Predicting the effectiveness of various detection strategies protecting spaces where smoke may not reach the ceiling

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Abstract

The detection of smoke in very large spaces is challenging – particularly if the heat output from the fire is small relative to the ceiling height and temperature gradients present such that smoke forms a stratified layer some distance below the ceiling. In such cases, ceiling mounted detectors are ineffective and will only operate when the heat output from the fire has increased sufficient to give the smoke enough energy to propagate to the ceiling.

This paper provides a summary of the preliminary findings coming from a research project, sponsored by the Fire Industry Association (FIA) in the UK and three industrial parties. The project has contrived a number of fire scenarios which when modelled in Fire Dynamics Simulator (FDS) have resulted in the formation of a stratified layer of smoke. These scenarios have been used to consider the relative performance of different detection strategies deployed in the space and the paper focuses on the relative effectiveness of angled beams compared to current, code-compliant, beam placement strategies.

Key findings from the modelling scenarios undertaken are; that the current recommendations for spacing supplementary/interstitial detectors at ¼H should be maintained, that angled beams are more effective than supplementary beams (unless stratification layer forms at the same height as the supplementary detectors), that the formulation of recommendations for the spacing of angled detectors should take into account the maximum horizontal spread of the stratified smoke layer and, that angled beams should be criss-crossed though the space to avoid excessive horizontal distances between any point in the space and its closest beam.

Keywords: Smoke detection, stratification, open spaces, high ceilings, angled beams, interstitial beams, OBSD, FDS.

Introduction

It is widely recognized that integrating detection technologies (such as aspirating smoke detectors (ASD) or optical beam smoke detectors (OBSD) mounted at the ceiling are the most effective way to detect smoke reaching ceilings in high spaces because they are better able to respond to the dissipated smoke (entering several sampling holes or obscuring extended lengths of the beam respectively). Previous research[1][2] has demonstrated, and installation codes [3] reflect, that such integrating technologies are more effective than point/spot based technologies in such applications but they still depend on smoke reaching the ceiling - unless they are deployed at multiple levels.

Multi-level detection using ASD or OBSD is often suggested as a good solution for mitigating the risk of smoke stratifying but the guidance on where and how to deploy them is typically non-specific. This is largely due to the challenges associated with predicting when and at what level smoke will stratify but it is also due to the large variety of 3-dimensional detection strategies that *could* be used.

Some examples include;

- The use of drop pipes to provide ASD sampling holes a few meters below the ceiling
- Multiple OBSDs located at intermediate levels, spaced sufficient to ensure that a rising plume of smoke is unlikely to pass through the layer undetected
- Multiple OBSDs deployed at an angle to the horizontal such that they provide multi-level coverage of the space.

This project presents the results from a number of fire scenarios which, when modelled in Fire Dynamics Simulator (FDS) [4], give rise to a stratified layer of smoke. The models have incorporated various detection strategies including examples of those listed above and some more traditional strategies using detection mounted at, or very close to, the ceiling.

Previous research

This project follows on from the FIA sponsored research undertaken by BRE [1]. The modelling scenarios (using FDS and JASMINE) presented in Part 1 were used as a starting point for this research project. The conclusions from Part 2; that smoke from relatively small fires can extend 43 m into a high ceiling space with temperature gradients of up to 0.28 °C/m, influenced changes in the UK and other European codes/guides [3]. However, despite the low threat they pose, concerns remain over how to reliably detect smoke (from small or incipient fires) which does not have sufficient thermal energy to rise to the ceiling.

While Andersson & Blomqvist [5] found that the CFD predictions using SOFIE did not accurately reflect their experimental data they acknowledged that CFD simulations are useful for “studying trends” and visualizing the problem and that the temperature gradient required to prevent smoke layer from a 300 W fire reaching 7 m ceiling is “substantial”.

NFPA 92B [6] quotes an equation presented by Morgan et al [7] for calculating the stratification height based on the fire heat output and the prevailing temperature gradient.

