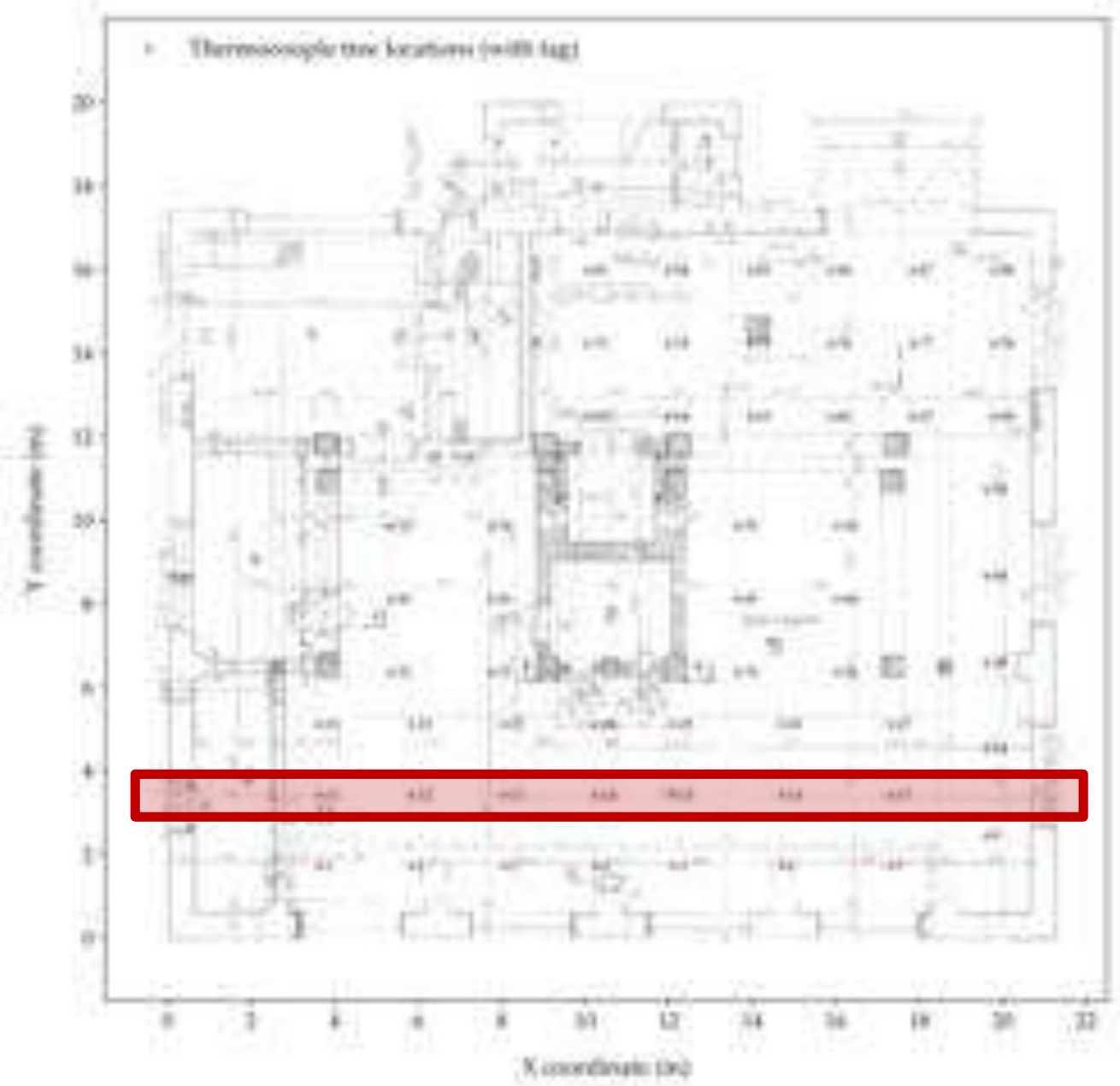


BRE Centre *for* Fire Safety Engineering

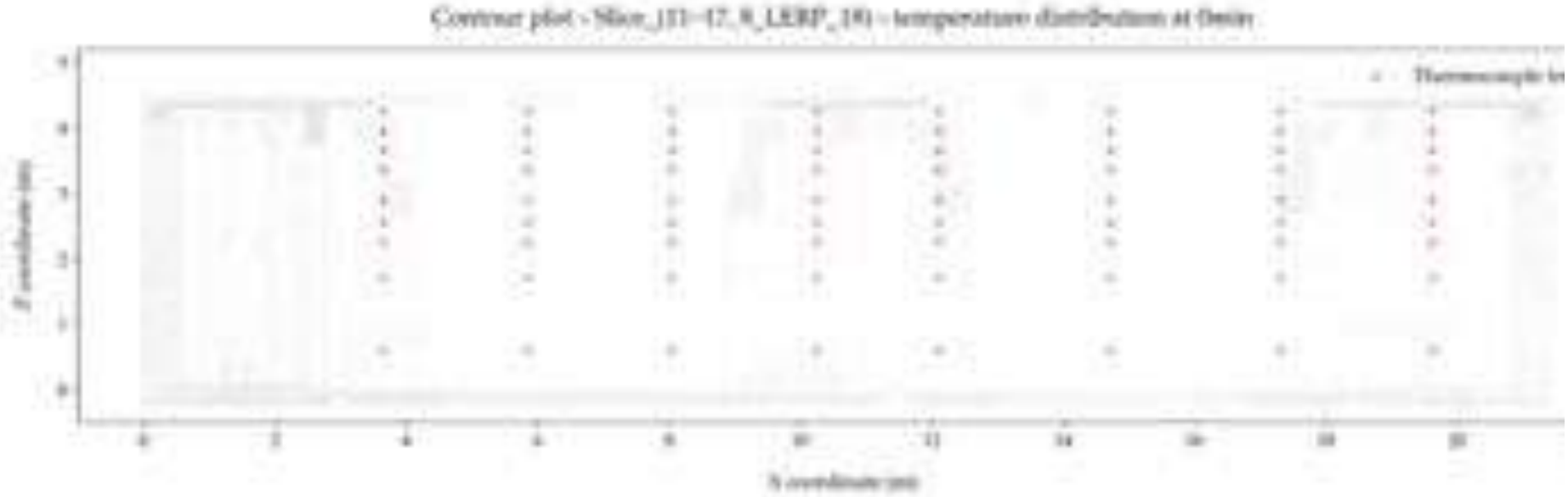
TEMPERATURE DISTRIBUTION IN ELEVATION SLICE 11~17 & 8_LERP_18, LERP (Linear interpolation)

Test building floor plan with TC tree locations

BRE Centre *for* Fire Safety Engineering



Temperature distribution in elevation slice 11~17 & 8_LERP_18, Video

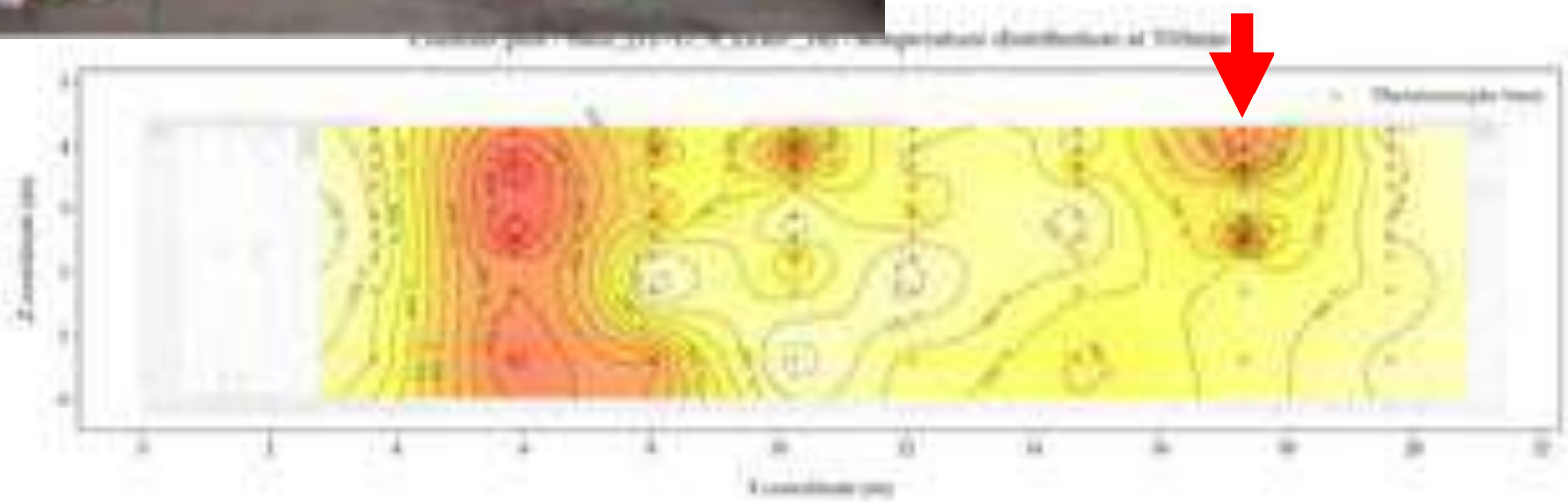


Linear interpolation

BRE Centre *for* Fire Safety Engineering

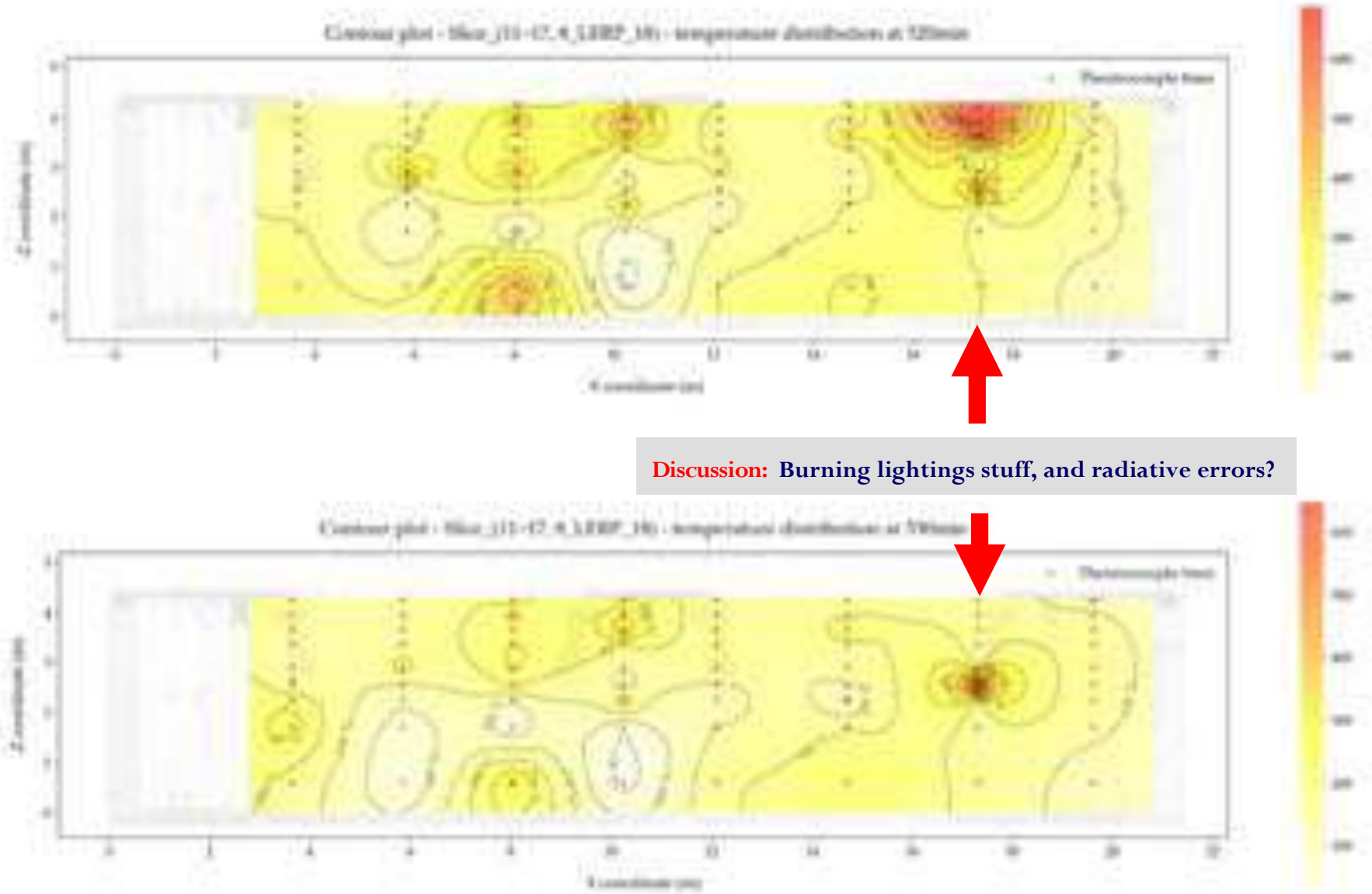
Temperature distribution in elevation slice 11~17 & 8_LERP_18

Discussion: Burning lightings stuff?



BRE Centre *for*

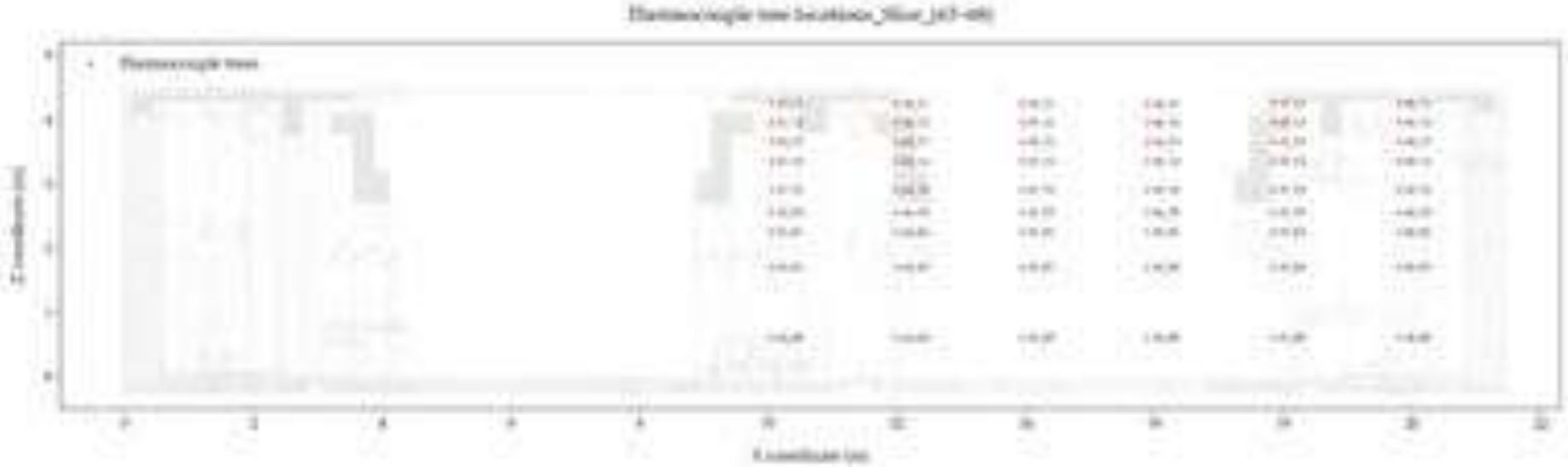
Temperature distribution in elevation slice 11~17 & 8_LERP_18



Discussion: Burning lightings stuff, and radiative errors?

BRE Centre *for* Fire Safety Engineering

Test building elevation with TC tree locations

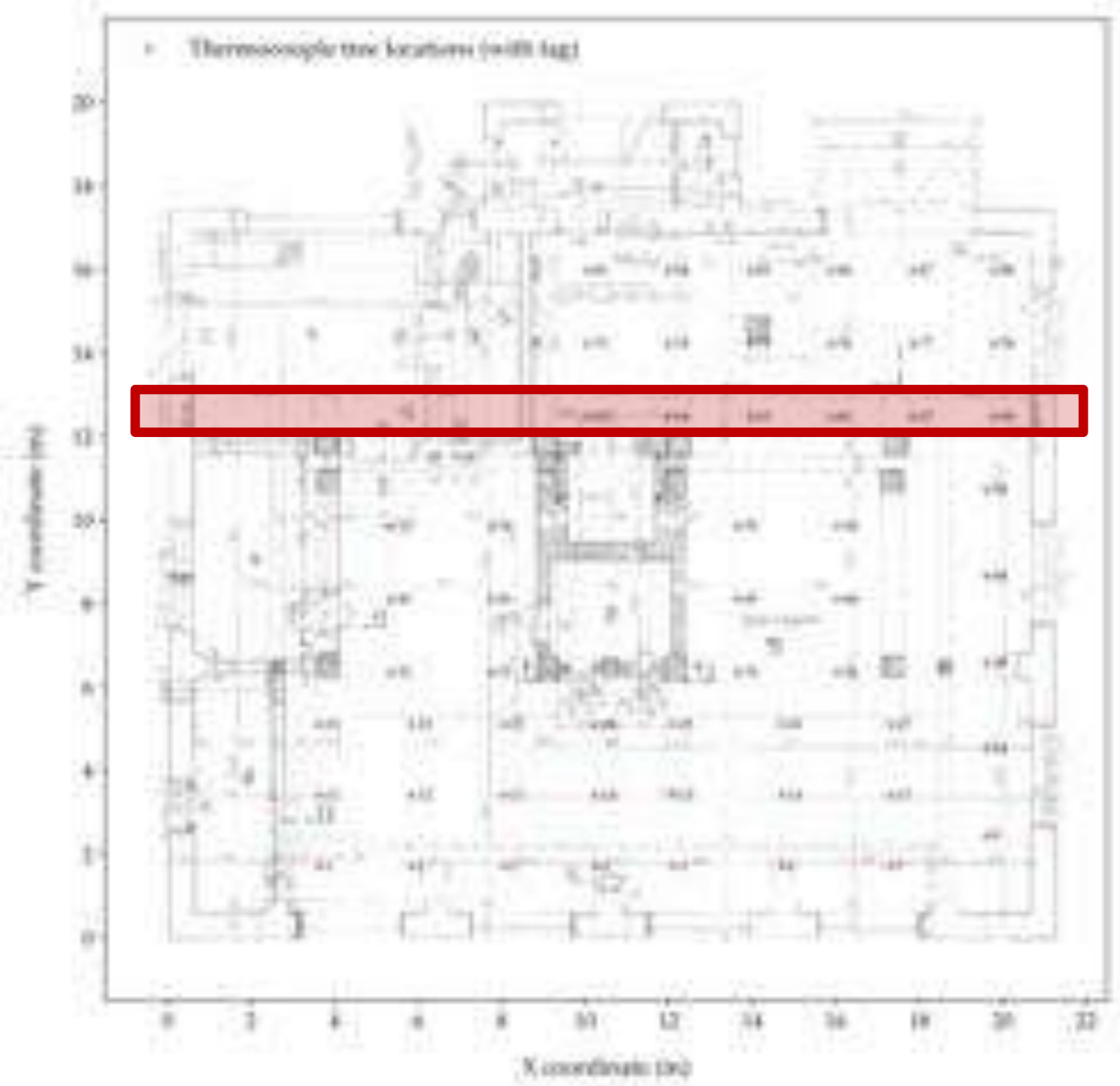


Test floor - front view (from drawings in 1958)

BRE Centre *for* Fire Safety Engineering

Test building floor plan with TC tree locations

BRE Centre *for* Fire Safety Engineering

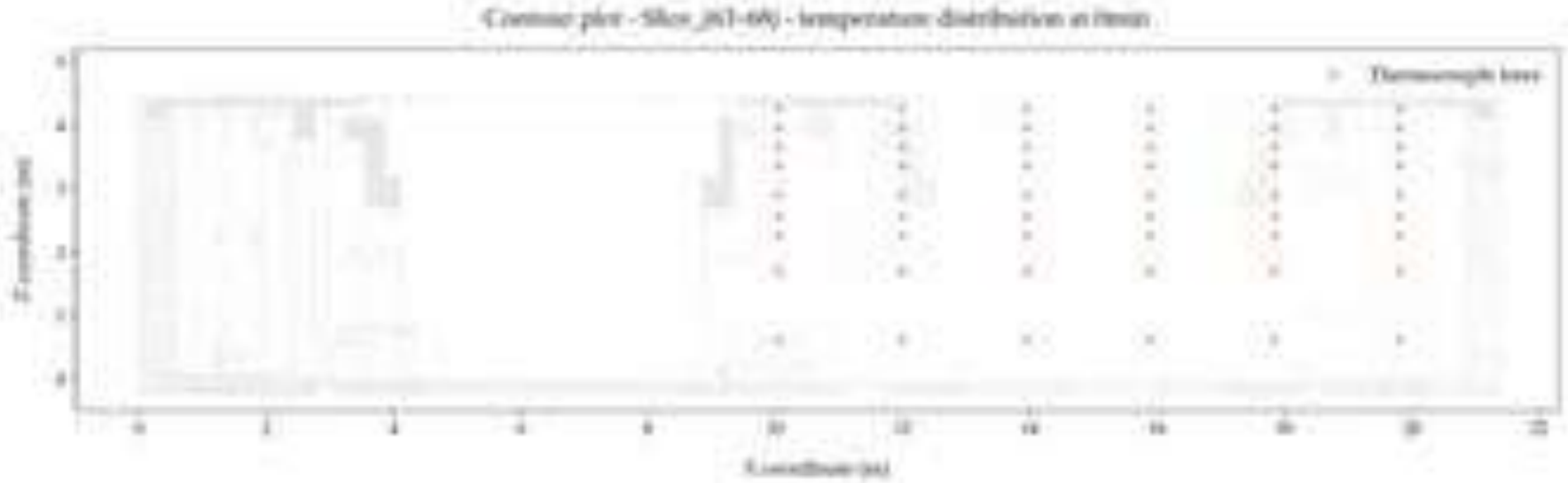


BRE Centre *for* Fire Safety Engineering

TEMPERATURE DISTRIBUTION IN ELEVATION SLICE 63~68

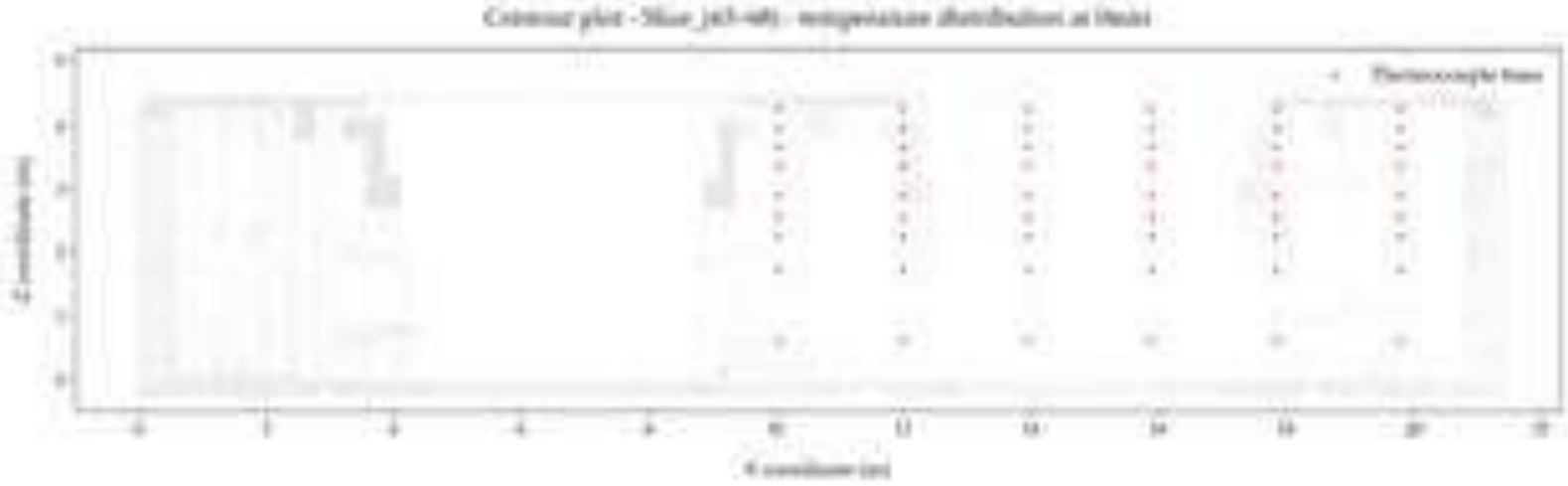
Temperature distribution in elevation slice 63~68, Video

