VESDA®

White paper

What is the least expensive smoke detection system that actually works for ceilings with beams?

Overview

Does the presence of ceiling structures such as beams or joists affect smoke detection performance? If so, is point detector performance more or less susceptible than that of air sampling detector systems? How does the arrangement and location of detection points influence performance? What is the most cost effective fire protection system for areas with such ceiling structures?

With this white paper, we will answer these questions and present a 'Performance-based Design', very early warning, fire protection solution using an Air Sampling Detection (ASD) system. We will show that this approach is not only significantly less expensive overall (purchase, installation and maintenance) than an equivalent point detector system, but that it actually provides a level of fire protection better than that demanded by the local codes and standards.

Vision Systems

The Issues Addressed

Introduction

Designing a fire protection system can quickly become an expensive exercise. Particularly where the structure of the ceiling raises questions about the appropriate number and location of smoke detectors needed to meet local codes and standards.

Ceiling Structure

It is very common for ceilings to be divided into a number of separate compartments by beams or joists. Two sets of parallel beams, orientated at right angles to one another, will result in a grid pattern just under the ceiling as shown in the figures below. The square or rectangular cavities created by the beams are known as 'Inter-beam Spaces'. Joists, arranged in parallel, will divide the ceiling into long trenches rather than Inter-beam Spaces. An example of this is also illustrated below.

Example of a waffle-ceiling

Example of a beamed ceiling in a warehouse

Example of a ceiling with joists

In cases where beams or joists are present, we anticipated the following effects on the movement of smoke:

1. That smoke will become trapped within the Inter-beam Spaces immediately above the fire source.
2. Its movement will be impaired by the barriers created by the beams or joists.

The US National Fire Protection Authority (NFPA) 72 code recommends that, for ceiling heights and beam depths equal or greater than 3.7 m and 300 mm respectively, every compartment (inter-beam space) should contain its own smoke detection point. This means either a point detector in every inter-beam space or an Air Sampling Detection (ASD) system sample hole in every inter-beam space.

Cost

Compliance with the NFPA 72 code would require either of the situations outlined below:

- The number of point detectors installed would need to equal the number of Inter-beam Spaces present in the area being protected.
- ASD pipe sample holes would need to be extended into each inter-beam space, using tubes branching out from the main pipe (as shown in the figure below).

Illustration of ASD pipe sample holes extended into Inter-beam Spaces using tubes branching out from the main pipe.

With this in mind, we asked the following questions when considering how the overall cost of a smoke detection system could be reduced:

- Is it necessary to place a detection point in every inter-beam space or would one in every second, third etc inter-beam space suffice?
- Could an acceptable level of fire protection be obtained with the detector points on the undersides of the beams and, if so, how far apart should the detection points be placed?
- Could an acceptable level of fire protection be obtained with ASD pipes on the undersides of the beams and, if so, how far apart should the sample holes be spaced?

To answer the above questions, we conducted two sets of tests: one set involving Computational Fluid Dynamics (CFD) computer modelling simulations of fire situations and the other set involving real fire events in a mock-up test area. Detailed reports for each of these studies can be obtained by contacting Vision Systems Ltd. (refer to the Contact Details section at the end of this paper). Summaries of both studies are presented below.

Note: Although both studies were conducted according to the US standards, the results also have relevance with respect to other national codes of practice.

Performance

By undertaking the research, outlined below, we also intended to compare the smoke detection performance of an Air Sampling Detection (ASD) system with that of standard point detectors. Descriptions of both types of smoke detector are presented later. The current perception is that ASD systems are for use in special circumstances only; in fact this is not the case.

Smoke Detection

The Smoke Detection Systems Tested

Both photoelectric point detectors and Air Sampling Detection (ASD) systems were tested; Alarm Response times for each device being used to gauge its performance.

In the case of the CFD computer models, detection points are generic and could represent either spot type detectors or sample holes for an ASD system. Data from the computer models must be interpreted according to the different methods of operation of the two devices.

For the in-situ tests, two commonly used photoelectric point detectors were compared with two ASD systems; the only difference between these ASD systems being the sample hole separation.

Point detectors

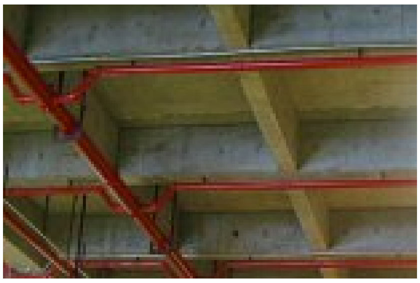
In both studies, two types of commonly used photoelectric point detectors were placed in the centre of Inter-beam Spaces and on the undersides of beams.