Fang et al [8] and Nielsen et al [9] present improvements to this equation based on some empirical and parametric studies. However, even if the stratification height in a particular scenario could be accurately predicted, in practice it will vary vastly according to the conditions and fire size. Hence the focus of this paper is to consider how numerical modelling might help to compare practical strategies for providing sufficient detector coverage to detect stratified smoke regardless of the height of the layer.

Initial challenge on beam detection modelling

One of the first challenges for the project was to correct the behavior of FDS to accurately predict the obscuration measured by each beam – particularly when installed at an angle and passing through several different areas within the volume (a.k.a. meshes within the FDS model). This was particularly relevant for the multi-mesh models used within this project and necessitated correction of a bug in the interpretation of the XYZ co-ordinates of the beam ends. Therefore, FDS version 6.5.3 (or later) is recommended for any follow up work.

Moreover, the visualization element of FDS, Smokeview, was extended to enable the path of OBSD to be visualized. Previously a beam was identified by a dot at the centre-point of the beam only – giving no insight into the trajectory of the beam within the protected volume. Smokeview can now provide illustrations such as depicted in Figure 1 below.

Fire Scenarios

The fire scenarios used in this project were contrived to provide a stratified smoke layer. These were developed by careful selection and adjustment of the FDS parameters – principally the initial temperature gradient and the heat output of the fire – to orchestrate a layer occurring at different levels. Five cases were considered as identified in Table 1 below. The default values, as highlighted in Table 1 result in a stratification layer forming at about 16 m above the floor.

Table 1. Fire scenarios.

Case	**Range modelled** (value in bold indicates the default)	**Units**
Fire Size (Heat Release Rate)	5, 10, **25**, 50 (constant) and >1200 (sofa)	(kW)
Temp Gradient	0.0, 0.15, 0.3 and **0.5**	(°C/m)
Soot Yield	0.01, **0.0185**, 0.04 and 0.08	(Kg/Kg)
Fire Location	LH wall, **central** and RH wall	
Cross-flow	**0.0**, 0.1 and 0.3	(m/s)

Beam detection strategies

Figure 1 illustrates the beams installed in the domain which measured 50 m by 50 m by 25 m high.

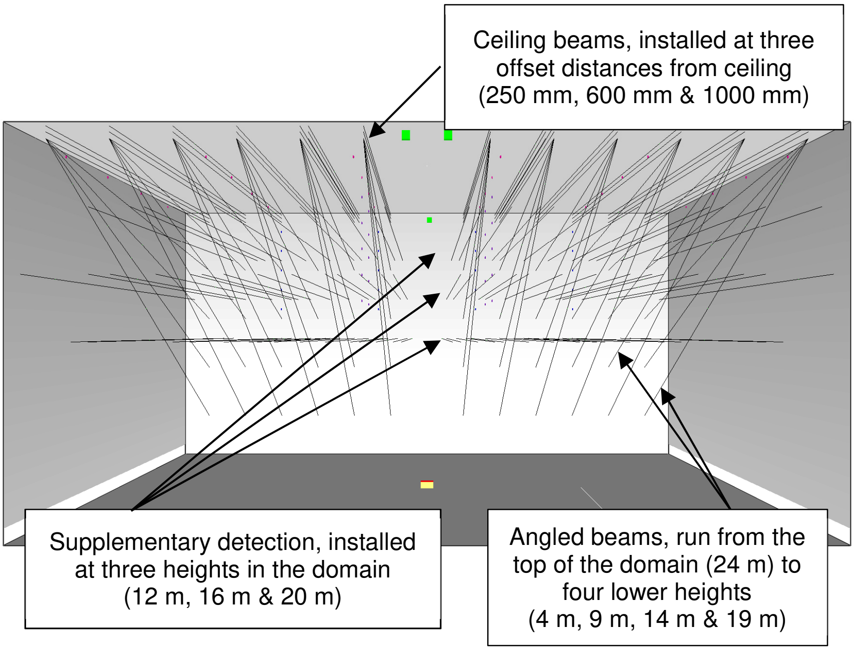

Fig. 1. General arrangement of beam detectors installed in the domain.