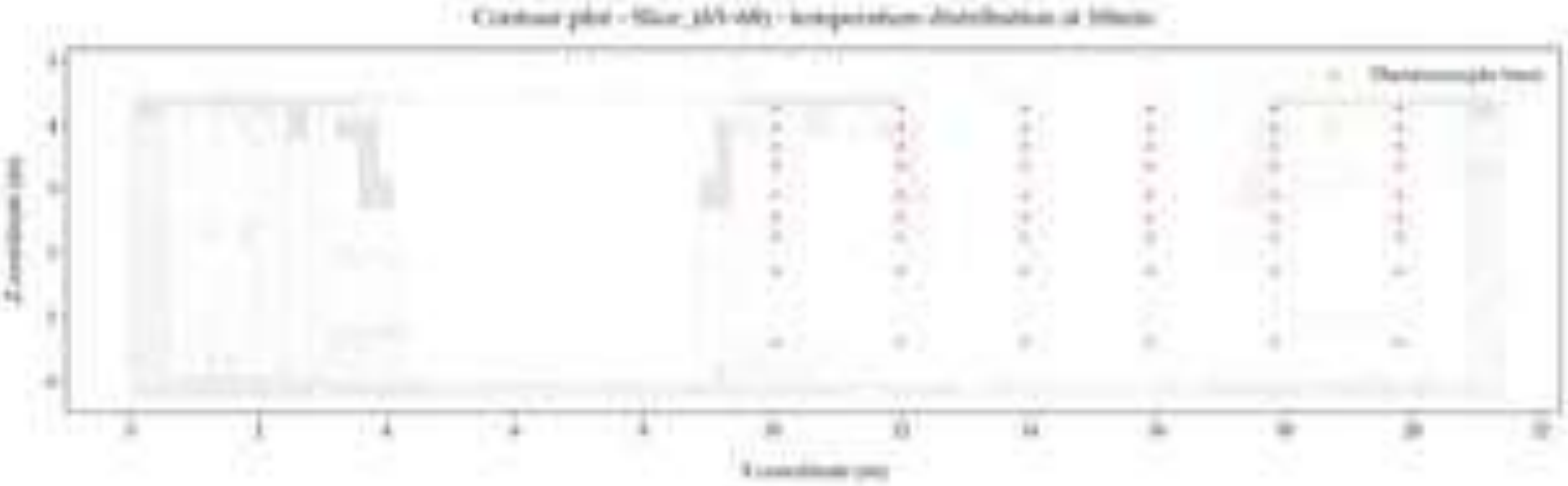
BRE Centre *for* Fire Safety Engineering



Linear interpolation

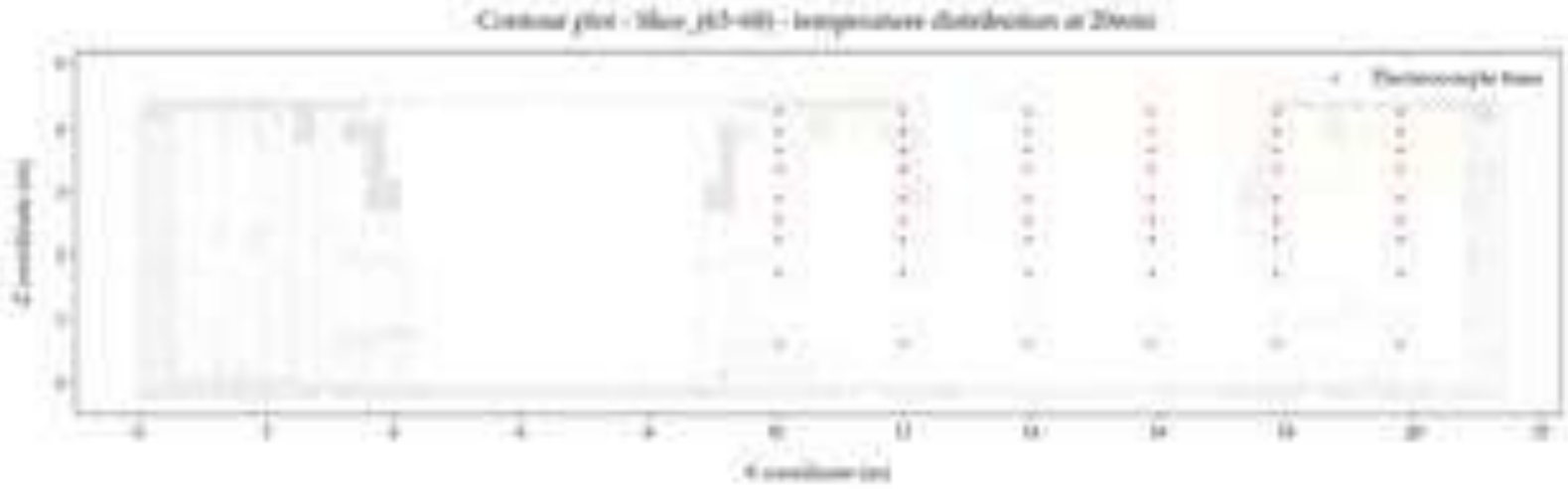
Temperature distribution in elevation slice 63~68

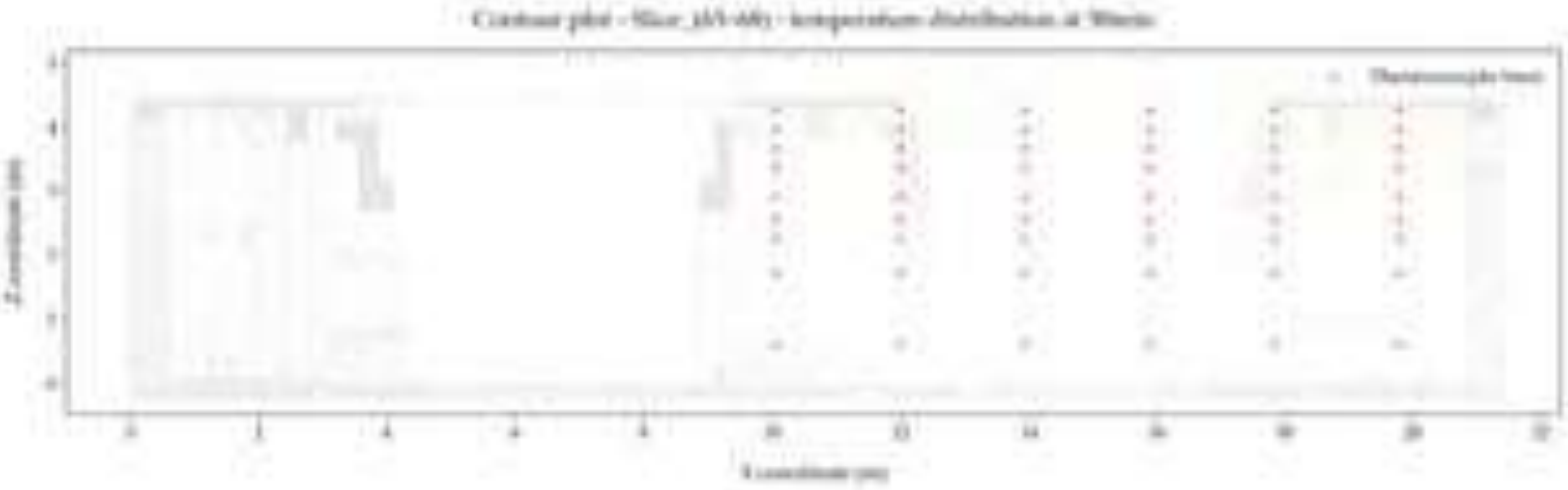




BRE Centre *for* Fire Safety Engineering

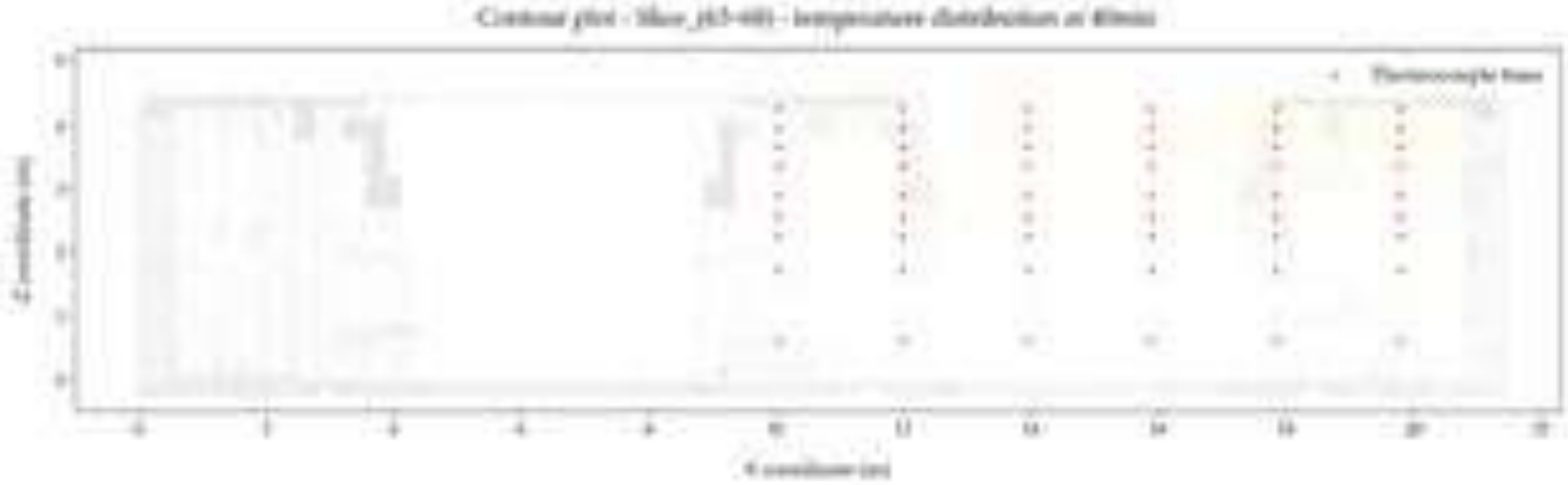
Temperature distribution in elevation slice 63~68

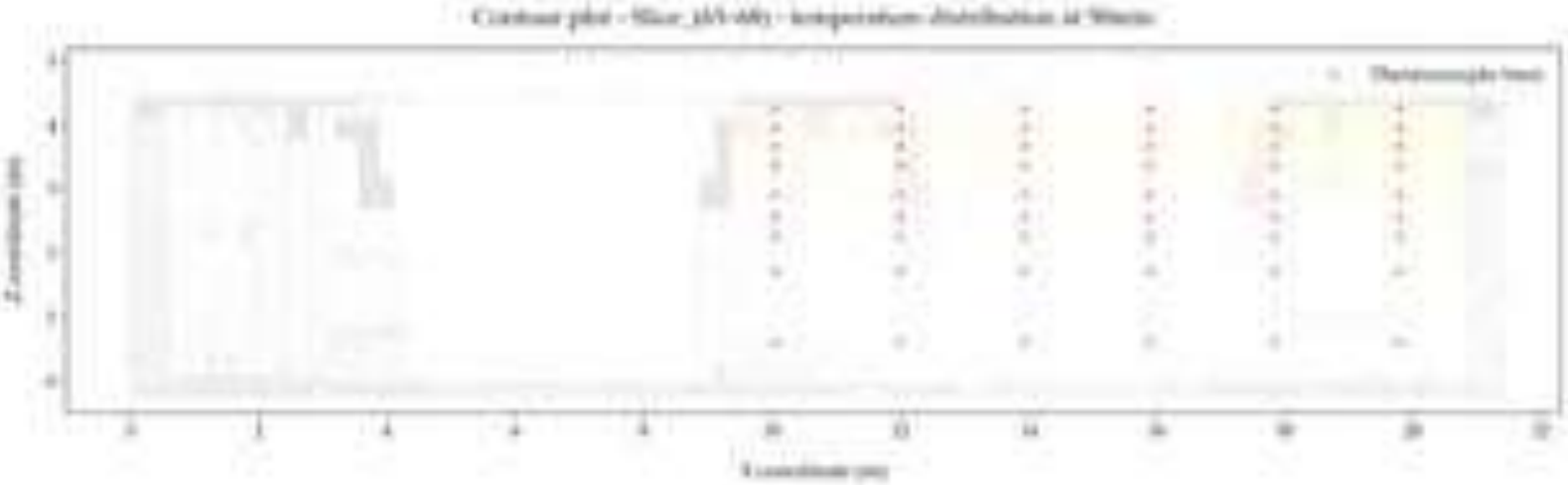




BRE Centre *for* Fire Safety Engineering

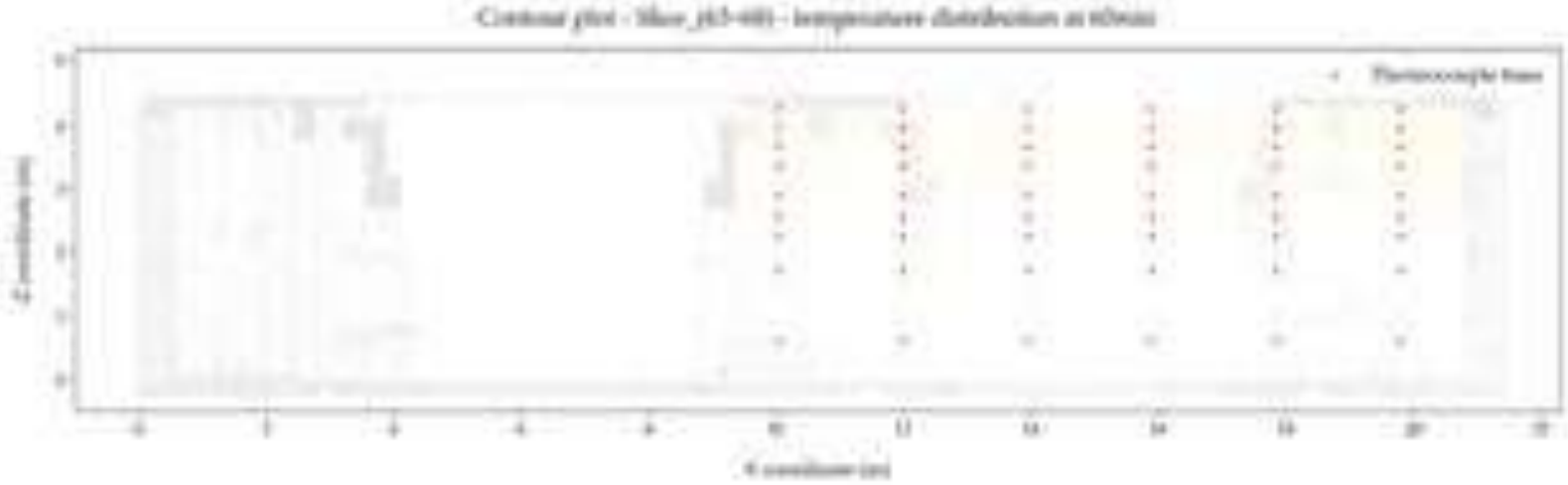
Temperature distribution in elevation slice 63~68

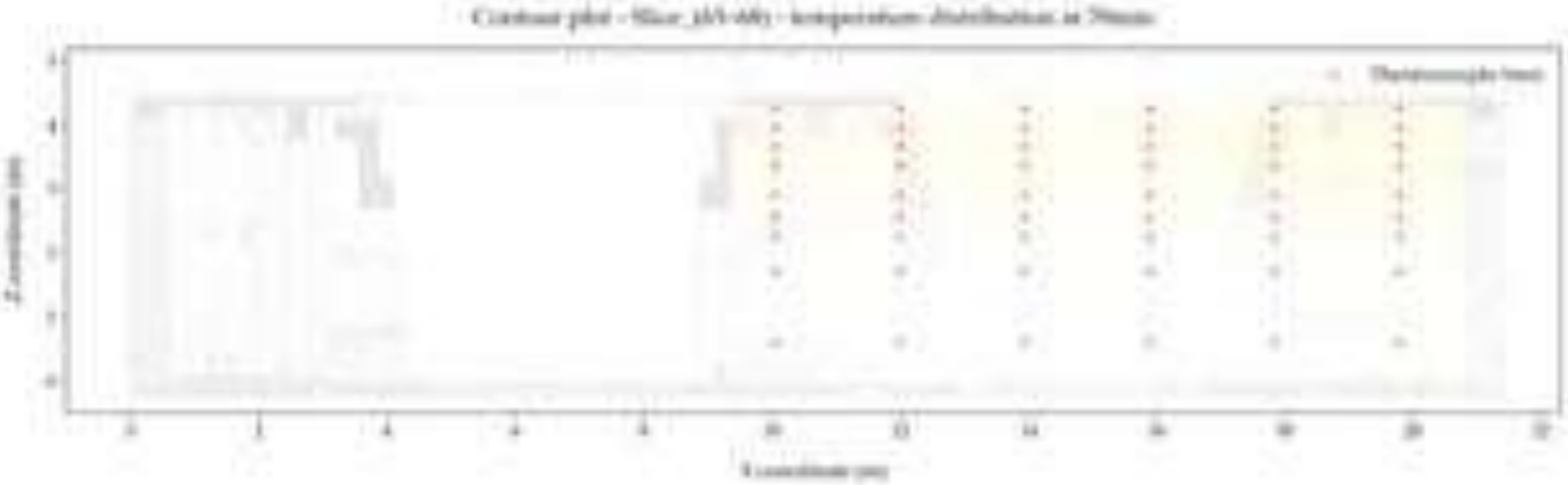




BRE Centre *for* Fire Safety Engineering

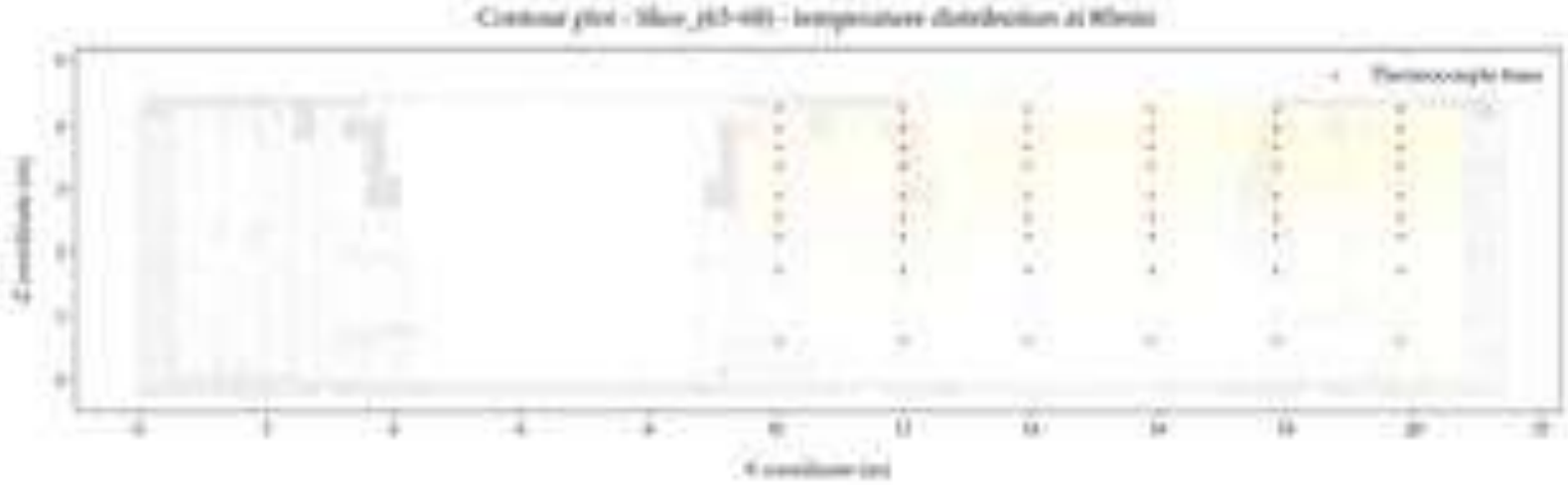
Temperature distribution in elevation slice 63~68

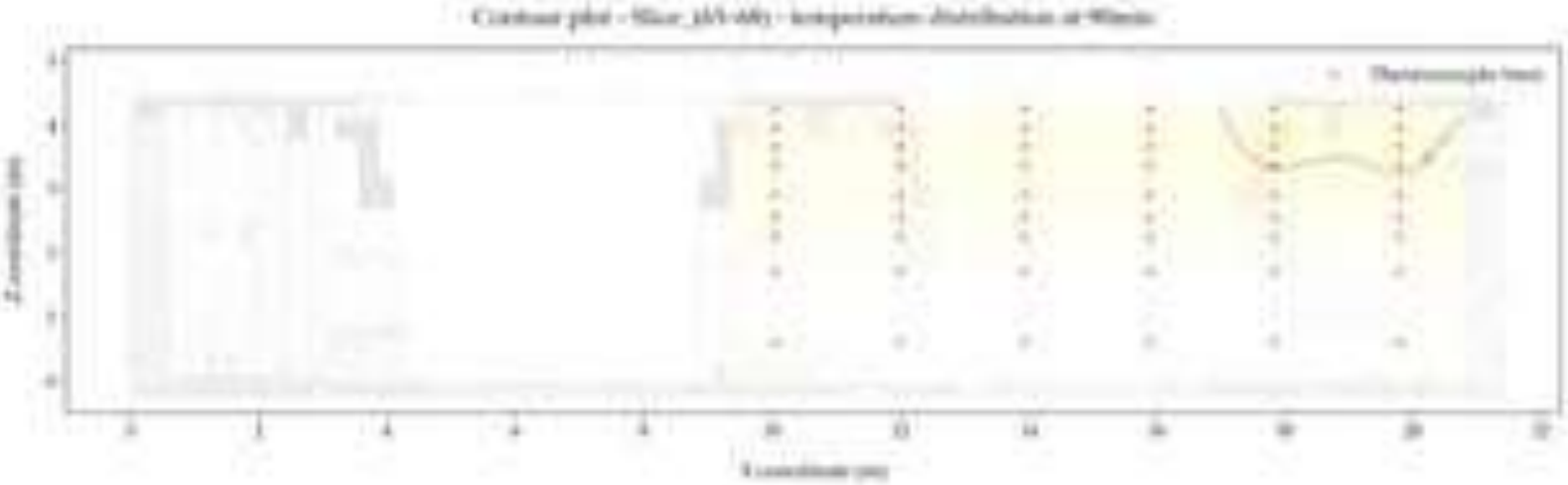




BRE Centre *for* Fire Safety Engineering

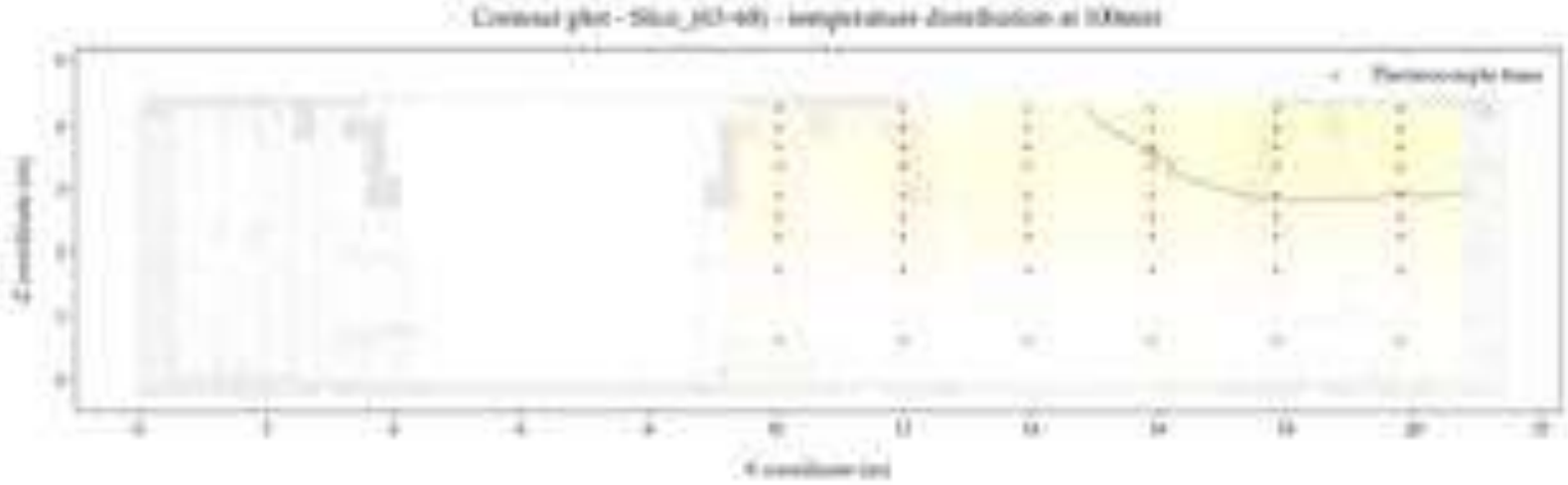
Temperature distribution in elevation slice 63~68