Photoelectric detectors are passive smoke detection devices; the smoke must make its own way into the detection chamber by overcoming several obstacles. In order to reach ceiling detectors, smoke particles must either obtain sufficient thermal energy from the fire to ascend to ceiling height or rely on simple diffusion. Once there, they must then penetrate the insect-proof cage which surrounds the detector chamber. If smoke makes it this far, it must then reach a preset density level or obscuration level in order to cause an alarm.

Inside the detector chamber there is a light beam. When smoke particles drift into the normally straight path of this light beam, they scatter it in all directions. Some of this scattered light, now travelling at an angle to the original beam, will strike a photoelectric sensor causing an electric current to flow and an alarm to be issued. The amount of smoke affects the extent to which light is scattered; the greater the amount of smoke, the greater is the extent to which light is scattered. The electric current generated when light hits the photoelectric sensor is proportional to the intensity of the light which, in turn, depends on the amount of smoke present. The relationship between amount of smoke, extent to which light is scattered, light intensity at the sensor and electric current are used to define the sensitivity of the detector.

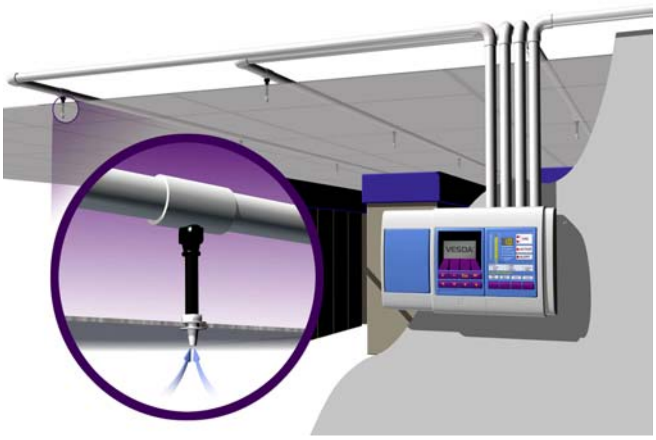
Air Sampling Detection Systems

Two ASD pipes, with different sample hole separation, were placed on the undersides of beams in both studies. A photograph of this arrangement is included below.



Example of an ASD pipe on the undersides of beams

Air Sampling detection systems consist of sections of small diameter pipe with sample holes drilled at regular intervals along their lengths. An air pump in the detection unit, at one end of these pipes, actively draws in air and smoke through these sample holes towards the smoke detector. In some ASD systems, the air is passed through a filter to remove large particles such as dust before entering the detection chamber. Once inside the detection chamber, either a laser light scattering or particle counting technique is used to determine the amount of smoke present in the air sample. The ability to actively collect air samples from the vicinity of the sample holes and the sensitivity of the smoke detection techniques, allows ASD systems to detect smoke very early - in the incipient (smouldering) stage of a fire event. ASD pipes can be run along the ceiling while the detection unit (containing the fan and detection apparatus) remains in a more convenient position. On a wall at an accessible height for example.



Example of the air sampling smoke detection technique

CFD Fire Modelling

The Technique Used

We used Computational Fluid Dynamics (CFD) modelling to determine which dimensions of a beamed ceiling influence the performance of Spot-type and air sampling smoke detectors. The results obtained were then used to generate a set of fire models for a number of rooms with a variety of different characteristics.

One of the fire models was for the setup that was tested in-situ (live smoke tests). The modelled in-situ test was then compared with results for the actual test.

The Fire Dynamics Simulator (FDS) used was developed by the National Institute of Standards and Testing (NIST). Although this fire simulation technique was part of a NFPA funded joint project between Vision Systems Ltd. (Australia) and the Schirmer Engineering Corporation (US), only our contribution is discussed in this white paper.

Sensitivity Study

In order to simplify the CFD computer simulations, we began by conducting a sensitivity study. The purpose of which was to determine the extent to which varying the following parameters effected Alarm Response Times for both point detectors and ASD systems:

- Inter-beam space depth.
- Inter-beam space size (beam spacing).
- Ceiling height.
- Beam width.
- Fire size.

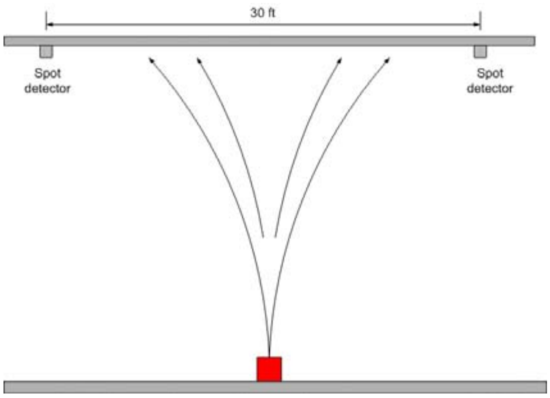
A parameter was considered to be ‘sensitive’ if altering it resulted in a greater than 10% difference in detector performance; Alarm Response Times being used for comparison.