The three sets of 12 ceiling beams were included to investigate whether the current UK recommendations; that they should be within 600 mm of the ceiling with a maximum 15 m lateral spacing between beams, are reasonable. They may also provide an indicative measure of the anticipated reading response of the modelled beam to a fire which we would expect it to detect.

Three sets of supplementary beams were included, spaced varyingly according to their height (being ¼H, ⅓H, ½H ⅔H). The first reflected current practice, as recommended in the UK (and other) codes, that interstitial horizontal beams, intended to detect a rising plume, should be spaced within ¼H. It is worth noting that this recommendation means that there should be a good chance of detecting a rising plume widening at a constant half angle of more than 15 degrees. As with the ceiling beams, the intention was to see if the model confirms or challenges the value of this current, well-established practice. Similarly, it also may provide another indicative measure of the *predicted* response/obscuration that would be expected to provide an alarm condition.

Finally, a total of 40 angled beams were included in the model to investigate their effectiveness compared to the two "code compliant" strategies described above. The abundance of beams reflects the benefits of using CFD; to simultaneously consider *and enable comparison of* several detection strategies.

Other detection strategies

In addition to the beam detectors, the FDS models also included a number of point type and ASD type detectors including:

- Point smoke detectors at the ceiling
- Various ASD systems with sampling holes positioned at the ceiling, down the walls and within the space (using drop pipes)

The results from these detection strategies are not considered in this paper which focuses on and compares the effectiveness of the beams.

Results, discussion and conclusions

The 19 fire scenarios modelled successfully produced a variety of stratification situations as depicted in Figure 2.

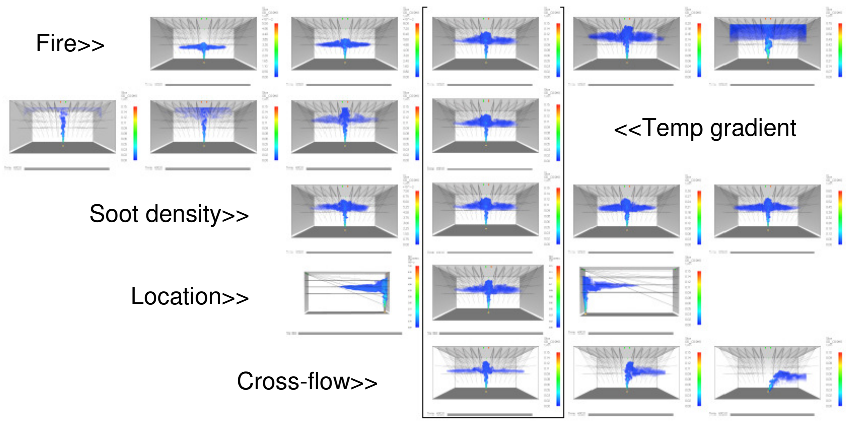

Fig. 2. Optical density of the 19 scenarios modelled.

The maximum height (overshoot) of the plume and the upper and lower boundaries of the stratified layer for 16 of the scenarios shown in figure 2 is represented by the grey bars in Figure 3.