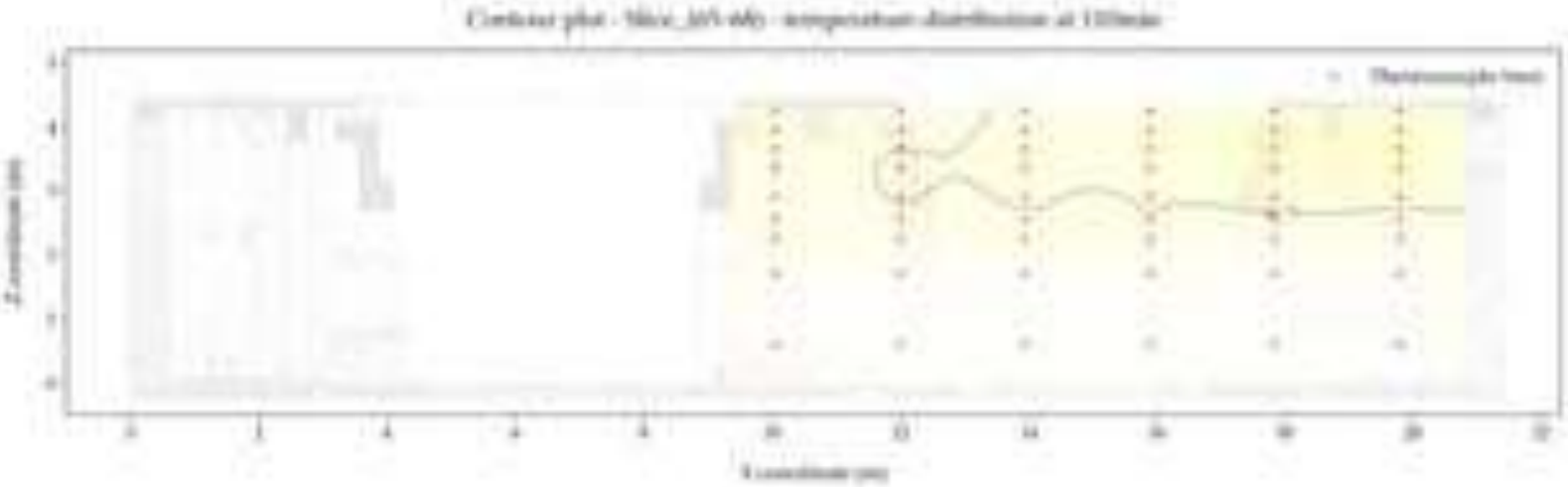




BRE Centre *for* Fire Safety Engineering

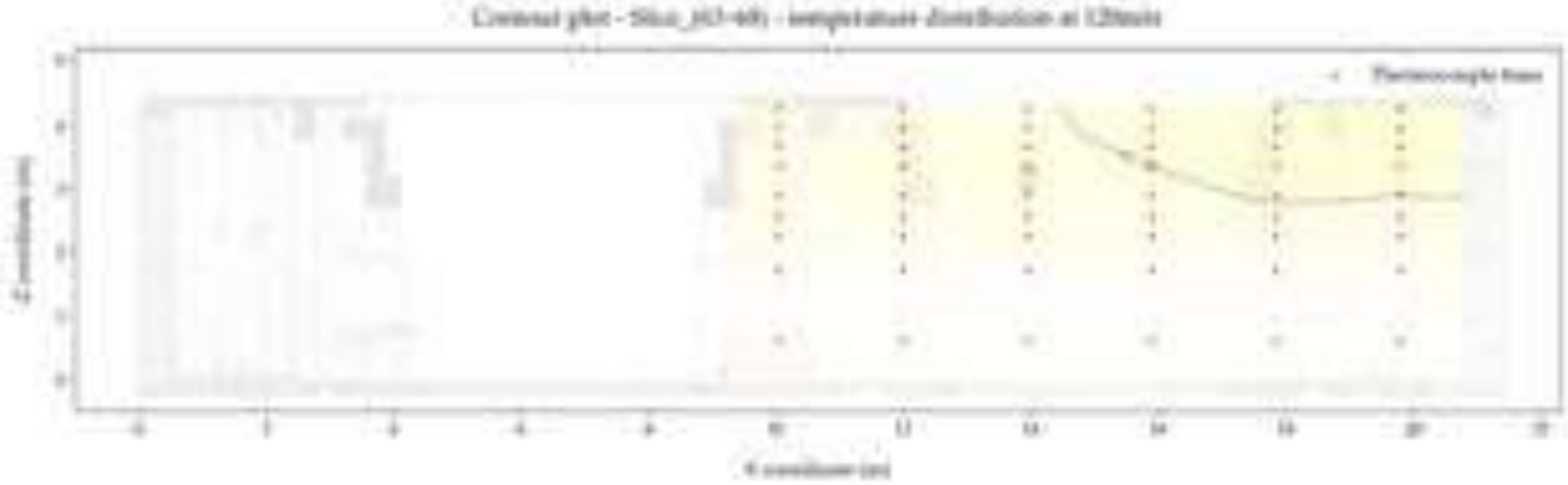
Temperature distribution in elevation slice 63~68

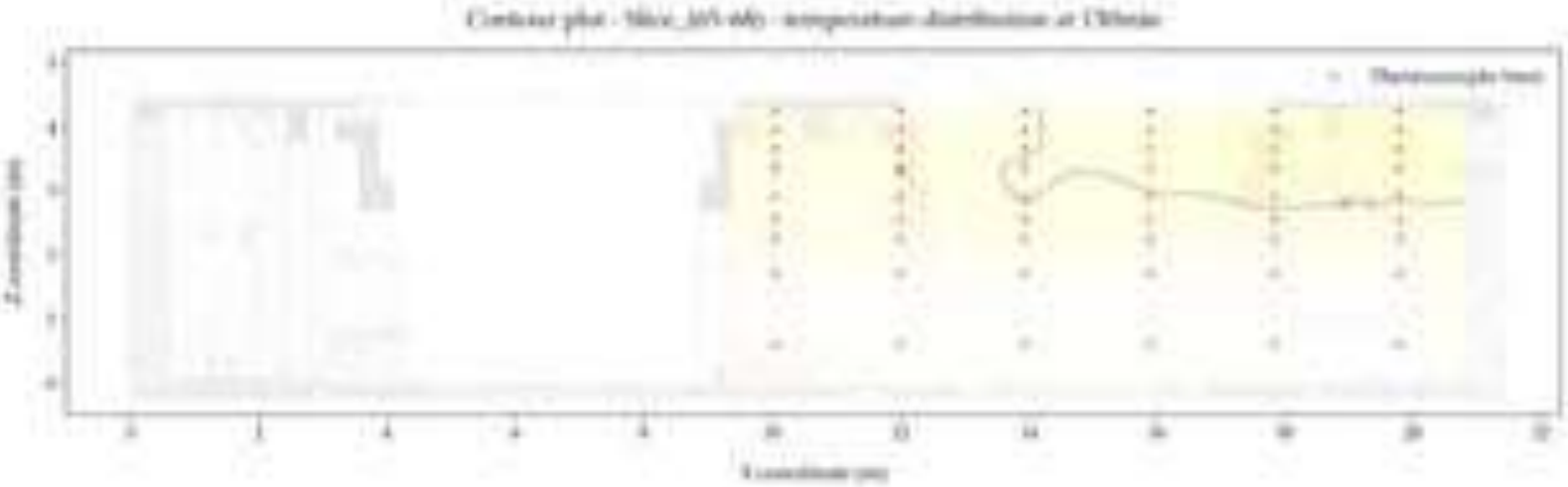




BRE Centre *for* Fire Safety Engineering

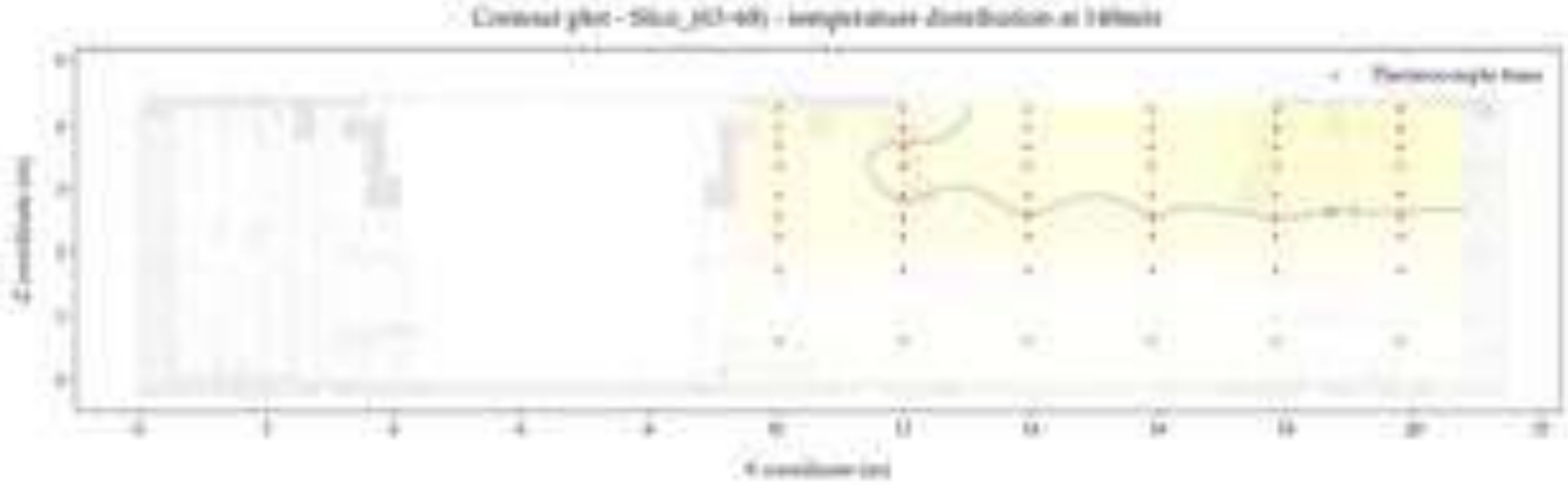
Temperature distribution in elevation slice 63~68

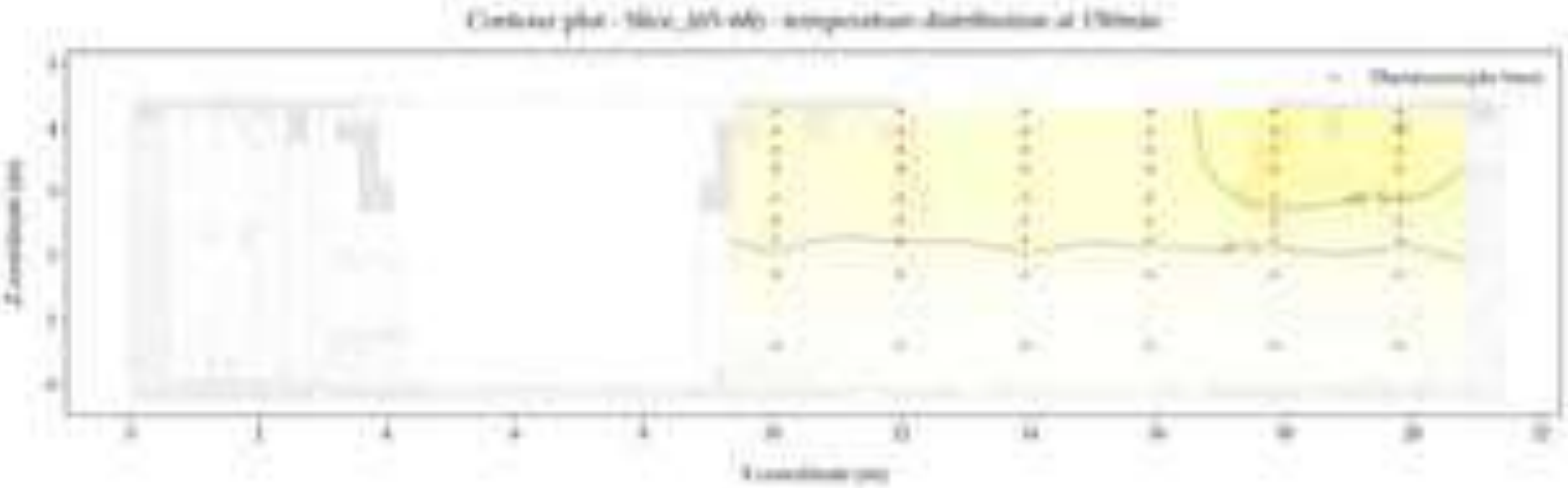




BRE Centre *for* Fire Safety Engineering

Temperature distribution in elevation slice 63~68

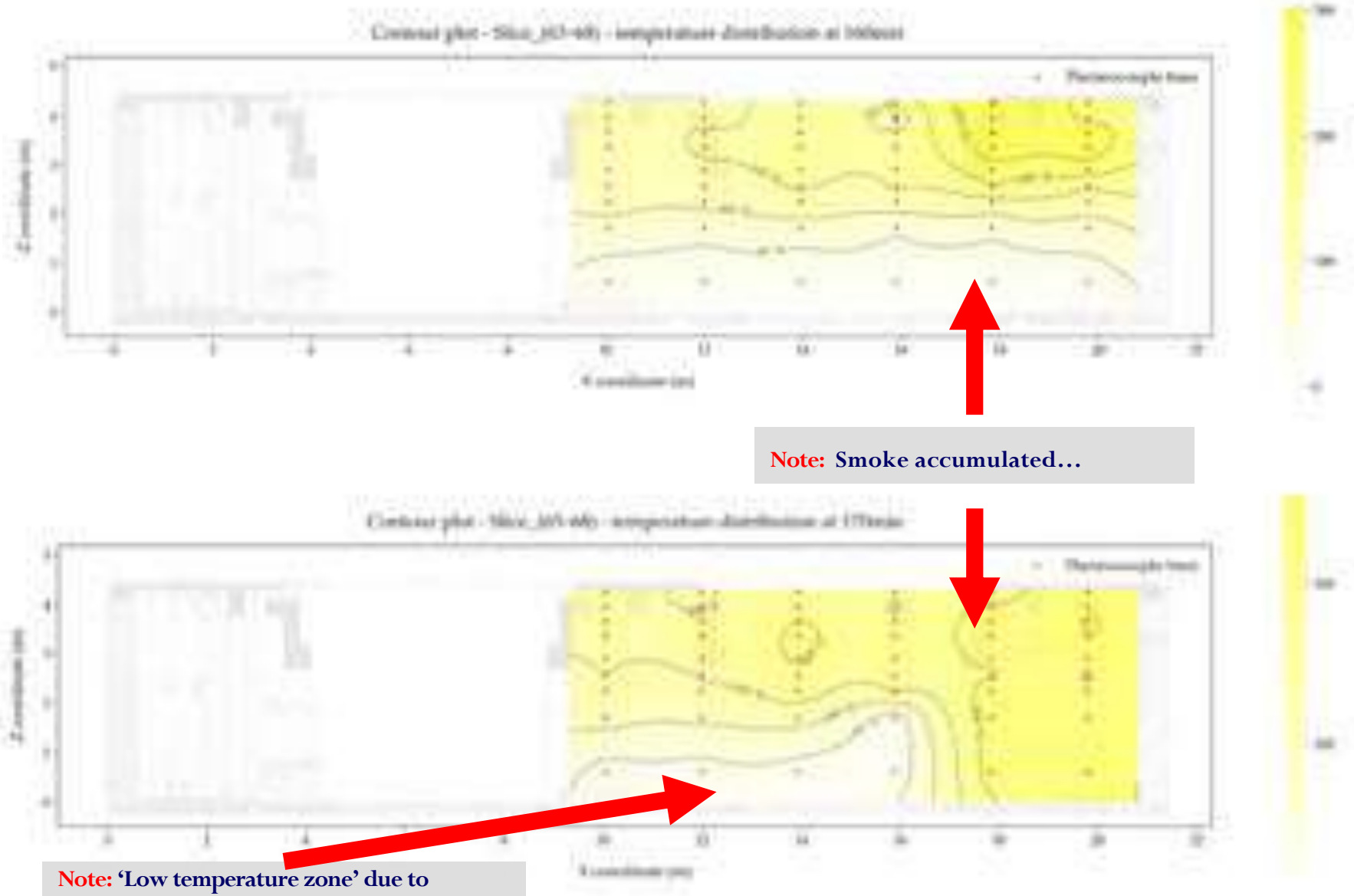




BRE Centre *for* Fire Safety Engineering

Temperature distribution in elevation slice 63~68

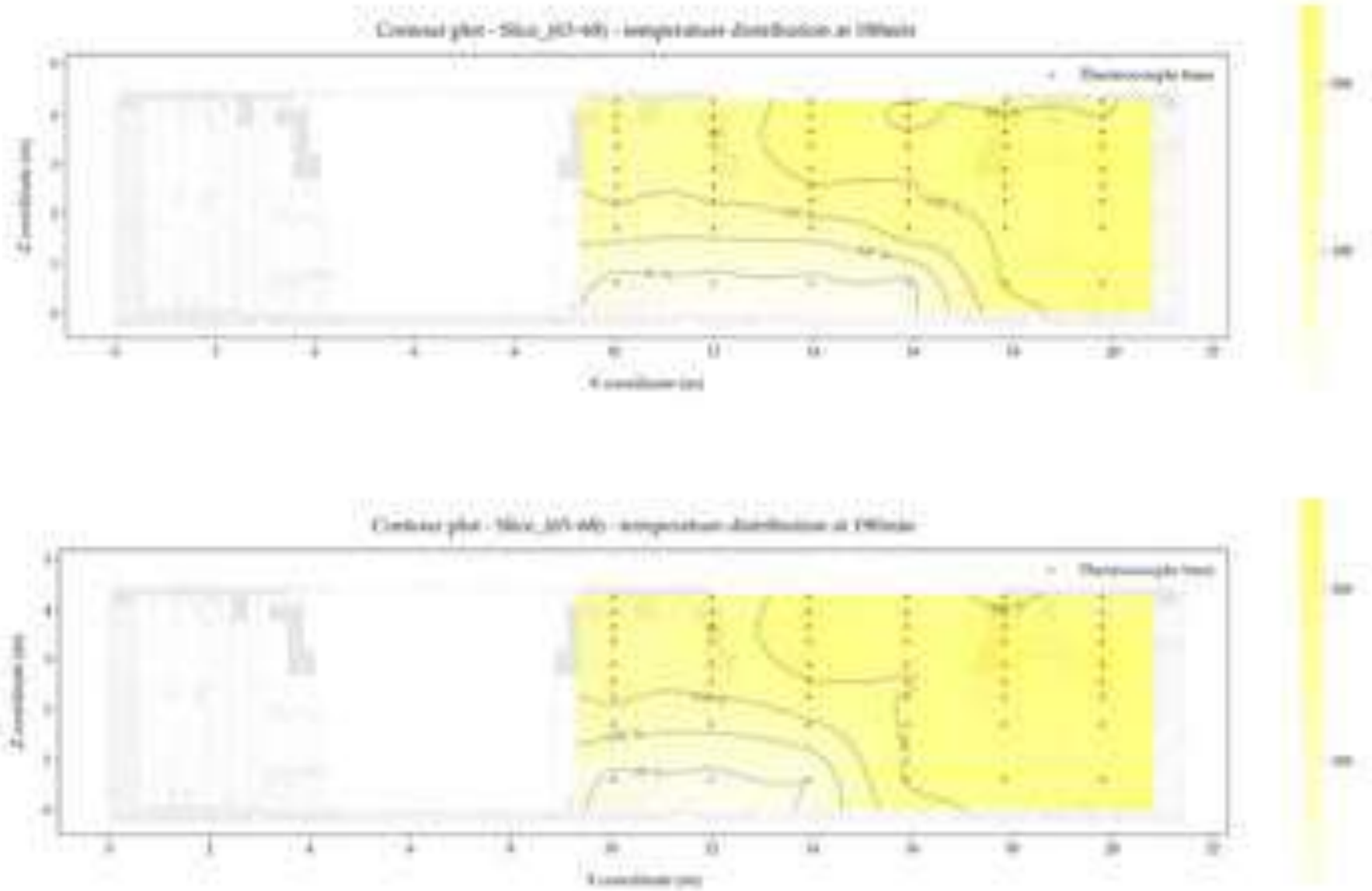
BRE Centre *for* Fire Safety Engineering



Note: Smoke accumulated…

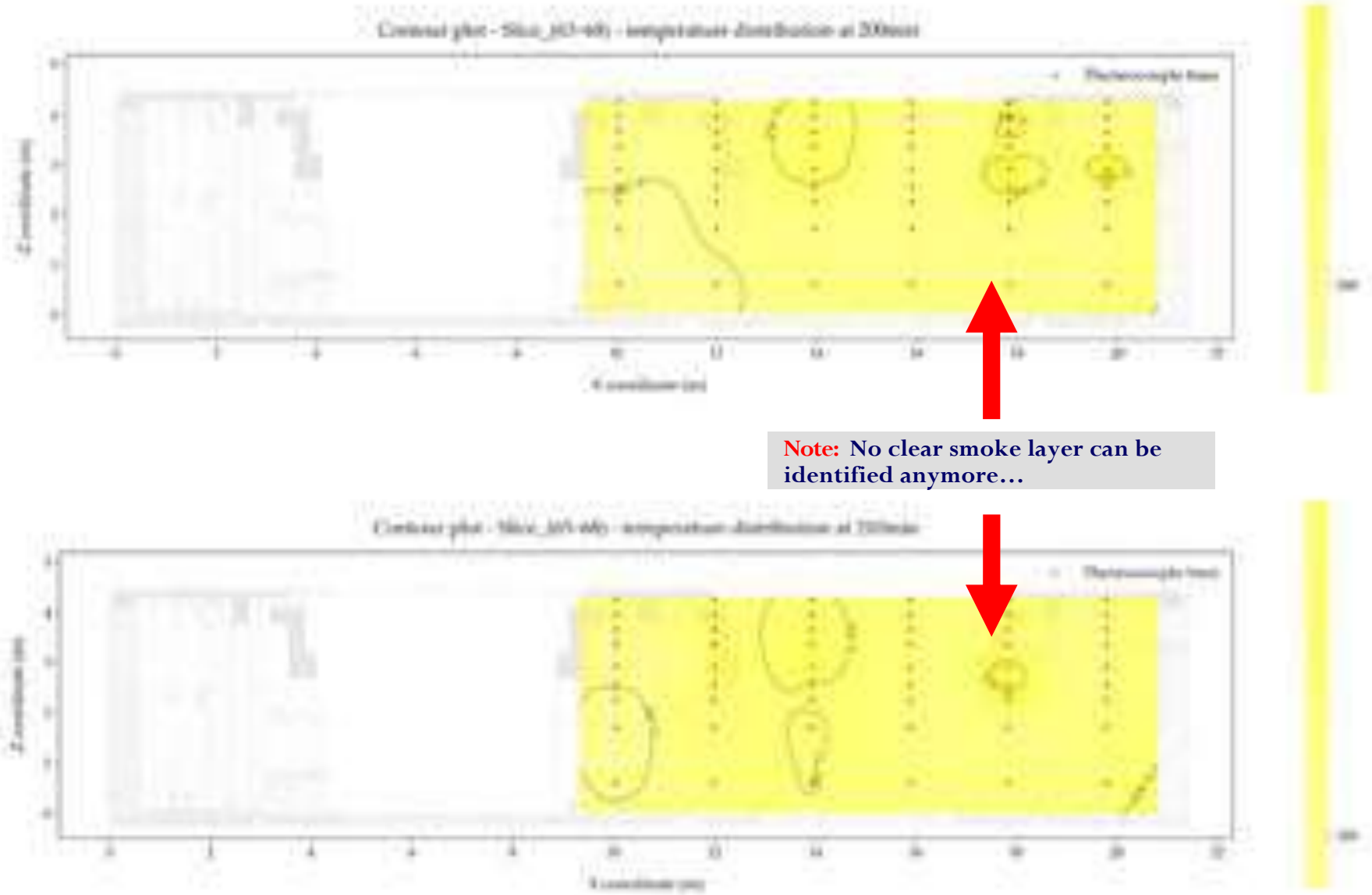
Note: 'Low temperature zone' due to 'viewing factor/shadow effects'