Only ceiling height and inter-beam space size were found to be sensitive. Although fire size was suspected to be a sensitive parameter, it was not possible to show this due to the fact that the fires modelled were all of low energy.

Simulation Parameters

For the purposes of the simulation, the fires were located in the worst possible location, that is, as far from a detection point as possible. Hence, fires were in the centre of a group of four detection points. Three fire types were modelled: a constant 100 kW fire, a constant 500 kW fire and a slow growth T-square fire. These fire sizes are relatively small (low energy) compared with the fire sizes normally used in smoke detection performance evaluations; the reason for this being to highlight the early warning capability of ASD systems.

The NFPA 72 code stipulates that, on a flat ceiling, detectors should be no more than 9.1 m apart. We used a CFD model of this situation, shown below, as a benchmark against which the detection performances for other ceiling structures and detection point positions could be compared.



The flat ceiling benchmark showing the worse-case scenario for fire location

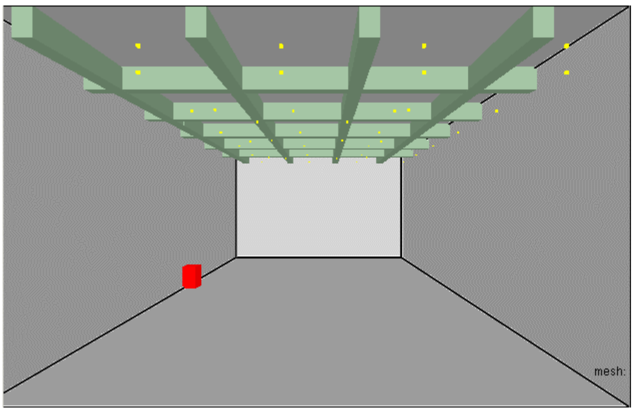
As for the sensitivity study, an acceptable limit of performance was set. In this case the detection systems had to perform better than the flat ceiling benchmark by 5% or more. Again, Alarm Response Times were used as a measure of detector performance.

For all of the modelled ceilings with beams and joists, detection points were placed in every inter-beam space to determine whether such placement is necessary. Detection points were also put on the undersides of beams at distances of 3.65 m and 4.57 m from the fire source (that is, half of a 7.3 m detector separation and half of the NFPA 72 recommended flat ceiling detector separation of 9.1 m). The ASD pipes were also placed on the undersides of beams near the fire and 4.57 m from it to assess whether adequate fire protection can be provided with the pipes in this position.

Alarm thresholds for the simulated point detectors and ASD systems were as follows:

- Point detector level 1 alarm = 0.8%obs/m.
- Point detector level 2 alarm = 5%obs/m.
- ASD system level 1 alarm = 0.1%obs/m.
- ASD system level 2 alarm = 0.2%obs/m.

The point detectors used were more sensitive than usual to compensate for the small fire sizes being modelled.



Example of a CFD model

Since the results of the sensitivity study suggested that ceiling height and inter-beam space size alterations would be most likely to affect detector performance, these two parameters plus inter-beam space depth were varied as part of the simulation process. Although inter-beam space depth was not found to be sensitive, by computer modelling, it was seen to be a significant factor in detector performance during the in-situ tests. For this reason and due to the fact that the NFPA 72 code includes beam depth restrictions, beam depth was also varied in the simulation runs. The ceiling heights and inter-beam space dimensions modelled are discussed later.

How The CFD Generated Data Was Analysed

All Alarm Response Times were converted into percentages, relative to a performance benchmark. In the CFD simulations, the benchmark Alarm Response Time was established by the first point detector on a flat ceiling to issue an alarm. On this benchmark model, Point detectors were spaced at 9.1 m, the NFPA 72 recommended spacing for flat ceilings.

Suppose that the benchmark Alarm Response Time was 20 seconds. An Alarm Response Time of 25 seconds would equal a relative percentage of 25%. Below is an example of how we calculated these relative percentages:

Relative % = 100((Alarm Response Time – Benchmark/)benchmark)
= 100((25 – 20)/20)
= 100 (0.25)
= <u>25%</u>

An Alarm Response Time of 15 seconds would equate to a relative percentage of –25%. Thus, positive percentages indicated a worse than benchmark performance while negative percentages indicated a better than benchmark performance.

For the CFD models, a percentage of less than –5% was considered to indicate that the detector placement was acceptable, that is, the more negative the number the better was the performance.