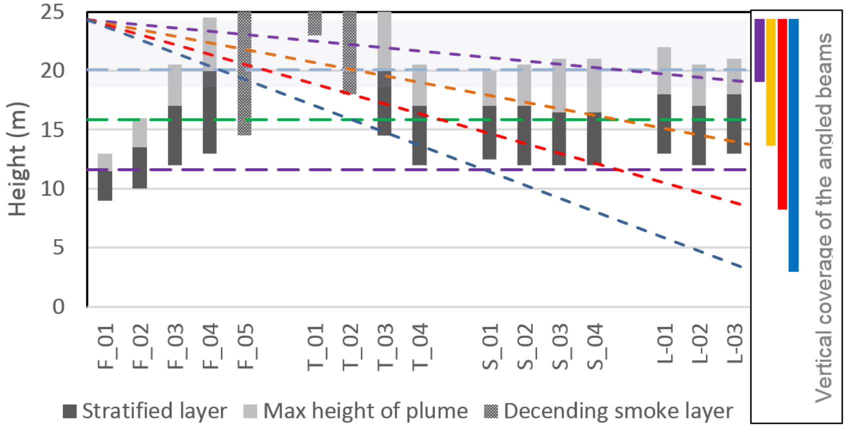

Fig. 3. Maximum plume height and stratification boundaries *overlaid* (for illustration) with the supplementary and angled beam trajectories.

From these figures it can be observed that as the fire size increases; the plume height increases and the stratification layer deepens. Smoke only reaches and spreads across the ceiling in three scenarios; F_05 (the only "real" fire HRR data), T_01 and T_02 (being 0 & 0.15°C/m).

The overlaid beam trajectories help to illustrate how the various beams responded to these plumes. For example; the supplementary beam at 16m (green dash) recorded high readings in all but 4 of the scenarios depicted, while the shallowest angled beam (purple dots+band) passed above most of the fires which was reflected in the low values recorded.

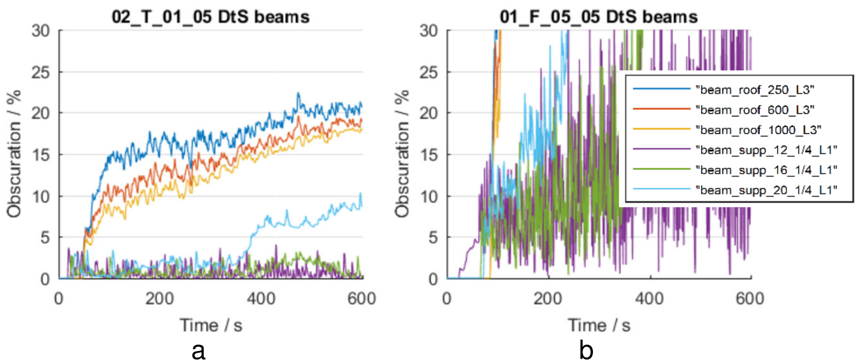

Fig. 4. Response of "code-compliant" beams to a 5 kW fire (with no ΔT) and to a sofa fire (with ΔT=0.5 °C/m).

Obscuration readings for the “code compliant” beams closest to the fire are depicted in Figure 4 for two fires. The three ceiling beams (blue, red & orange) are positioned 7.5m from the fire (a.k.a. 15 m spacing) while the three supplemental beams are in accordance with spacing of ¼H.

From Figure 4a it is clear that while the beam closest to the ceiling records the highest obscuration (blue), the two other ceiling beams show similar performance. The delay to the alarm as a result of having the beam further away from the ceiling depends on the alarm threshold. For example, at 10 %obsc the delay as a result of positioning the beam 1 m (as opposed to 250 mm) from the ceiling is about one order of magnitude (~150 s compared to 75 s) but at 15 %obsc the delay is more pronounced (~400 s compared to 100 s). With a small 5 kW fire such a 5 minute delay may be tolerable and it is worth noting that in the real “sofa” fire scenario (Figure 4b), the time difference to reach 15 %obsc is negligible for the three beams within 1m of the ceiling.

The results presented in Figure 4a also indicate that the rising plume from the small 5 kW fire is sufficiently narrow to pass between the supplementary beams – the top level of such detection (at 20 m) only registering as the smoke layer descends from the ceiling (at ~400 s). However, in the sofa fire scenario, the supplementary beams detect the rising plume and would signal an alarm with a threshold of 15 %obsc.

Considering these observations (and those from other scenarios), it is recommended that the maximum spacing of supplementary detectors should not be reduced from ¼H.