Temperature distribution in elevation slice 63~68



BRE Centre *for* Fire Safety Engineering

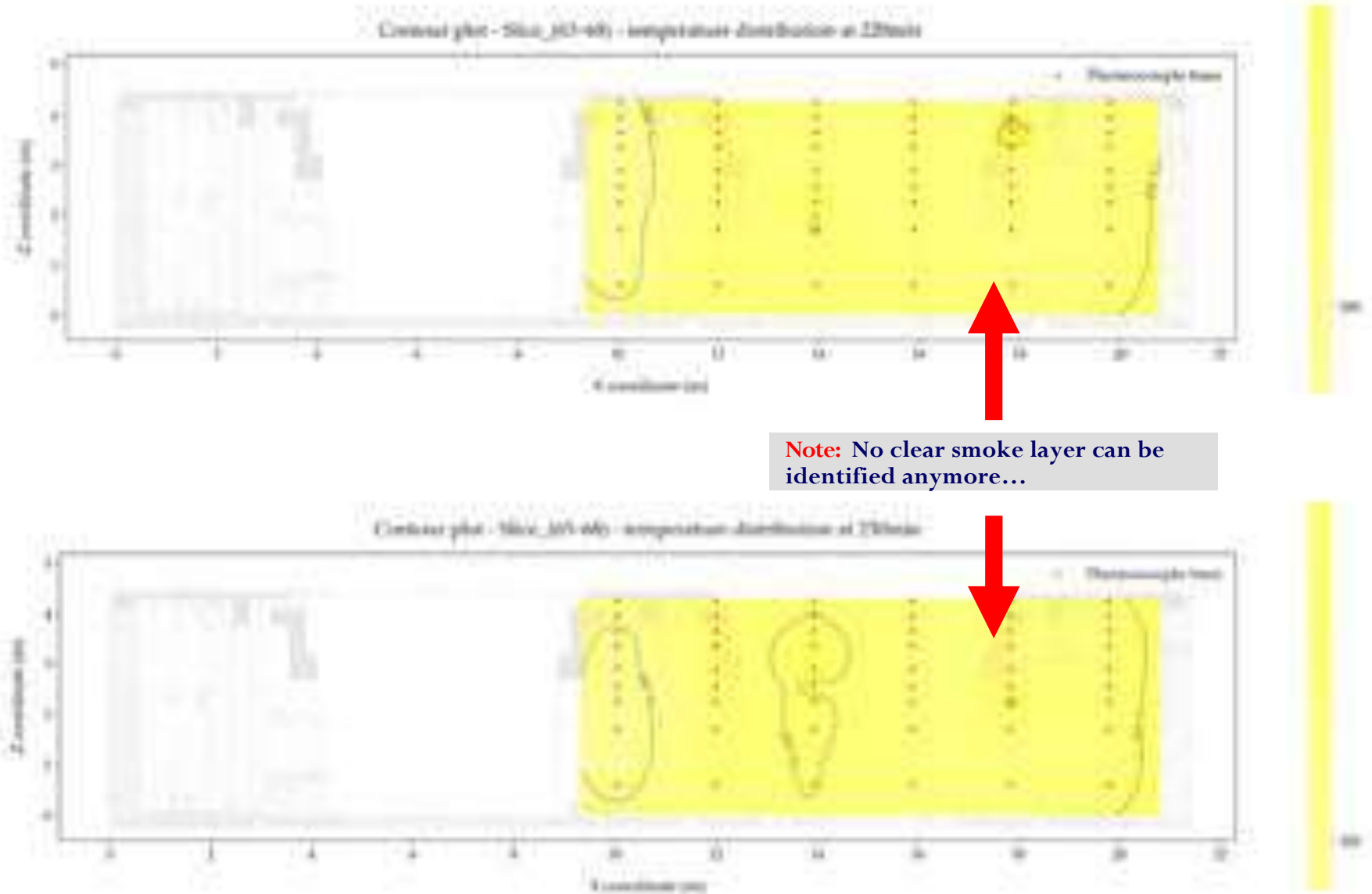
Temperature distribution in elevation slice 63~68



Note: No clear smoke layer can be identified anymore…

BRE Centre *for* Fire Safety Engineering

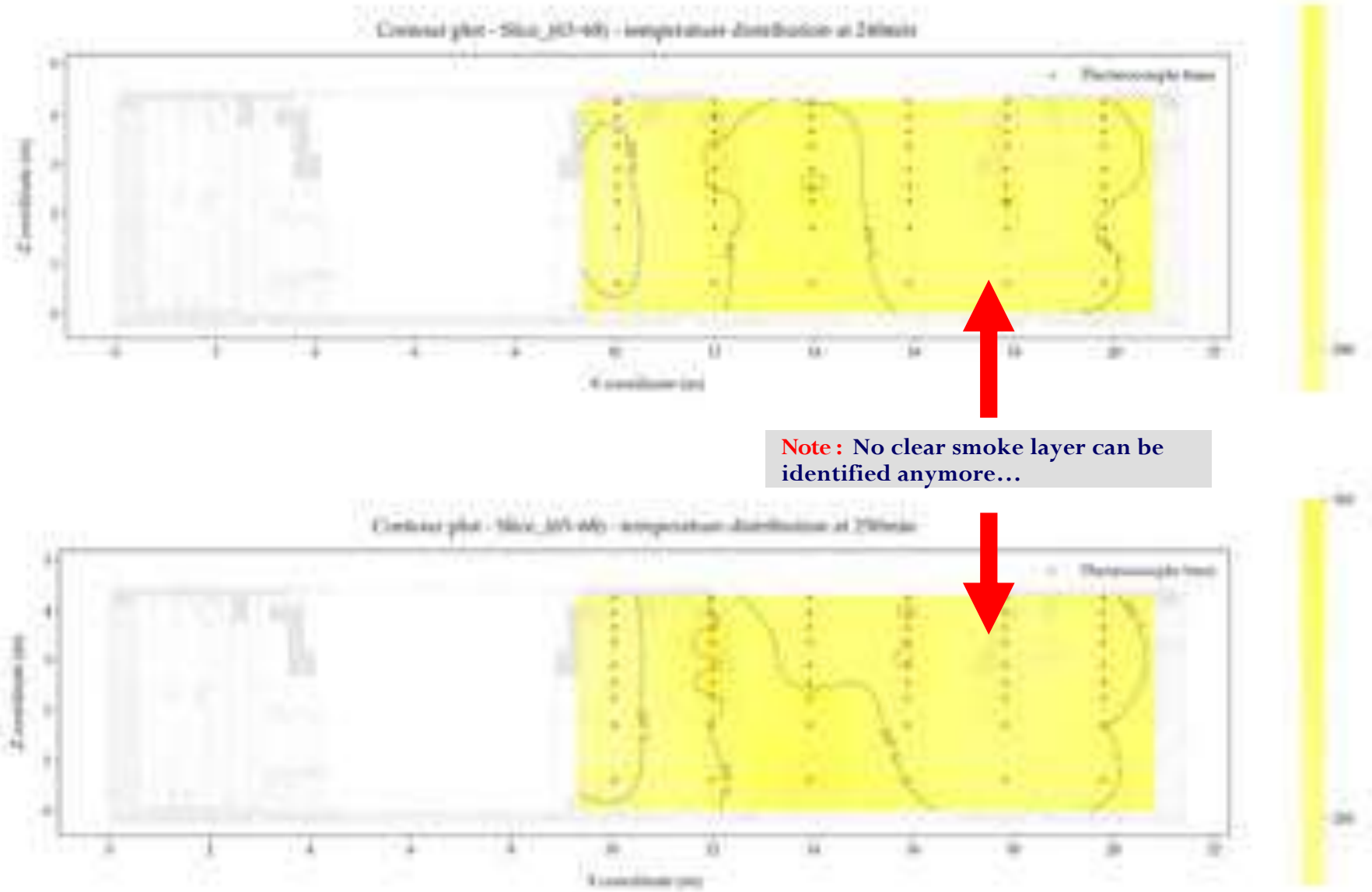
Temperature distribution in elevation slice 63~68



Note: No clear smoke layer can be identified anymore…

BRE Centre *for* Fire Safety Engineering

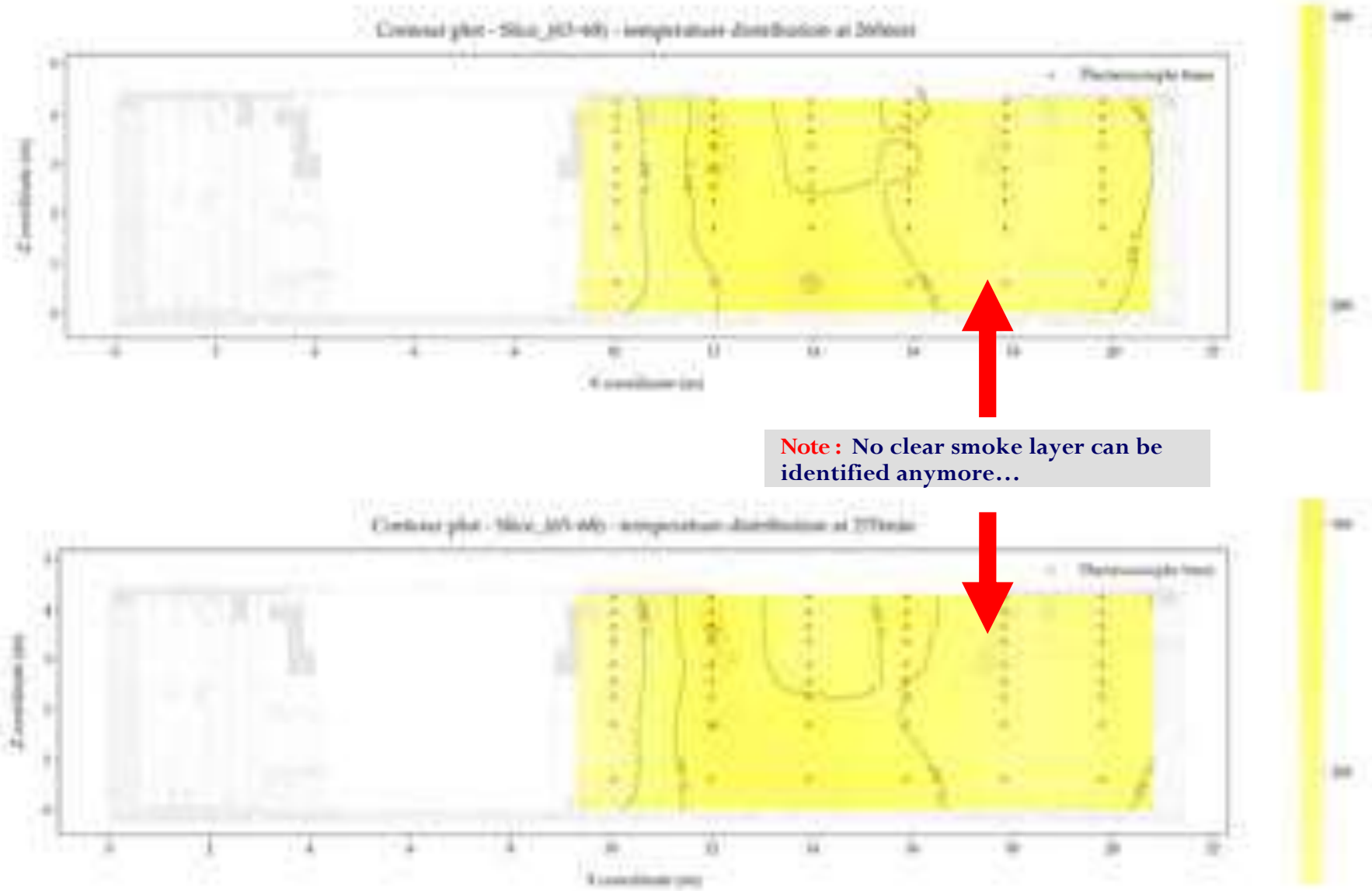
Temperature distribution in elevation slice 63~68



Note : No clear smoke layer can be identified anymore…

BRE Centre *for* Fire Safety Engineering

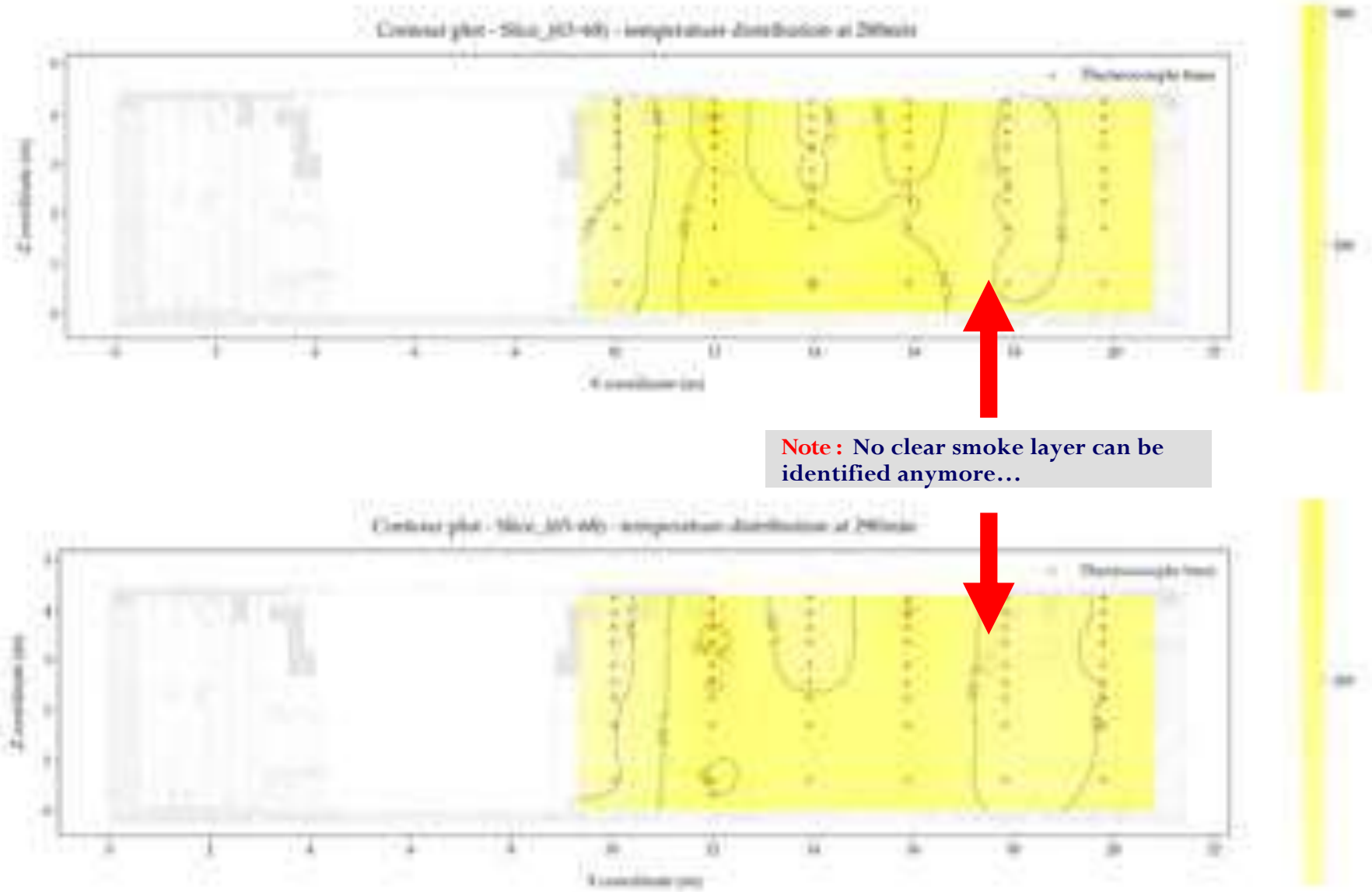
Temperature distribution in elevation slice 63~68



Note : No clear smoke layer can be identified anymore…

BRE Centre *for* Fire Safety Engineering

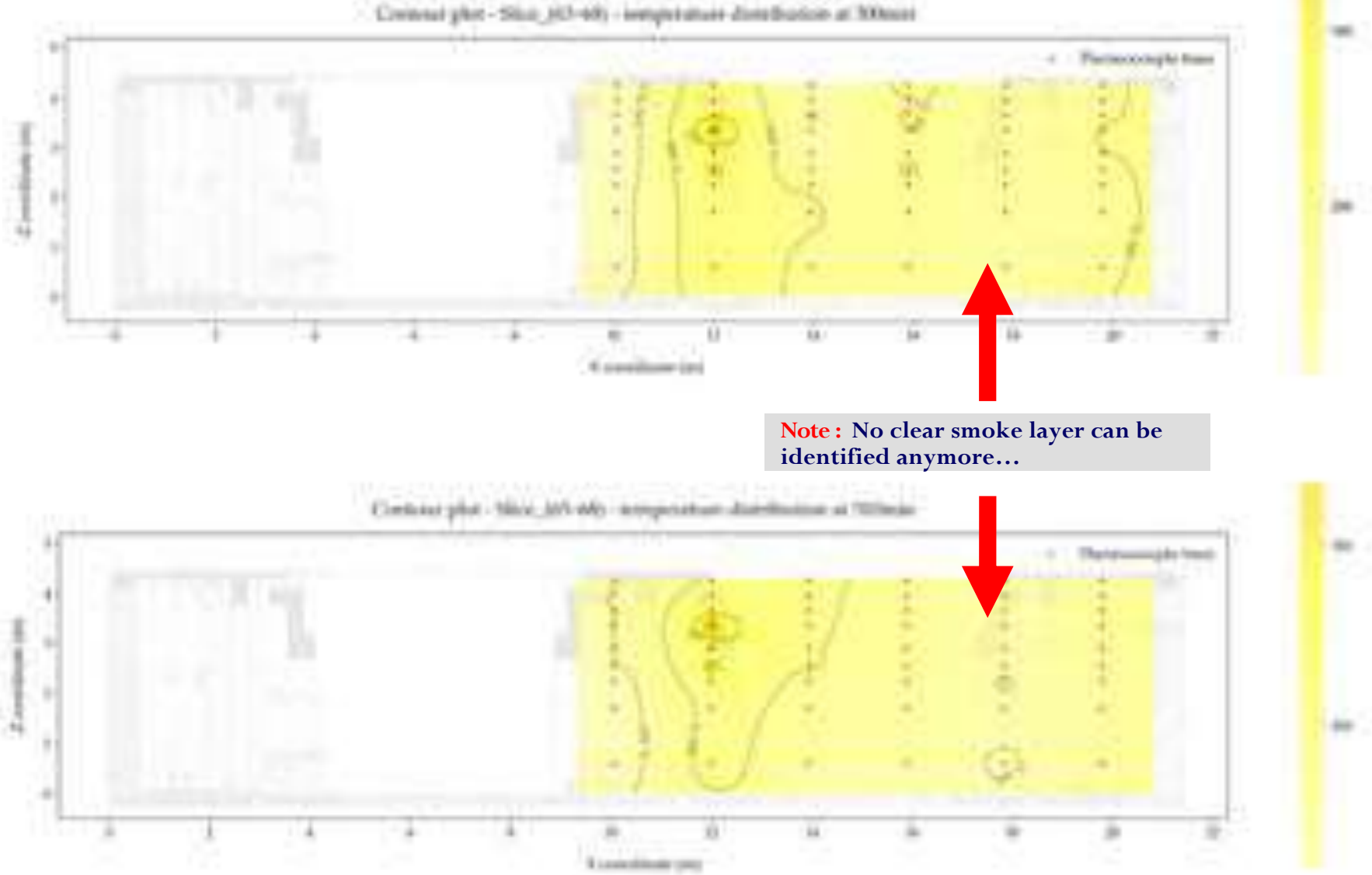
Temperature distribution in elevation slice 63~68



Note : No clear smoke layer can be identified anymore…

BRE Centre *for* Fire Safety Engineering

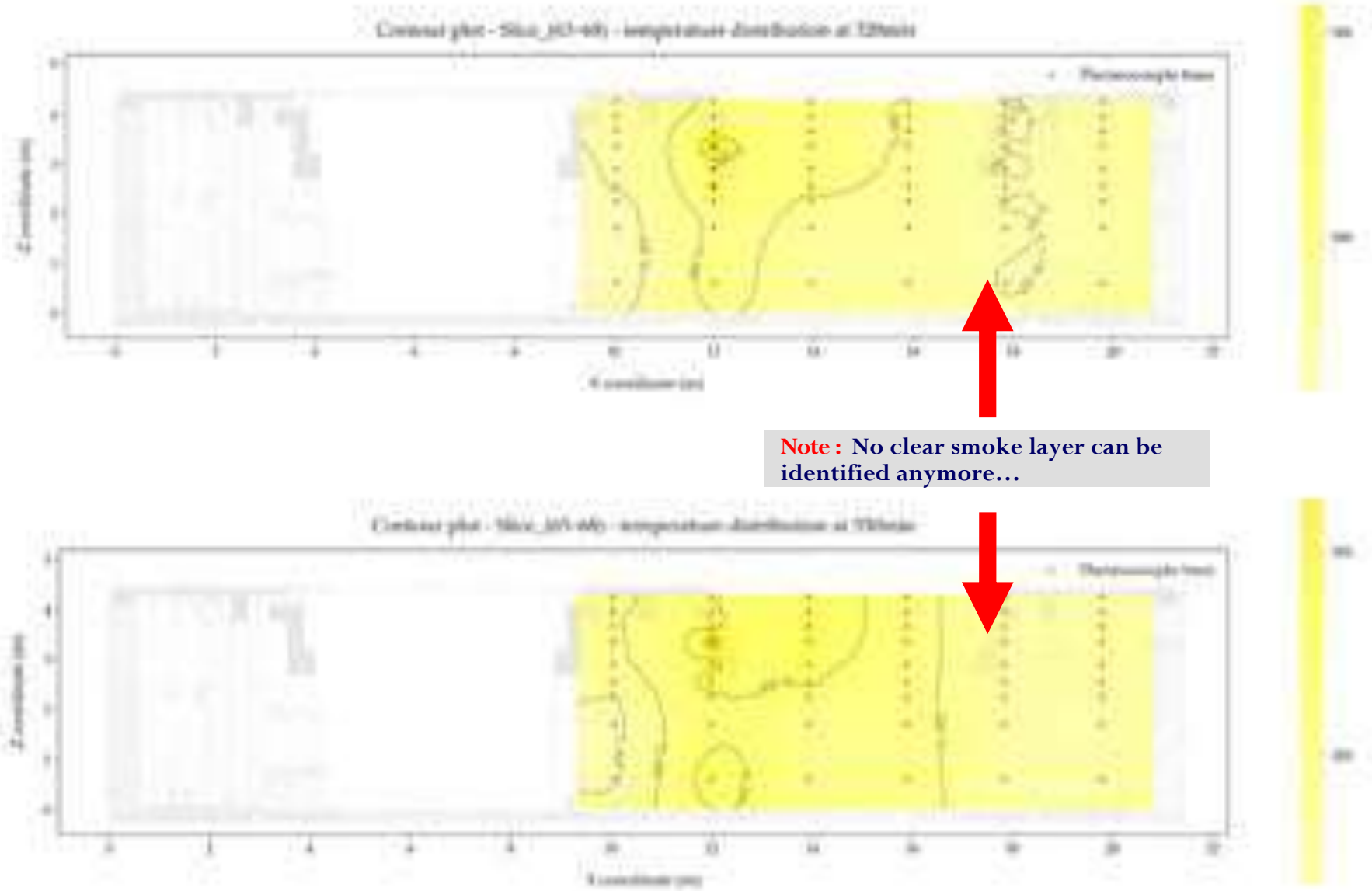
Temperature distribution in elevation slice 63~68