Figure 5 depicts the lateral spread of the stratified layer at 600 s, – which clearly increases with increased fire size. This spread (or extent) of the plume is an important factor when considering what the recommended maximum distance between angled beams might be. The spread is largely dependent on energy provided by the fire as this eventually determines the horizontal velocity of the smoke as it moves away from the centerline of the plume into the layer. This horizontal velocity eventually falls to zero – leaving additional smoke to deepen the plume as opposed to extending its reach.

This limitation on the lateral extent of the stratified layer must be considered when formulating a recommendation for the spacing of angled detectors.

Closing remarks

There is insufficient space to present all the results from the project in this short paper. Further analysis and verification of the data generated is anticipated but initial indications are that strategically deployed angled beams can provide more effective (and cost efficient) detection of stratified smoke than current recommendations to deploy a matrix of supplementary detectors spaced at ¼H to detect the rising plume.

Moreover, the results indicate that there is value in criss-crossing the beams though the space (see Figure 6) to avoid excessive horizontal distances between any point in the space and its closest beam.

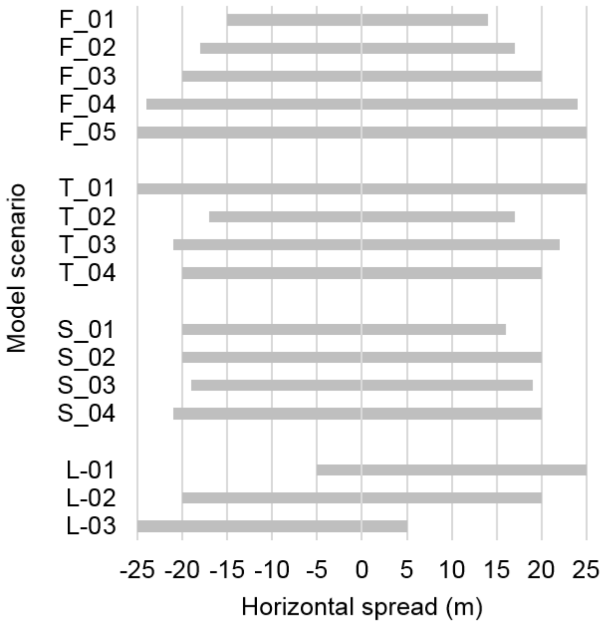

Fig. 5. Horizontal spread/extent of the smoke layer at 600 s.

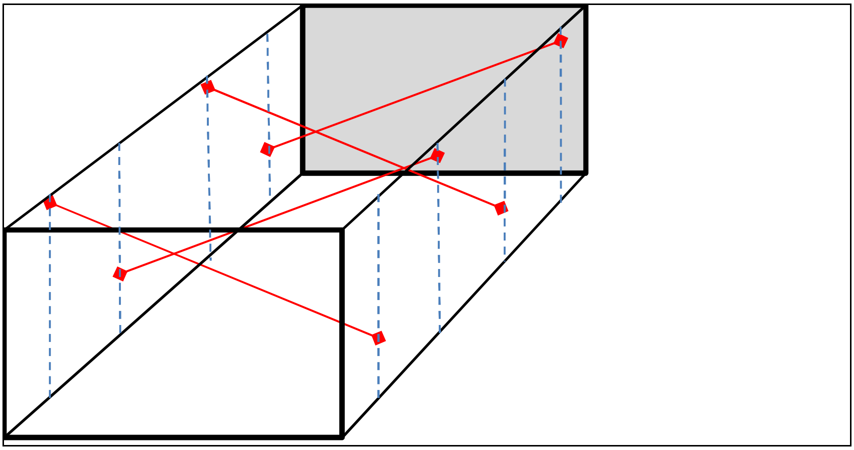

Fig 6. Criss-crossed angled beams.

Acknowledgements

Special thanks go to the following sponsors without whose financial support the project would not have been possible.

- The Fire Industry Association (FIA)
- Xtralis UK Ltd (now part of Honeywell)
- FFE Ltd
- Laluvein Consulting Ltd

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