Note : No clear smoke layer can be identified anymore…

BRE Centre *for* Fire Safety Engineering

Temperature distribution in elevation slice 63~68



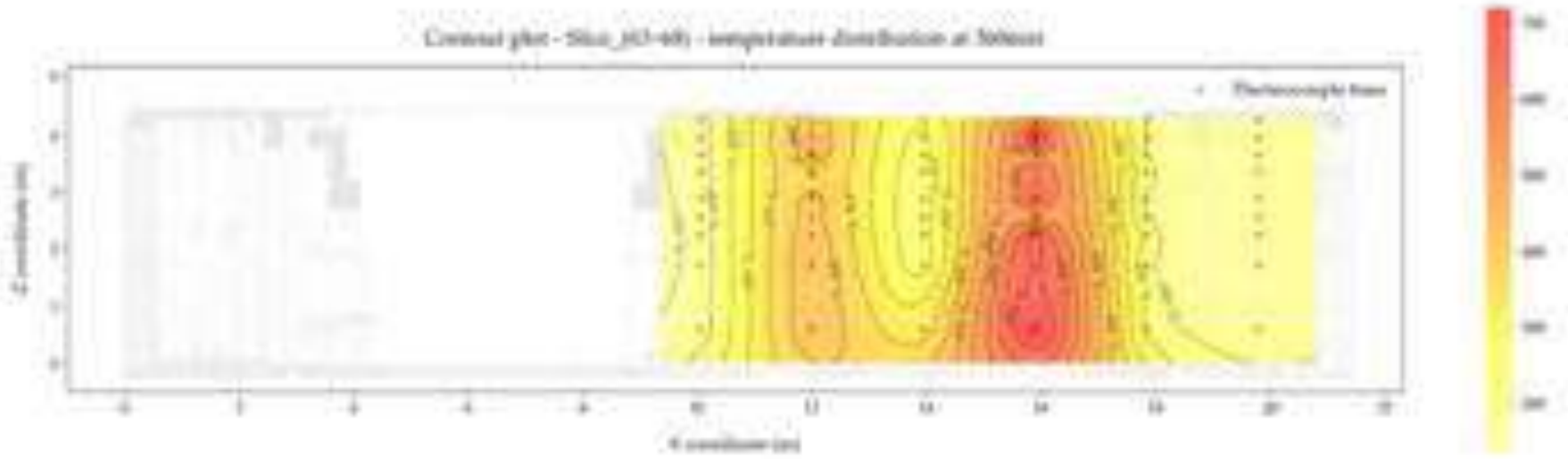
Note : No clear smoke layer can be identified anymore…

BRE Centre *for* Fire Safety Engineering

Temperature distribution in elevation slice 63~68

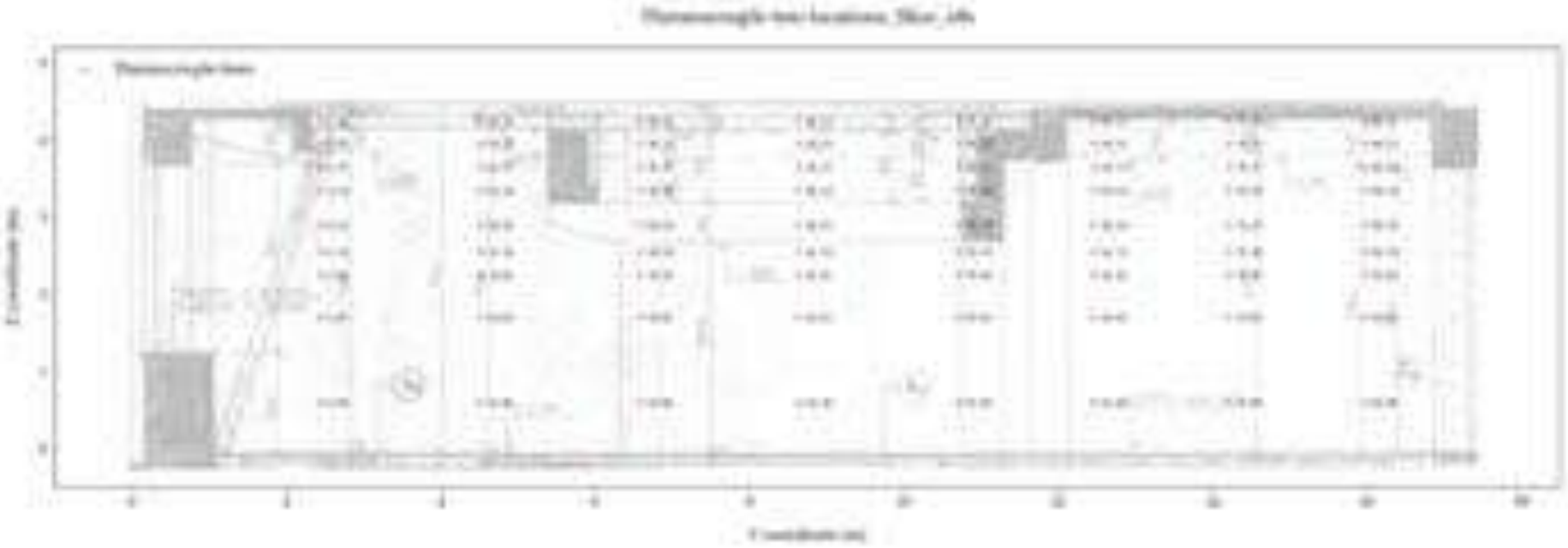
Discussion: fire plume approaching

Temperature distribution in elevation slice 63~68



BRE Centre *for* Fire Safety Engineering

Test building elevation with TC tree locations



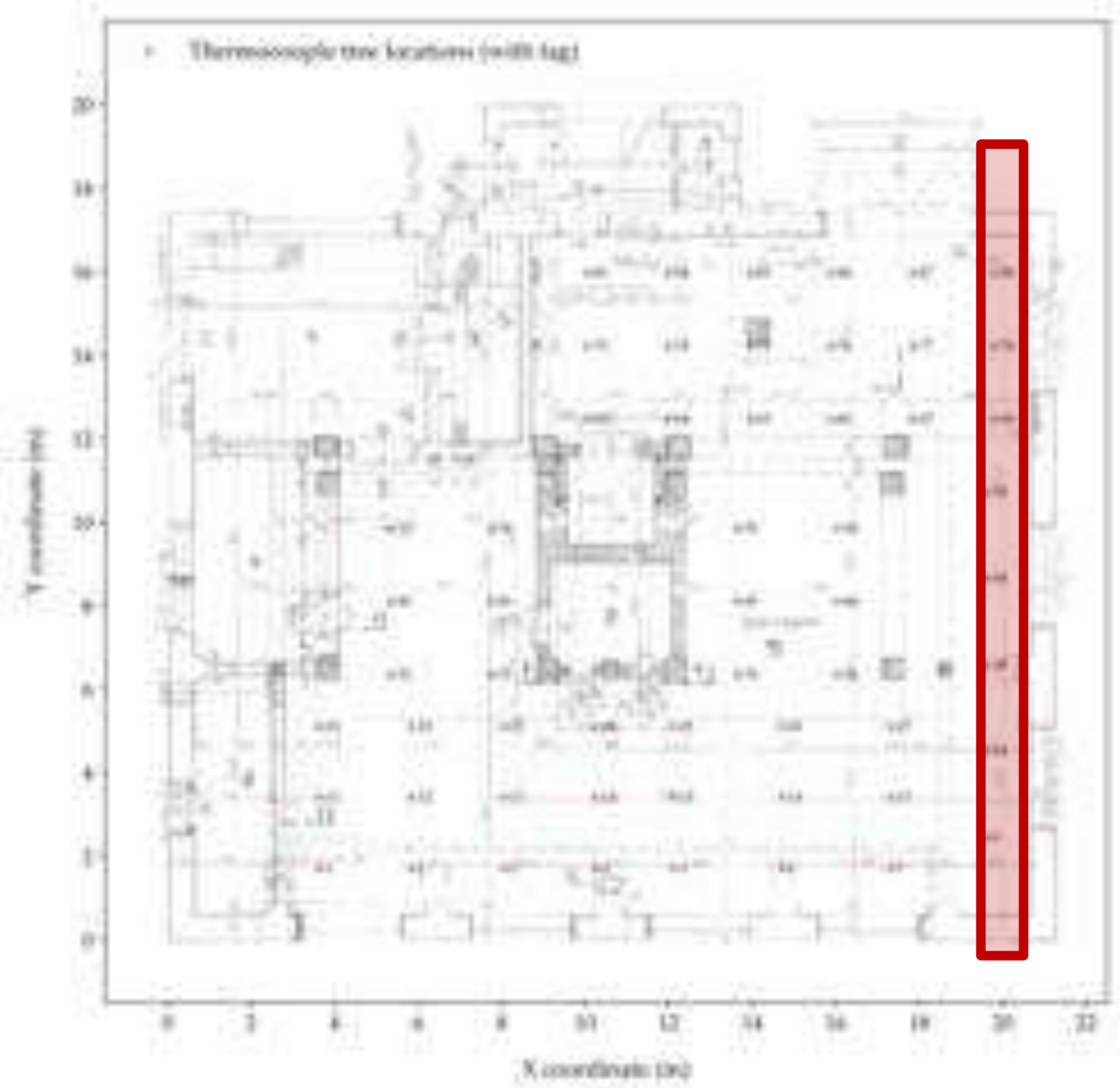
Test floor - front view (from drawings in 1958)

BRE Centre *for* Fire Safety Engineering

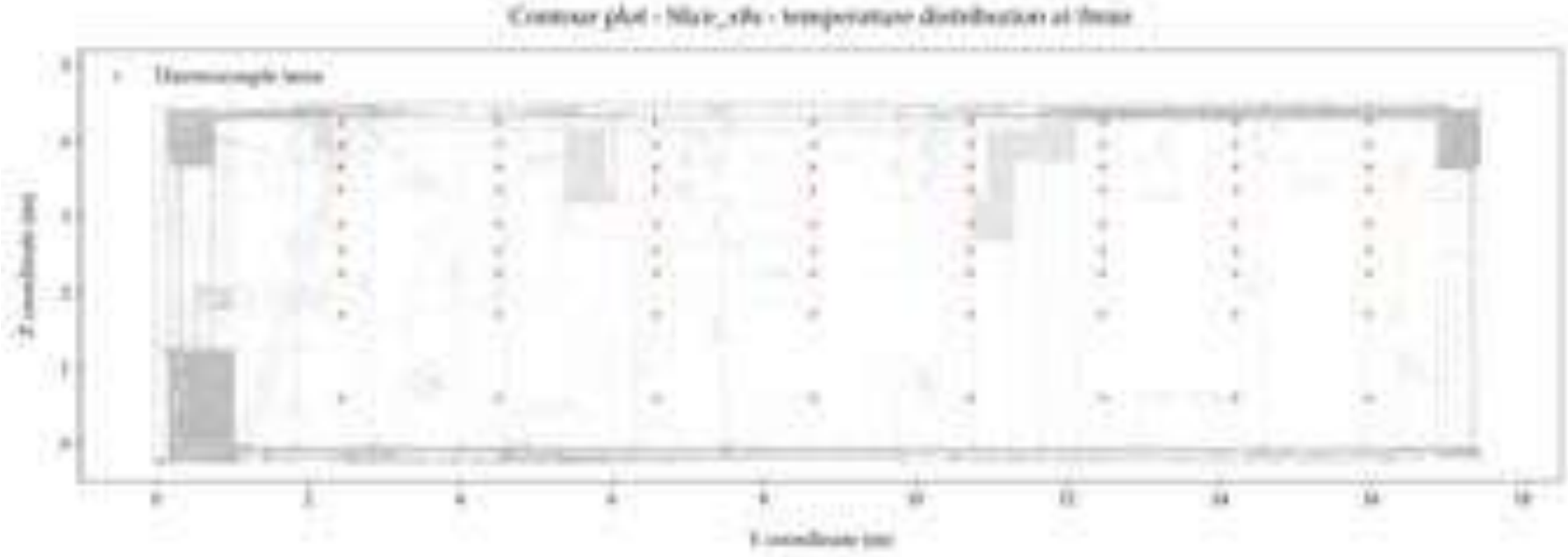
TEMPERATURE DISTRIBUTION IN ELEVATION
SLICE x8s
(i.e. TC8, TC18, TC38, TC48, TC58, TC68, TC78, TC88)

Test building floor plan with TC tree locations

BRE Centre *for* Fire Safety Engineering



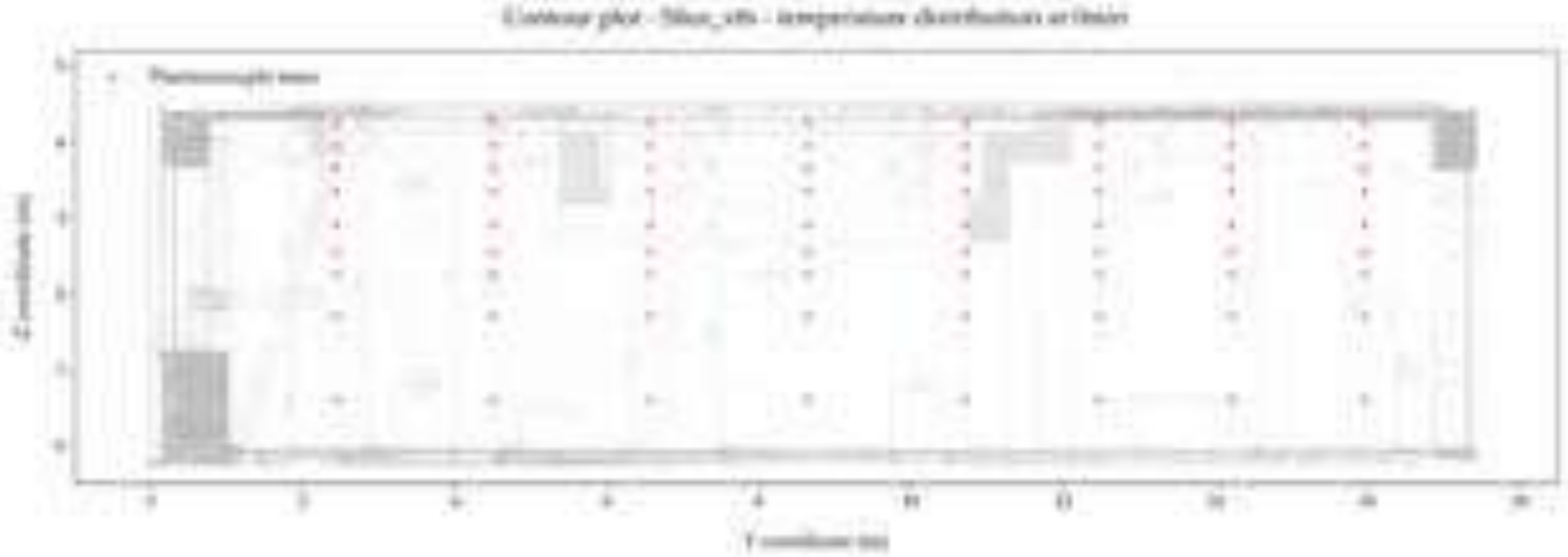
Temperature distribution in elevation slice x8s, Video

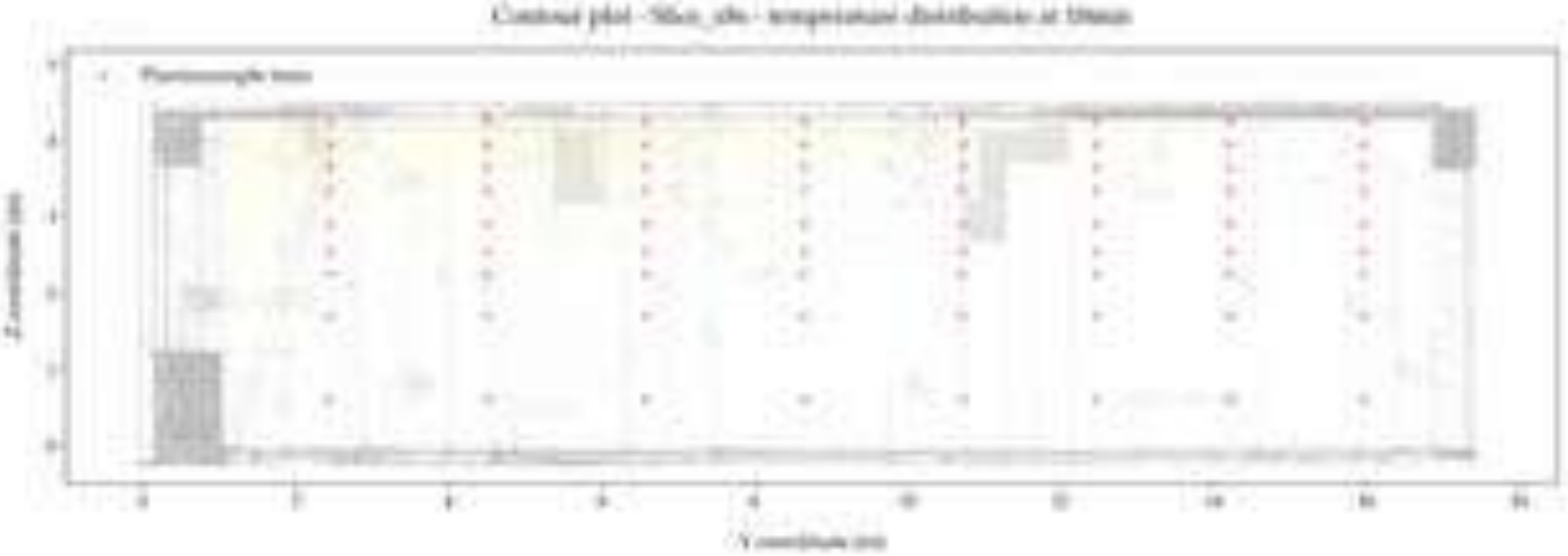


Linear interpolation

BRE Centre *for* Fire Safety Engineering

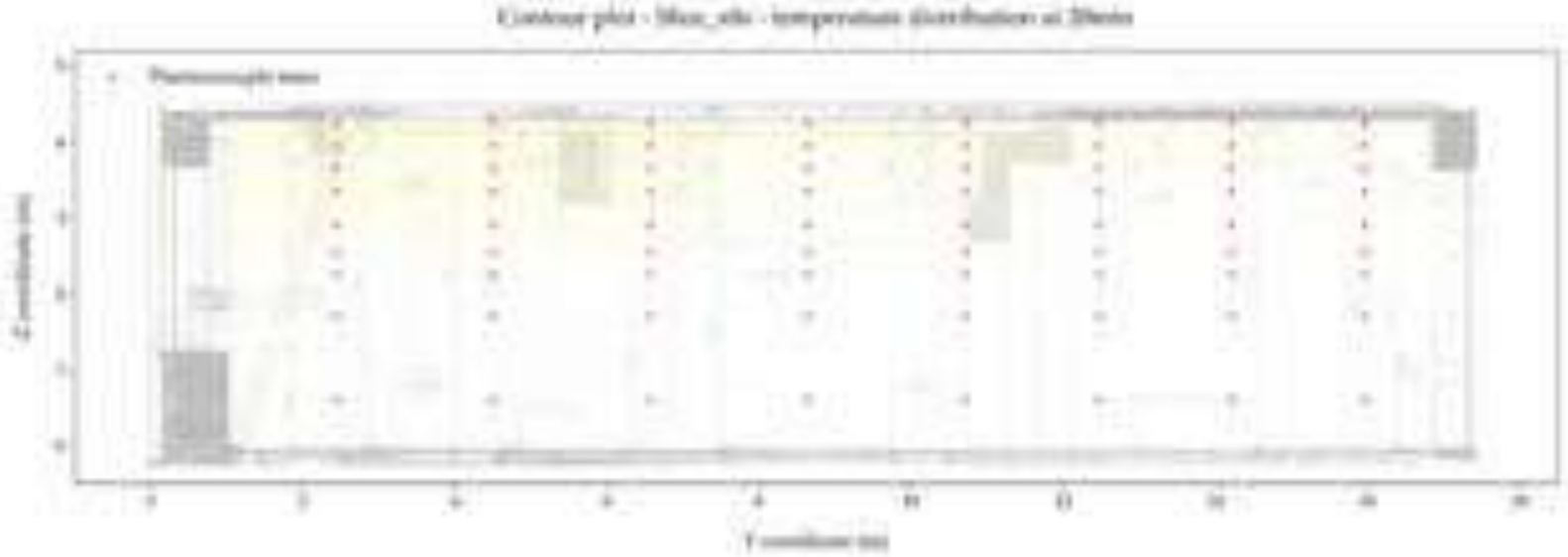
Temperature distribution in elevation slice x8s

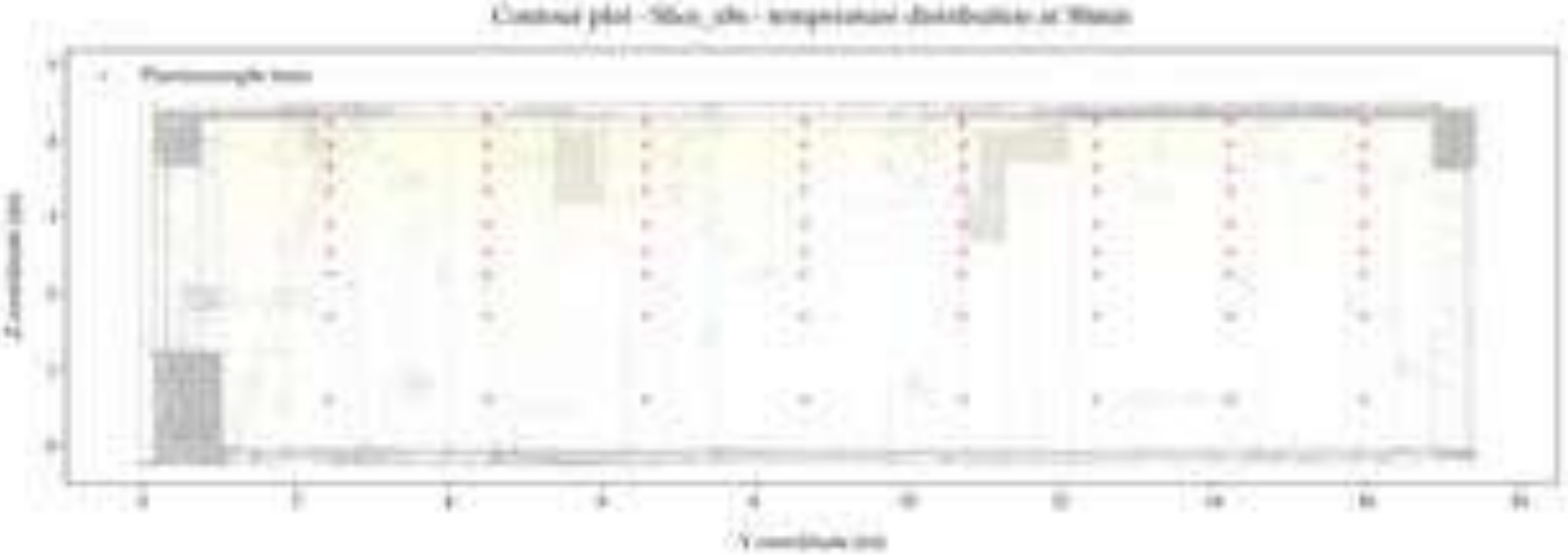




BRE Centre *for* Fire Safety Engineering

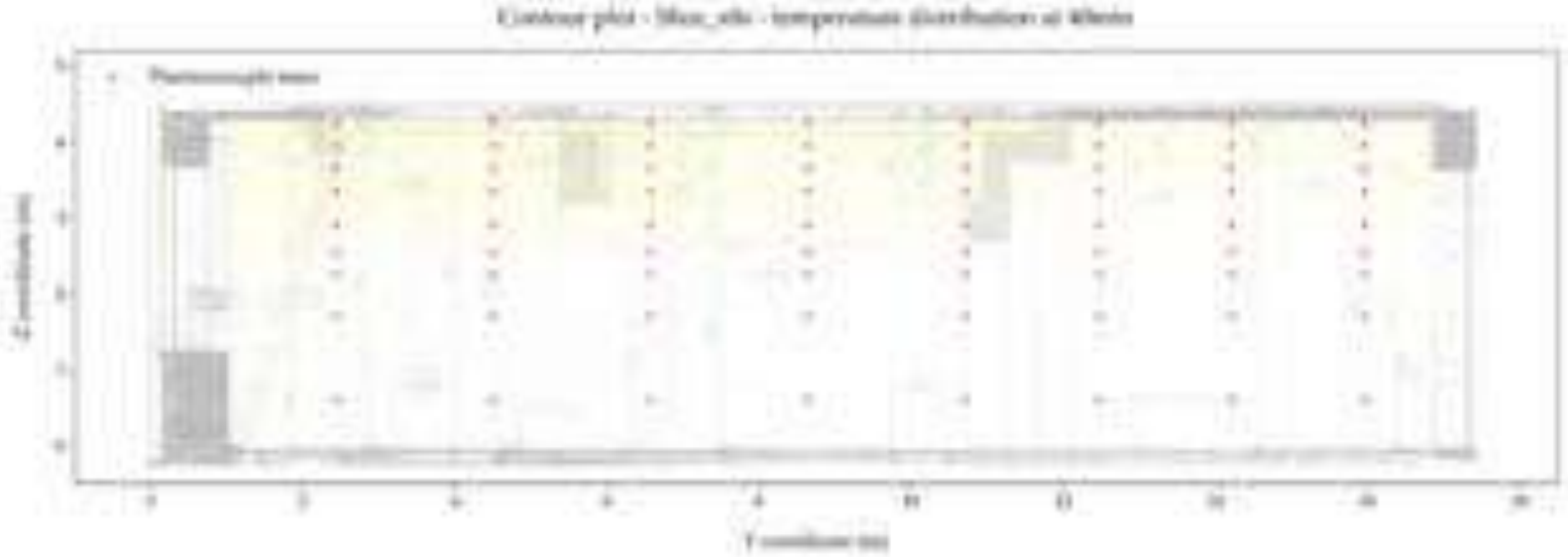
Temperature distribution in elevation slice x8s

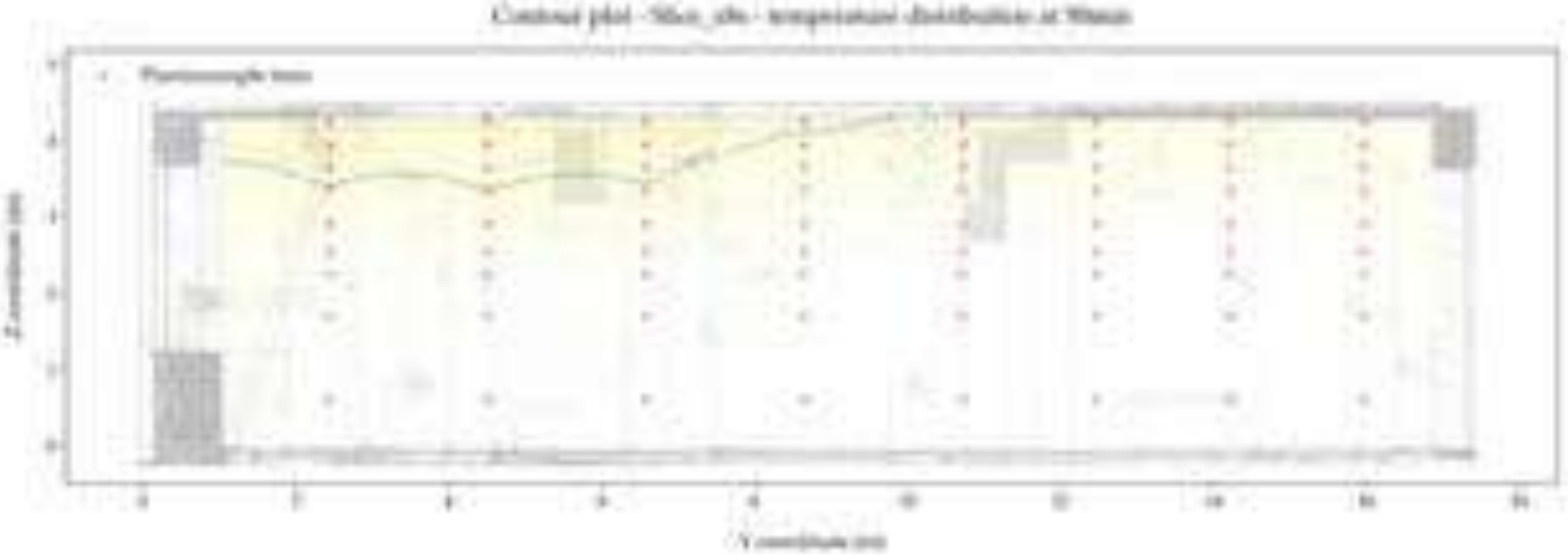




BRE Centre *for* Fire Safety Engineering

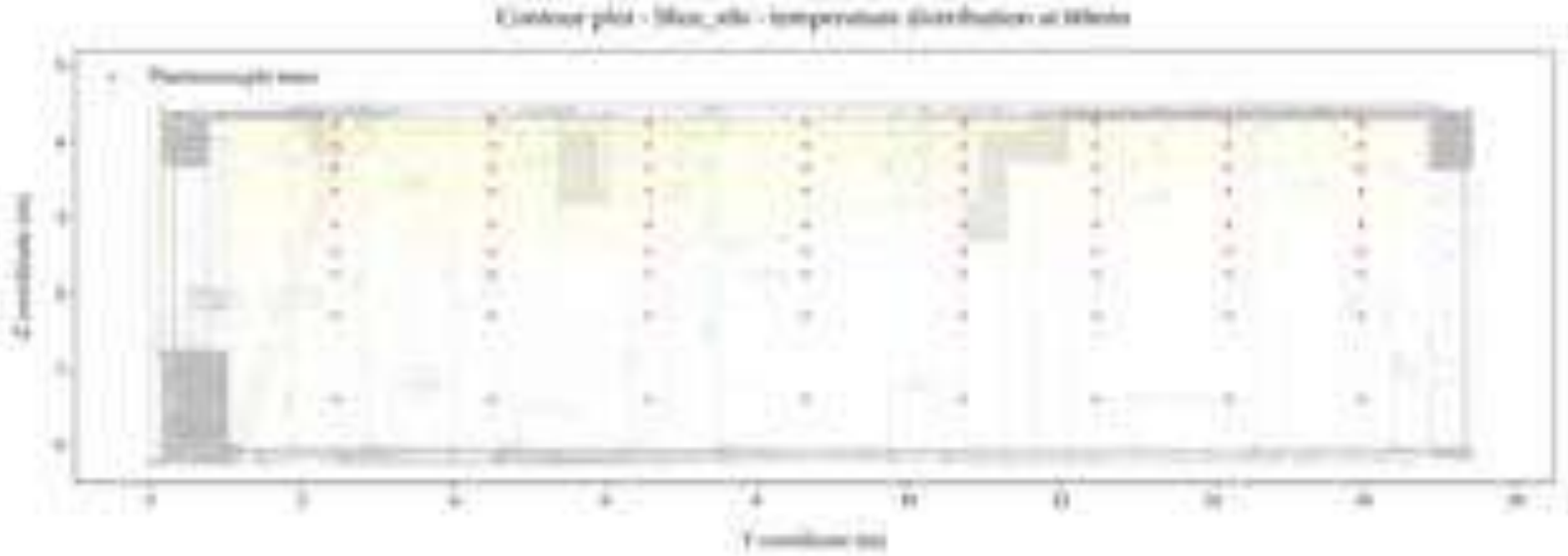
Temperature distribution in elevation slice x8s

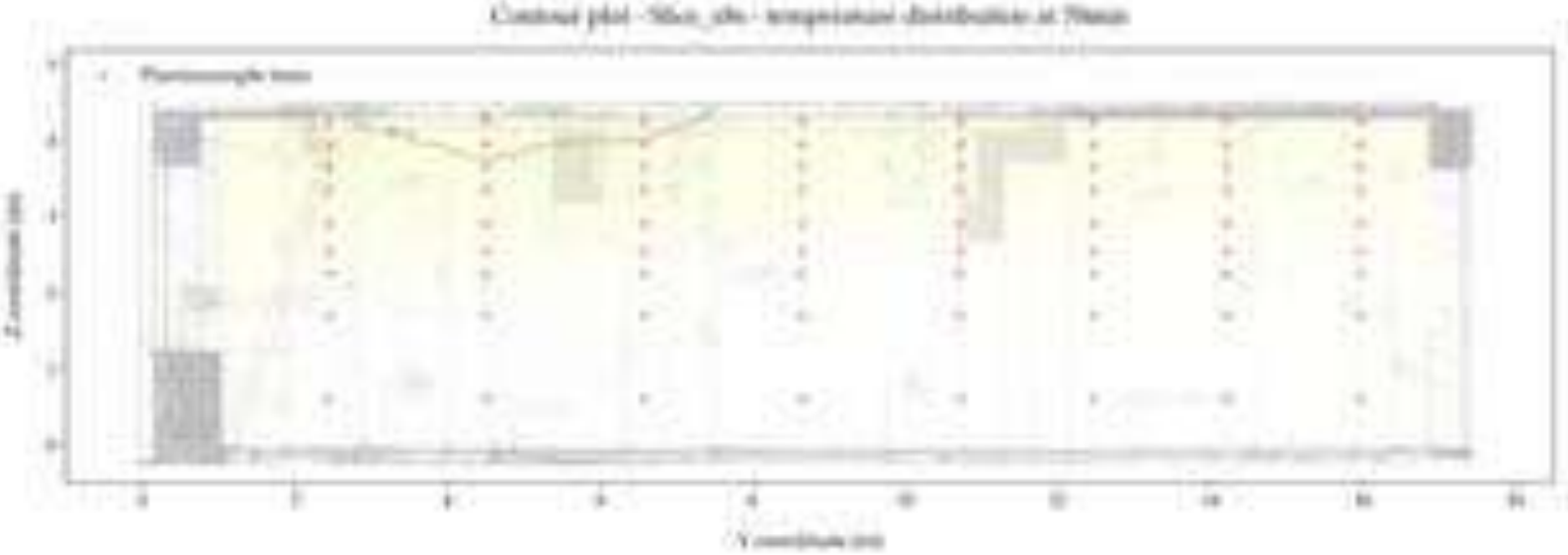




BRE Centre *for* Fire Safety Engineering

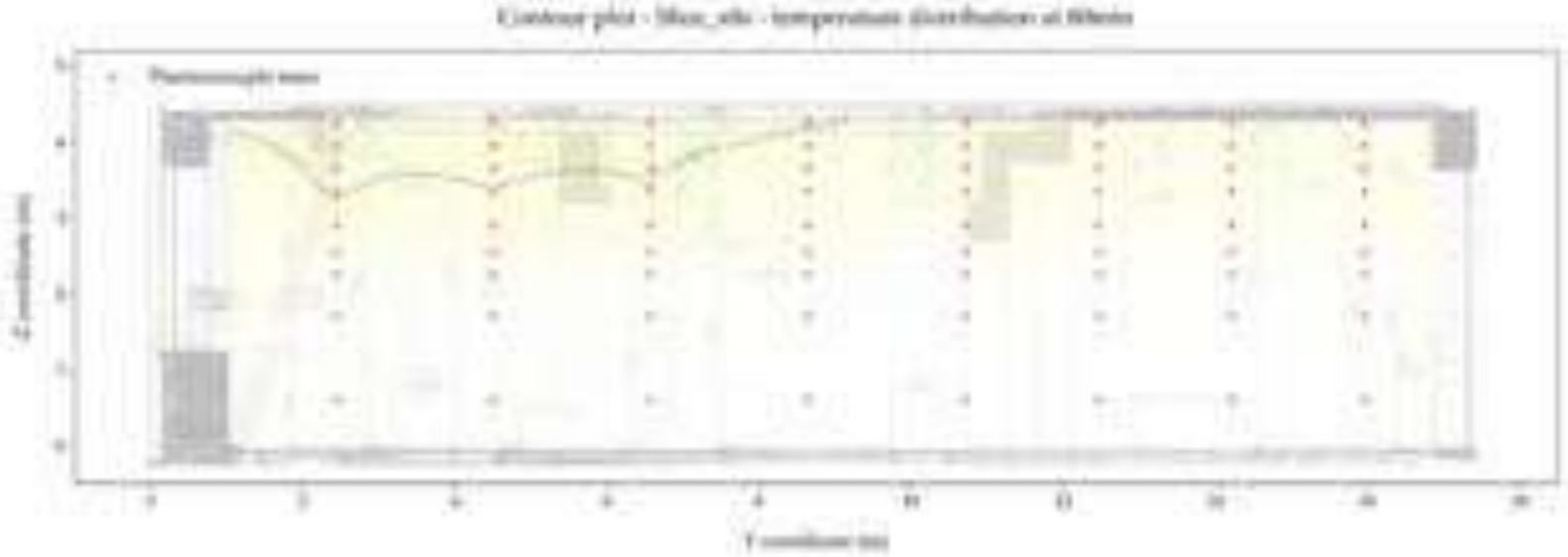
Temperature distribution in elevation slice x8s

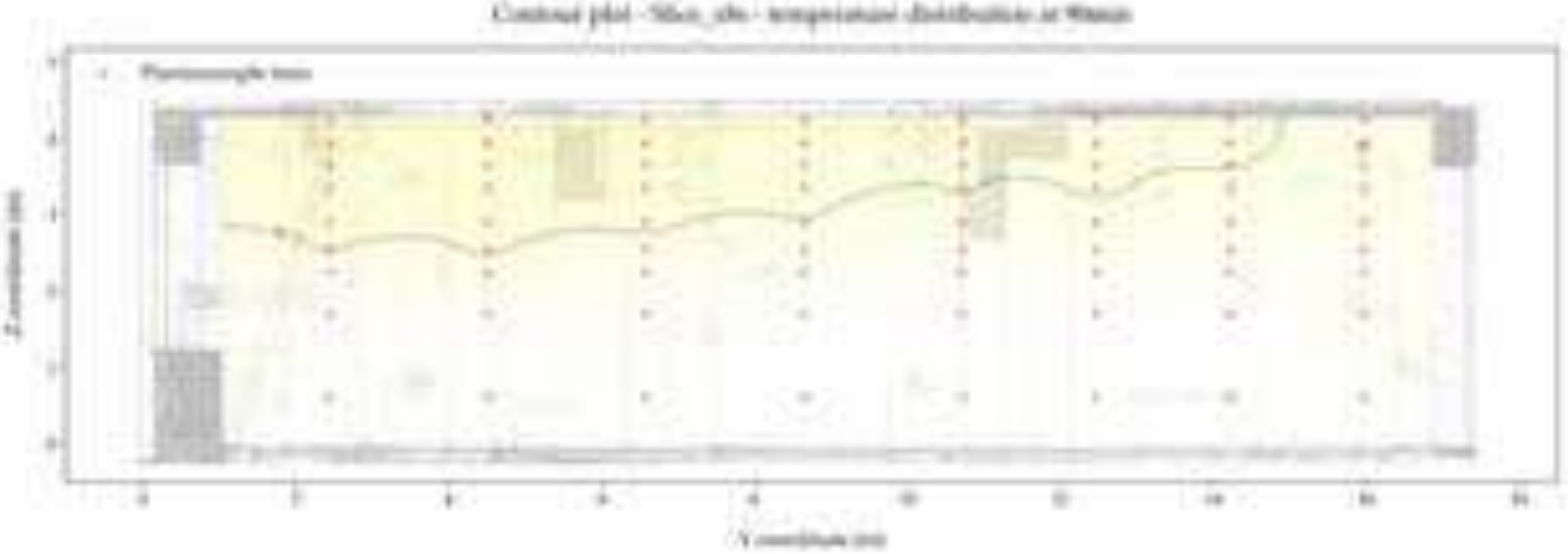




BRE Centre *for* Fire Safety Engineering

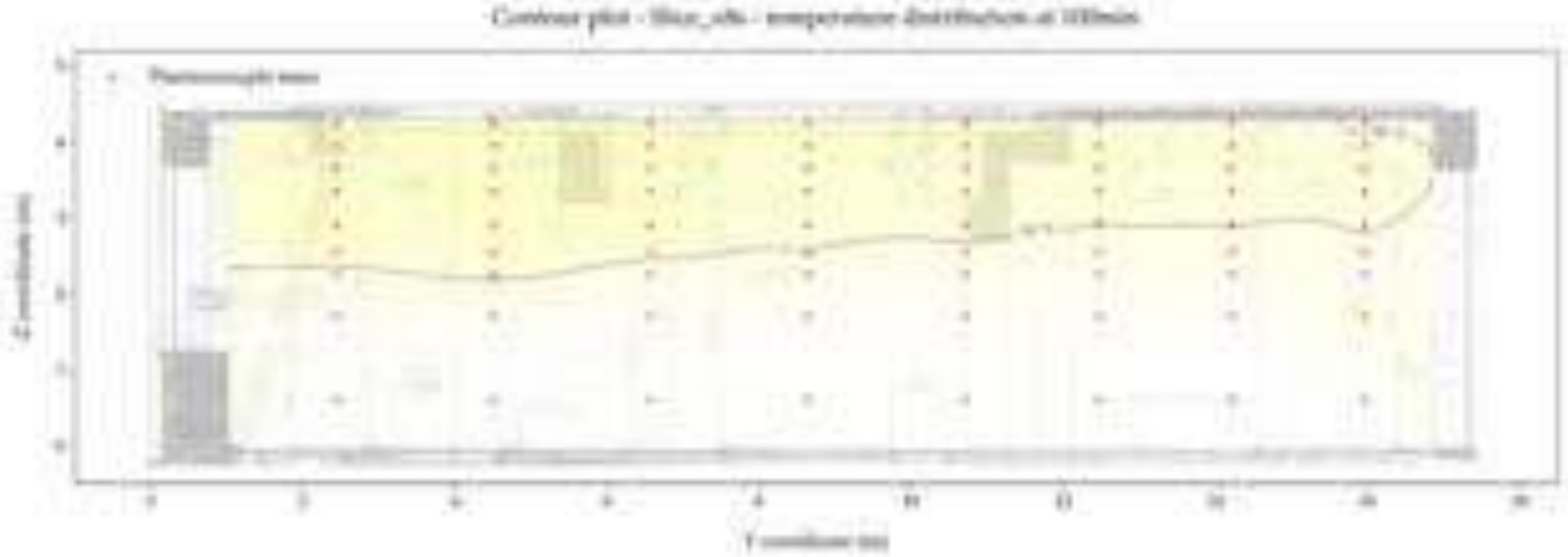
Temperature distribution in elevation slice x8s

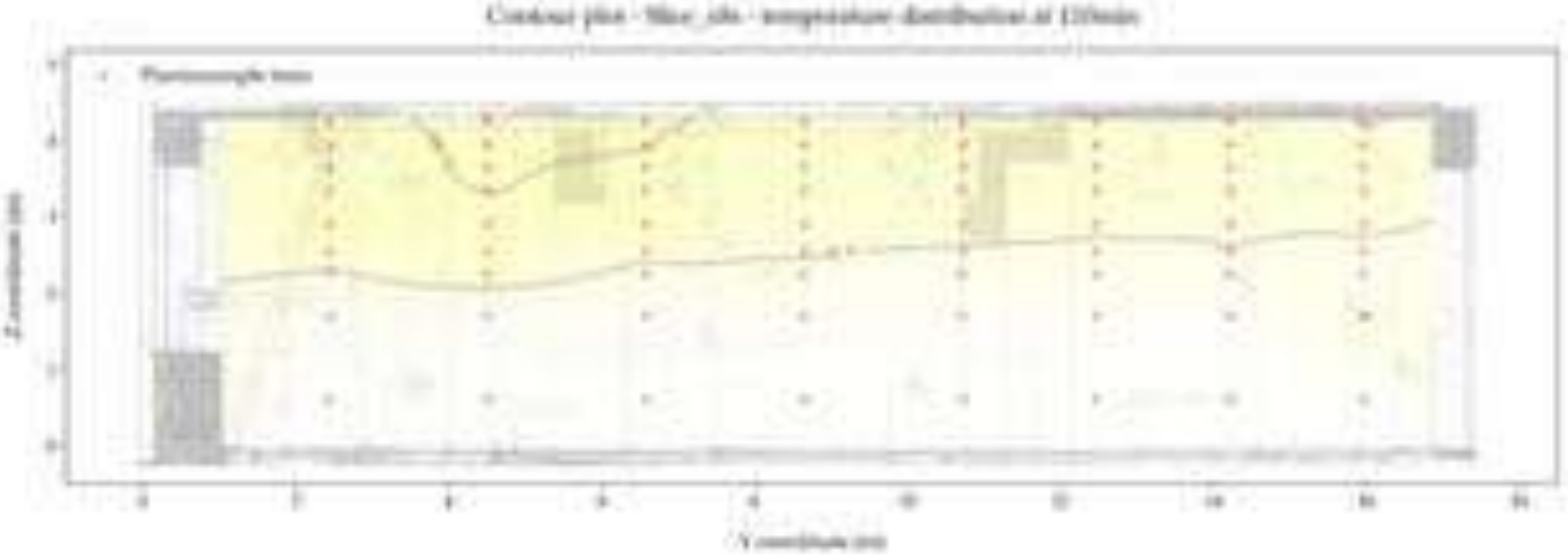




BRE Centre *for* Fire Safety Engineering

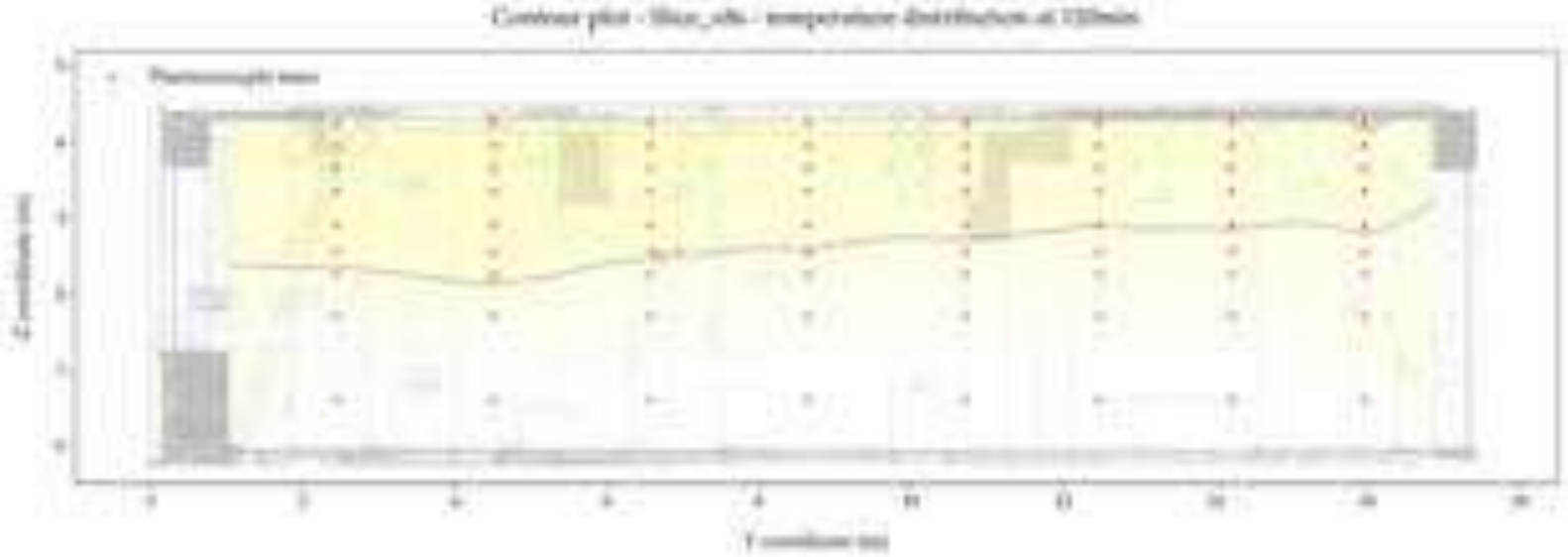
Temperature distribution in elevation slice x8s

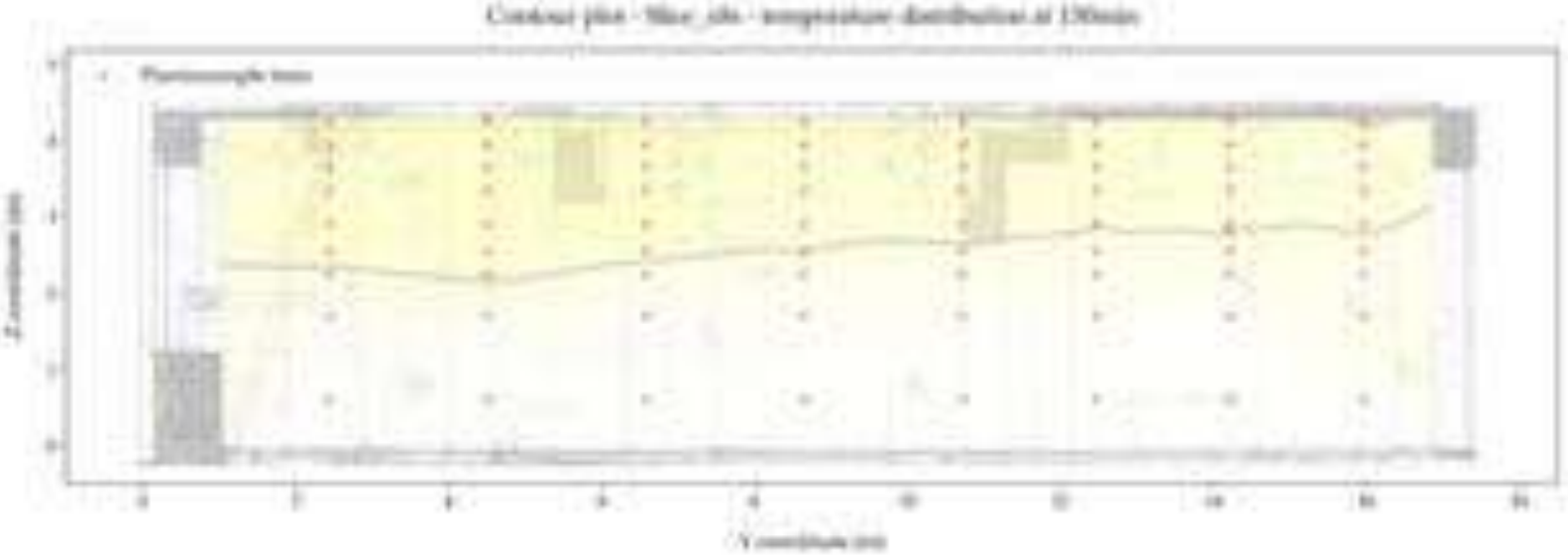




BRE Centre *for* Fire Safety Engineering

Temperature distribution in elevation slice x8s

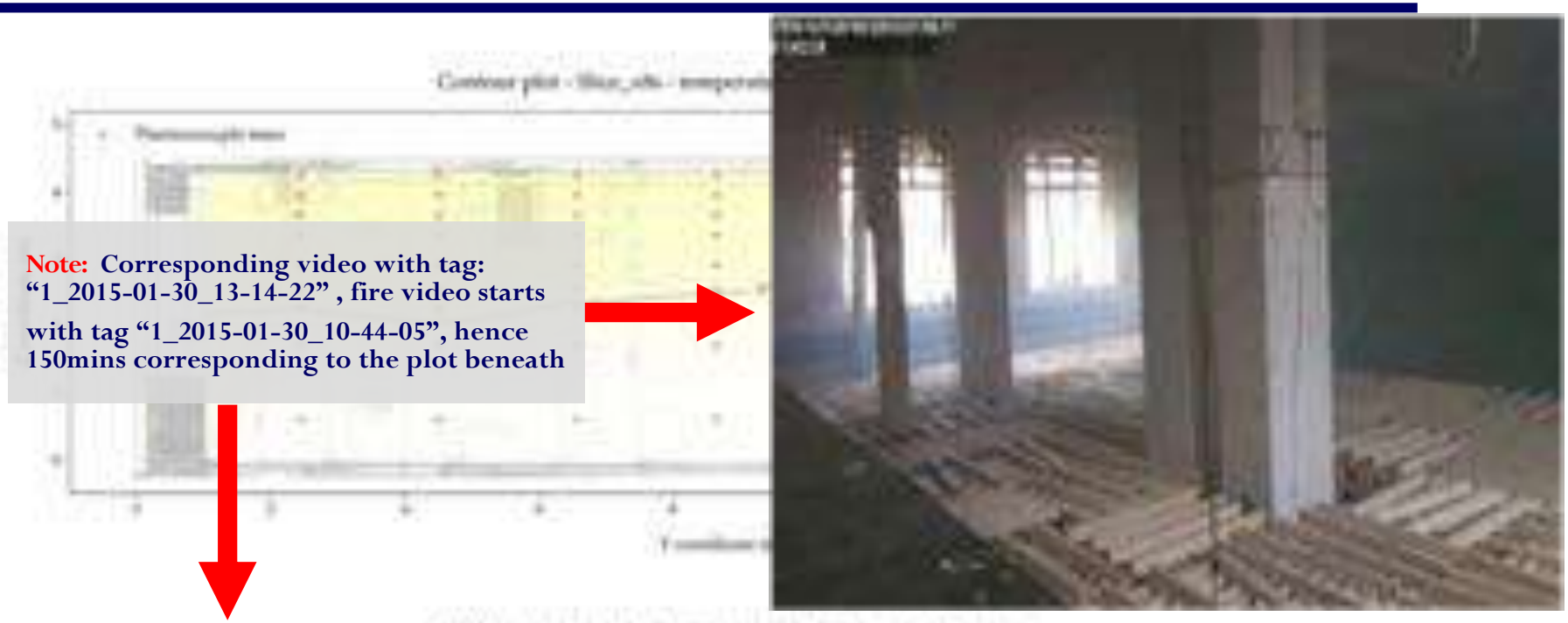




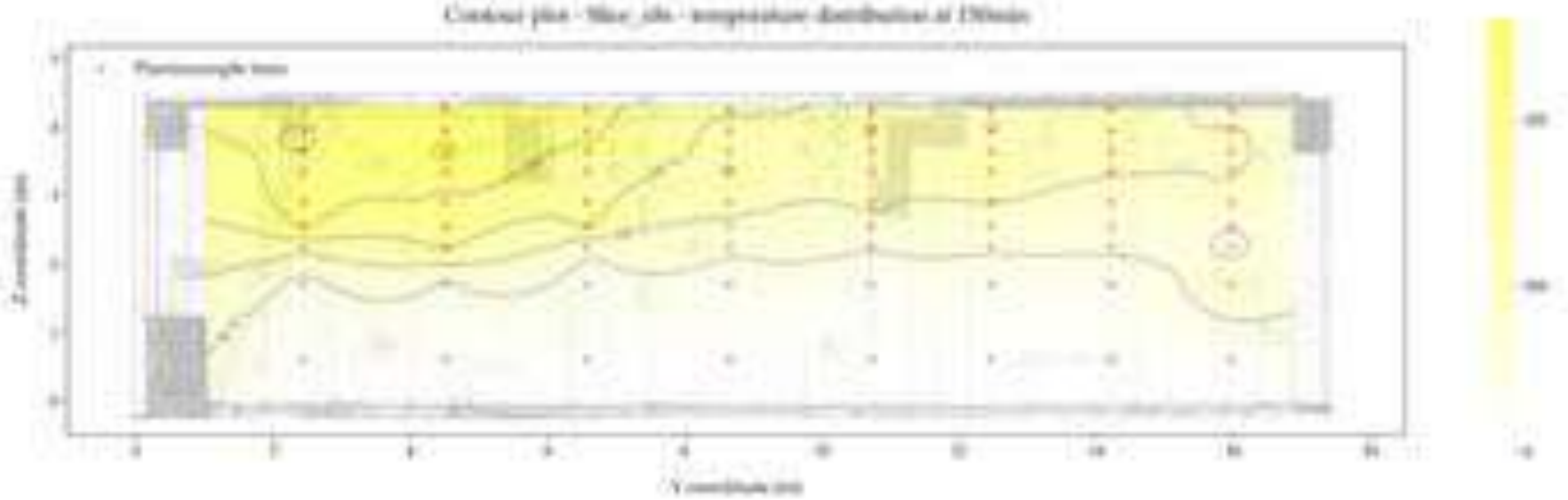
BRE Centre *for* Fire Safety Engineering

Temperature distribution in elevation slice x8s

BRE Centre *for* Fire Safety Engineering



Note: Corresponding video with tag: "1_2015-01-30_13-14-22" , fire video starts with tag "1_2015-01-30_10-44-05", hence 150mins corresponding to the plot beneath



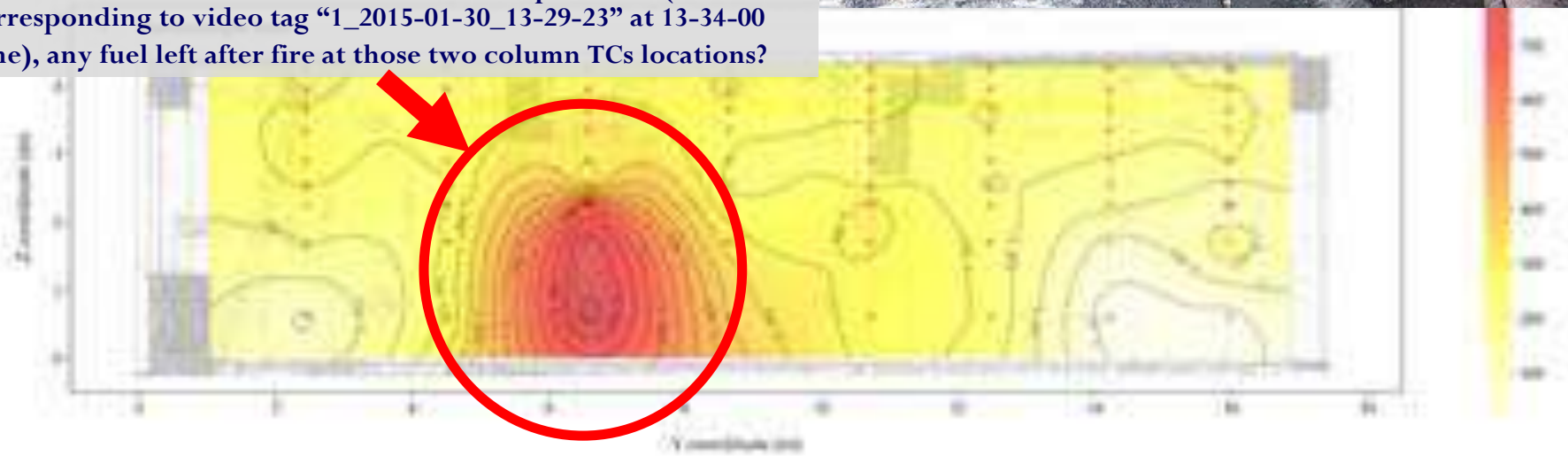
Temperature distribution in elevation slice x8s

BRE Centre *for* Fire Safety Engineering

Discussion: Heat not retained due to the openings, or a steel door with lower thermal inertia?

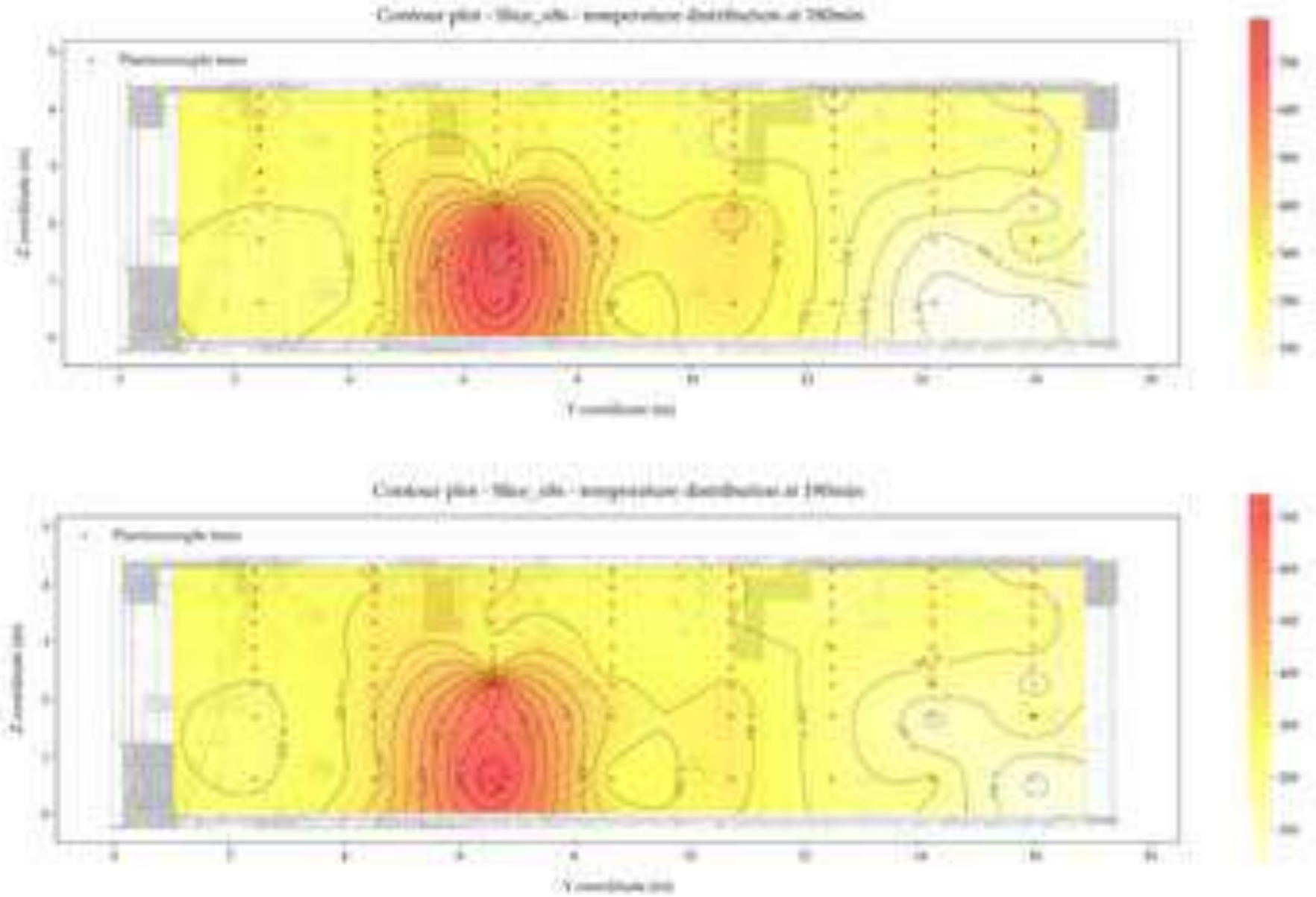
Note: Higher temperature with more heat retained

Discussion: The bottom becomes hotter, due to the near-field approaching/patrol-induced partial flashover. However, why the left two columns of TCs remain such low temperature? (170min is corresponding to video tag "1_2015-01-30_13-29-23" at 13-34-00 time), any fuel left after fire at those two column TCs locations?



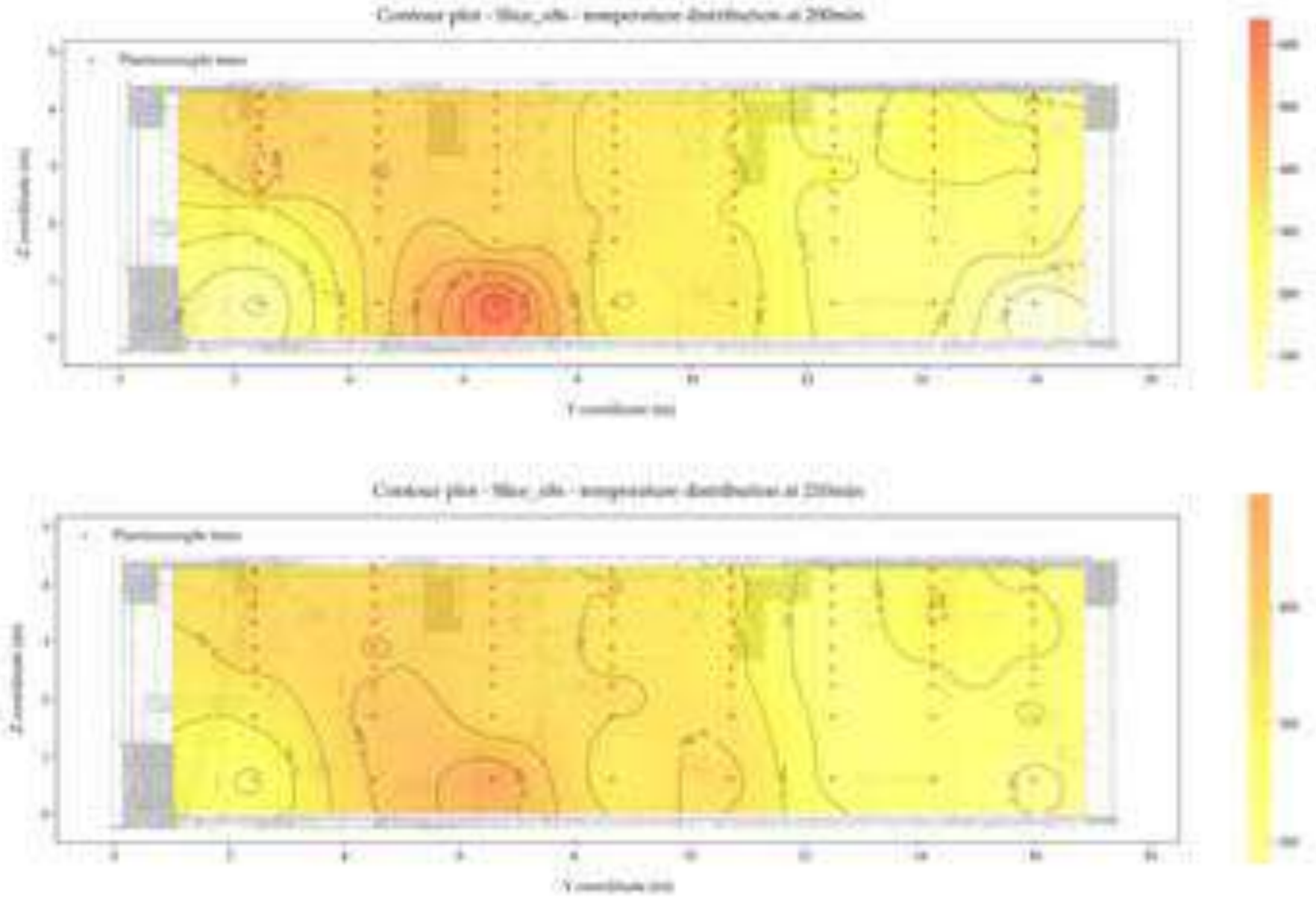
Temperature distribution in elevation slice x8s

BRE Centre *for* Fire Safety Engineering



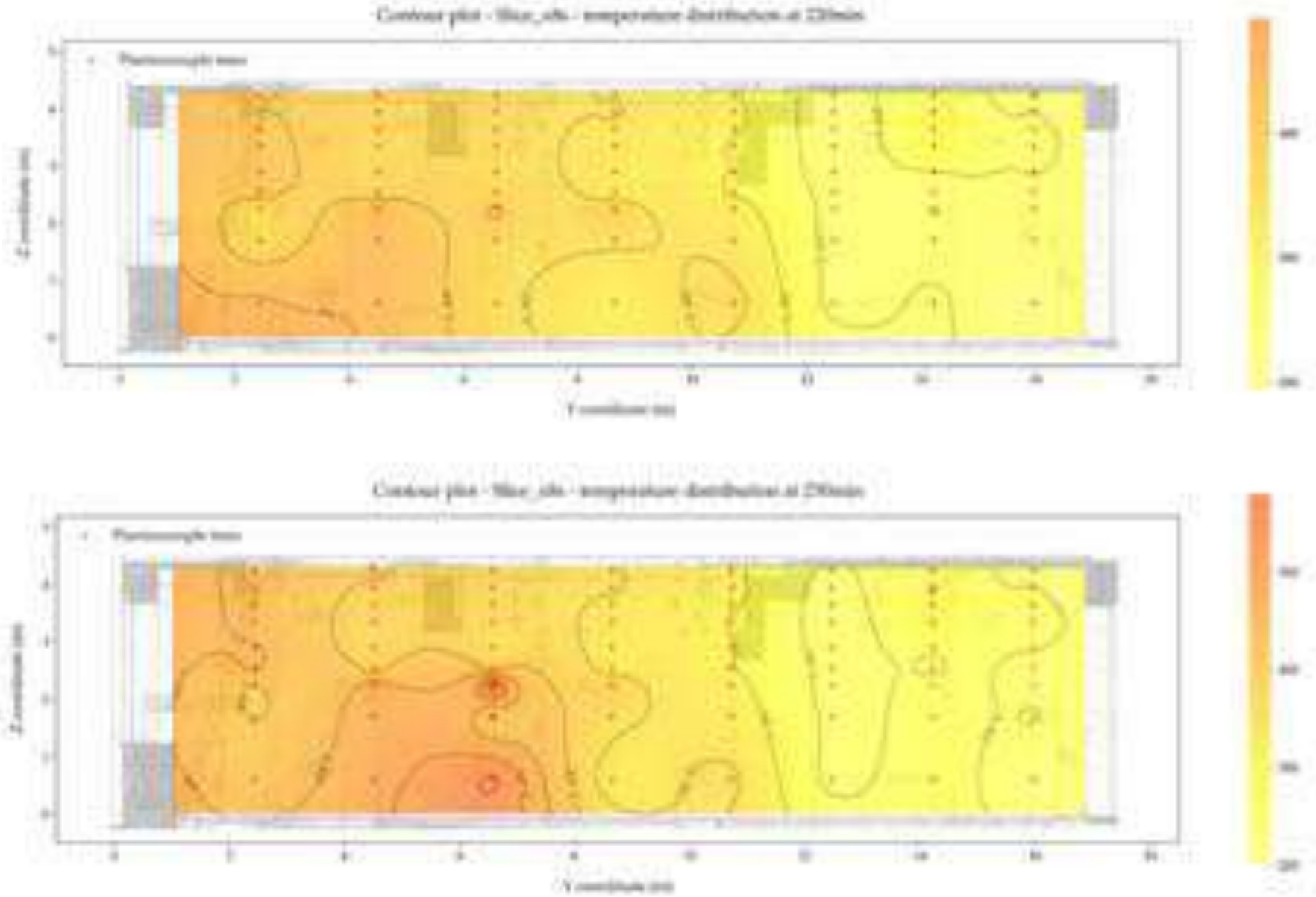
Temperature distribution in elevation slice x8s

BRE Centre *for* Fire Safety Engineering



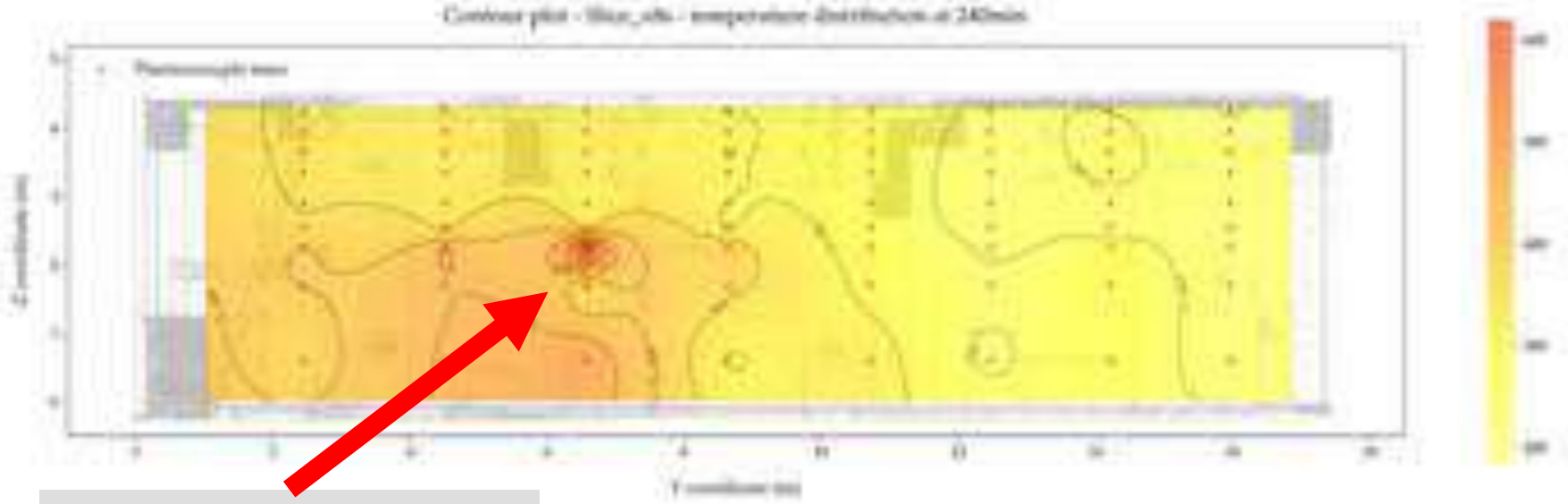
Temperature distribution in elevation slice x8s

BRE Centre *for* Fire Safety Engineering

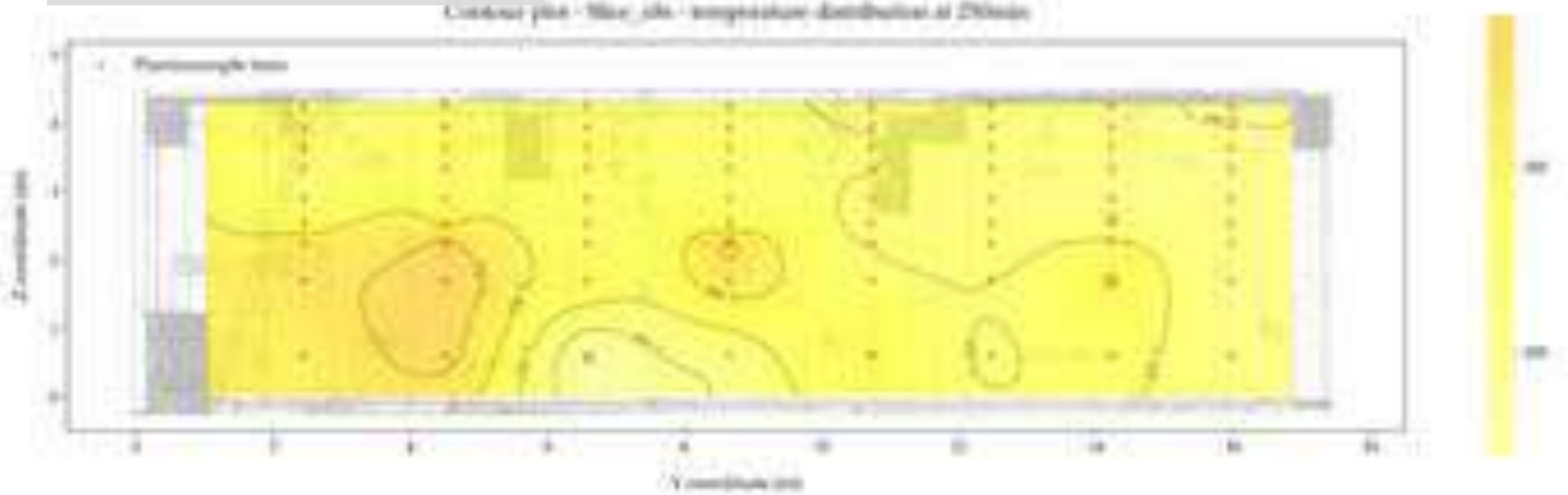


Temperature distribution in elevation slice x8s

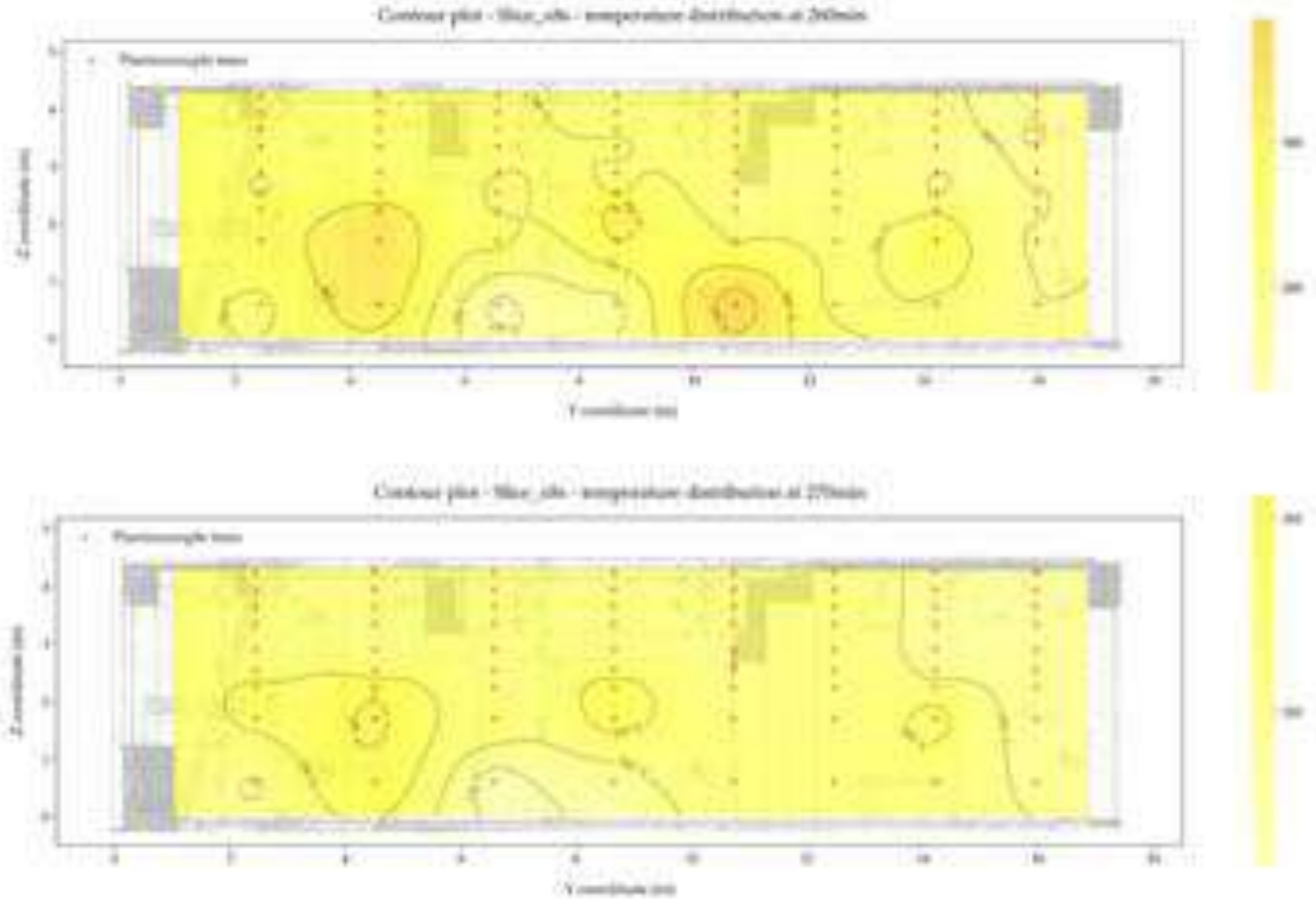
BRE Centre *for* Fire Safety Engineering



Discussion: **Errors due to radiation, or just burning lighting stuff?**

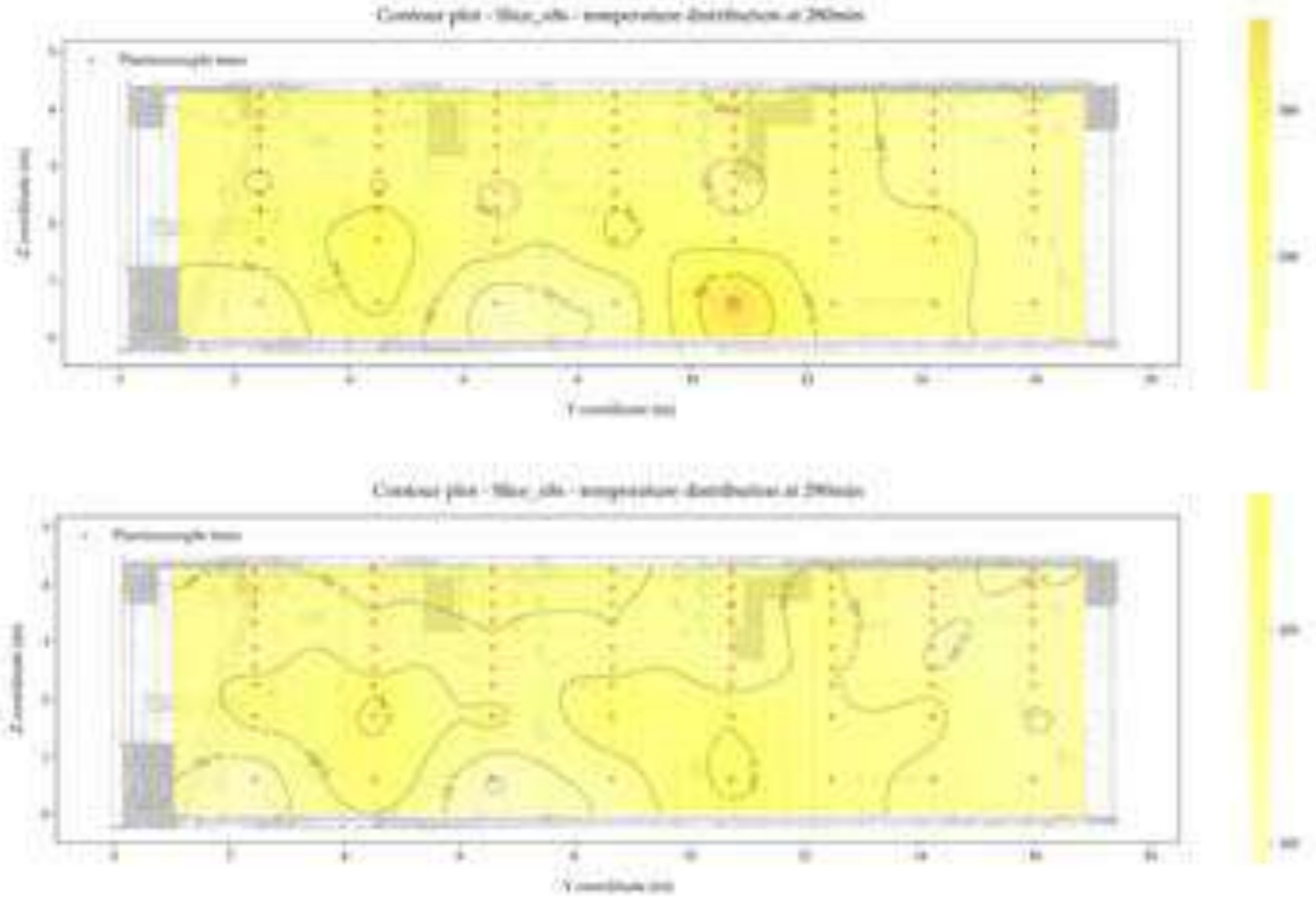


Temperature distribution in elevation slice x8s



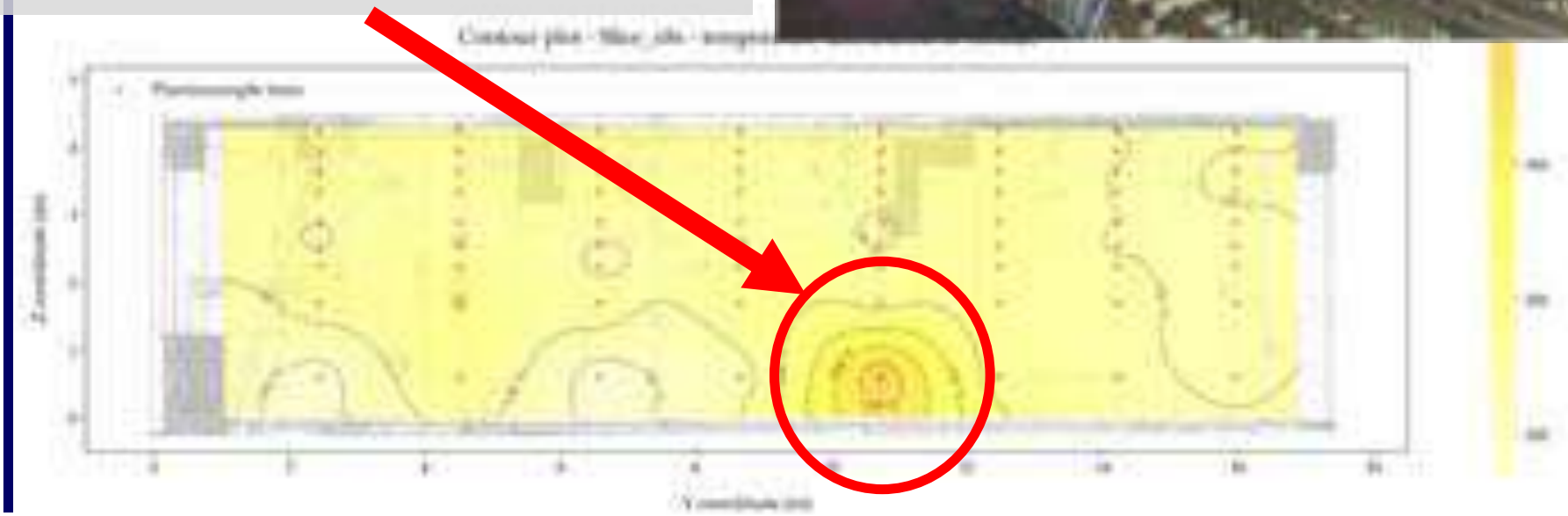
BRE Centre *for* Fire Safety Engineering

Temperature distribution in elevation slice x8s



BRE Centre *for* Fire Safety Engineering

Temperature distribution in elevation slice x8s

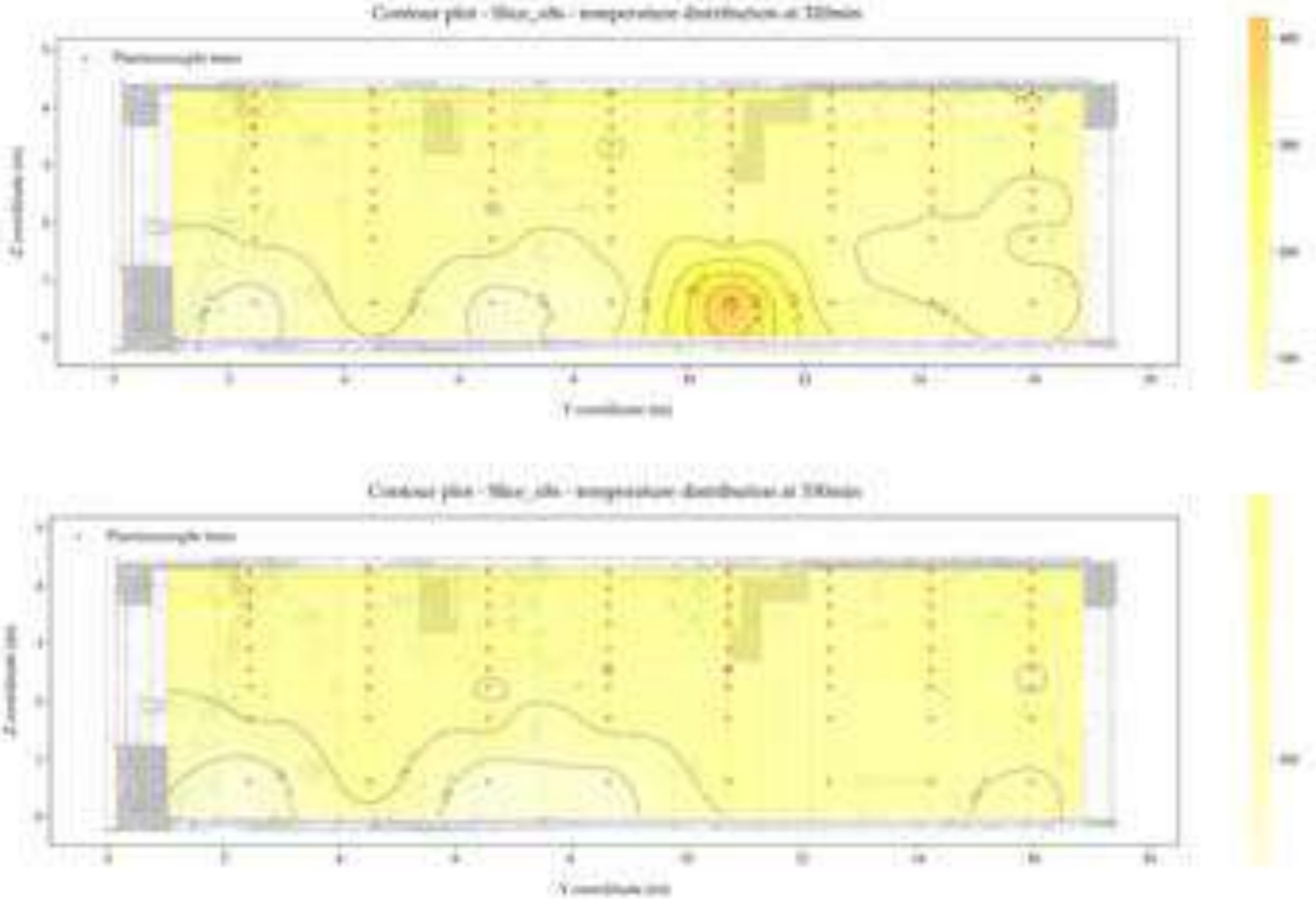


Discussion: According to the video (tag: 1_2015-01-30_15-44-39), it is apparent that this is due to radiation errors.

BRE Centre *for* Fire Safety Engineering

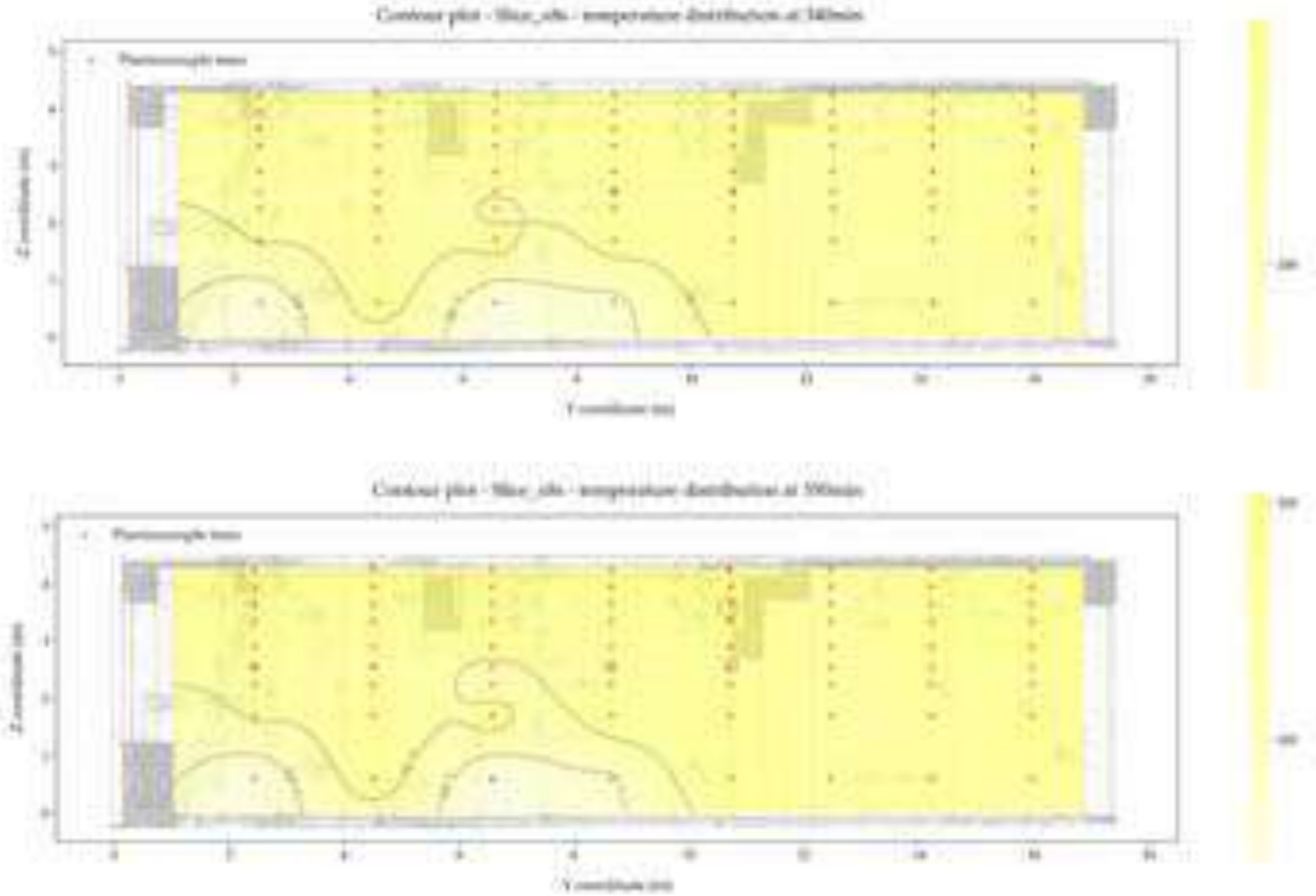
Temperature distribution in elevation slice x8s

BRE Centre *for* Fire Safety Engineering

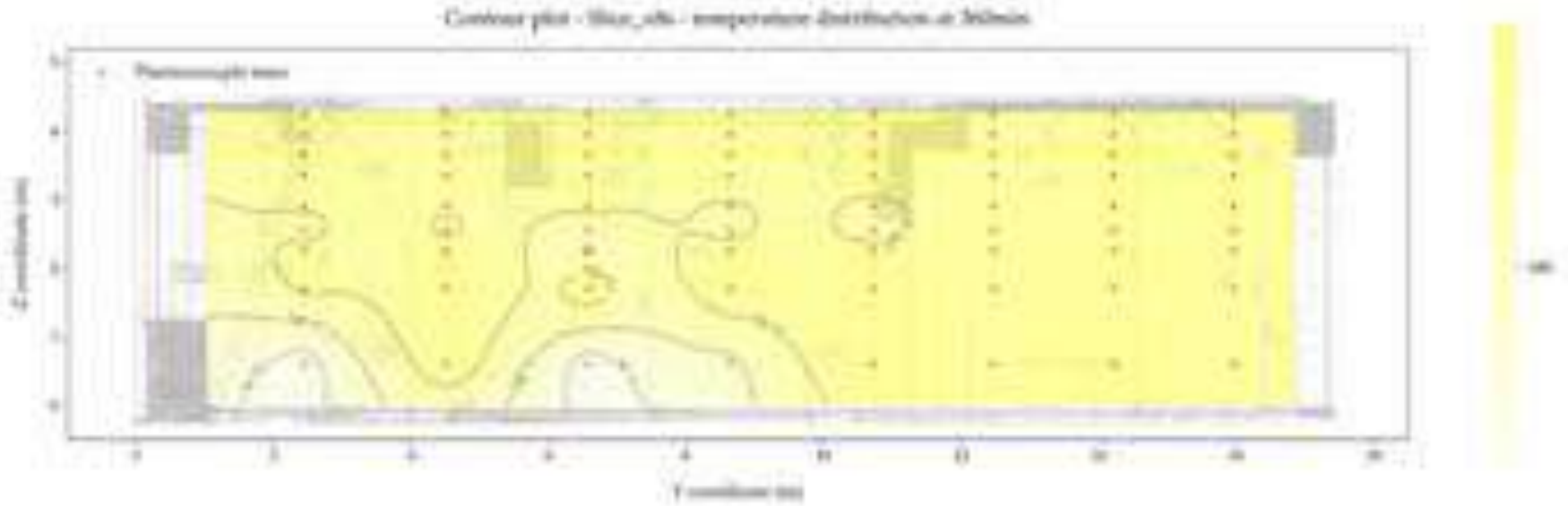


Temperature distribution in elevation slice x8s

BRE Centre *for* Fire Safety Engineering



Temperature distribution in elevation slice x8s



BRE Centre *for* Fire Safety Engineering

Current project

BRE Centre *for* Fire Safety Engineering

TRAFIR Project

Characterization of TRAvelling FIRes in large compartments

Funding from the Research Fund for Coal and Steel (RFCS) - European Commission

Eight work packages (1/07/2017 → 31/12/2020):

- **testing** (isolated elements and simplified fire progression, as well as a full-scale large compartment)
- **modelling** (both simplified analytical/phenomenological models and CFD).

Project partners:

ArcelorMittal

The University of Edinburgh

Université de Liège

SP Technical Research Institute of Sweden

Ulster University