What The CFD Models Revealed

Point detectors Inside Inter-beam Spaces

The table below shows our calculated relative percentages for the first point detector inside an inter-beam space to issue an alarm. These percentages are relative to the flat ceiling benchmark CFD model. Negative percentages indicate better than benchmark performance, positive percentages indicate worse than benchmark performance.

Relative percentages of performance for the CFD modelled Point detectors inside Inter-beam Spaces.
✓= acceptable performance ✗ = unacceptable performance

Ceiling Height	Inter-beam space Dimensions	Point detector in every Inter-beam space	Point detector in every 2nd Inter-beam space	Point detector in every 3rd Inter-beam space
3.7 m	$0.81\ m^2$	-10% ✓	-10% ✓	17% ✗
	$3.24\ m^2$	-3% ✗	0% ✗	30% ✗
	$13.32\ m^2$	0% ✗	13% ✗	53% ✗
5.5 m	$0.81\ m^2$	-10% ✓	-3% ✗	13% ✗
	$3.24\ m^2$	-7% ✓	0% ✗	33% ✗
	$13.32\ m^2$	-3% ✗	23% ✗	63% ✗
7.3 m	$0.81\ m^2$	-10% ✓	-7% ✓	17% ✗
	$3.24\ m^2$	-7% ✓	-7% ✓	37% ✗
	$13.32\ m^2$	-3% ✗	58% ✗	73% ✗
11.0 m	$0.81\ m^2$	-6% ✓	-6% ✓	9%✗
	$3.24\ m^2$	-6% ✓	-6% ✓	28% ✗
	$13.32\ m^2$	-9% ✓	35% ✗	44% ✗
15.2 m	$0.81\ m^2$	-8% ✓	-5% ✓	11% ✗
	$3.24\ m^2$	-5% ✓	-3% ✗	45% ✗
	$13.32\ m^2$	-8% ✓	58% ✗	58% ✗

It is clear from these results that placing a point detector in every third inter-beam space is not an option; all relative percentages being worse than the NFPA 72 flat ceiling benchmark. In some cases, particularly with higher ceilings and smaller Inter-beam Spaces, it may be feasible to place point detectors in every second inter-beam space. This is due to the fact that performance, compared with the benchmark, is more than 5% better (less than -5%). However, in the majority of cases, we do not think it advisable.

Point detectors On The Undersides Of Beams

The table below shows our calculated relative percentages for the first point detector on the undersides of beams to issue an alarm. Percentages are for Point detectors both 3.7 m and 4.57 m from the fire source and are relative to the flat ceiling benchmark CFD model. Negative percentages indicate better than benchmark performance, positive percentages indicate worse than benchmark performance.

Relative percentages of performance for the CFD modelled Point detectors on the undersides of beams.
✓= acceptable performance ✗ = unacceptable performance

300 mm Deep Inter-beam Spaces	**Ceiling Height**	**0.81 m² Inter-beam Spaces**	**3.24 m² Inter-beam Spaces**	**13.32 m² Inter-beam Spaces**
NFPA 72 Separation (9.1 m)	3.7 m 5.5 m 7.3 m	6% ✗ 9% ✗ 9% ✗	15% ✗ 21% ✗ 18% ✗	15% ✗ 18% ✗ 12% ✗
Close Separation (7.3 m)	3.7 m 5.5 m 7.3 m	0% ✗ 0% ✗ 3% ✗	12% ✗ 15% ✗ 12% ✗	12% ✗ 12% ✗ 3% ✗
600 mm deep Inter-beam Spaces				
NFPA 72 Separation (9.1 m)	3.7 m 5.5 m 7.3 m	27% ✗ 12% ✗ 15% ✗	30% ✗ 34% ✗ 25% ✗	15% ✗ 25% ✗ 21% ✗
Close Separation (7.3 m)	3.7 m 5.5 m 7.3 m	6% ✗ 6% ✗ 9% ✗	21% ✗ 27% ✗ 15% ✗	12% ✗ 21% ✗ 18% ✗

These results indicate that point detectors on the undersides of beams, for any of the situations modelled, did not perform adequately. All percentages for point detectors were positive and, hence, worse than the benchmark.

ASD Pipes On The Undersides Of Beams

The table below shows our calculated relative percentages for the two different sample hole separation ASD systems. ASD pipes are 4.57 m from the fire source. Percentages are relative to the flat ceiling benchmark CFD model. Negative percentages indicate better than benchmark performance, positive percentages indicate worse than benchmark performance.

Relative percentages of performance for the CFD Modelled ASD sample holes on the undersides of beams.
✓= acceptable performance ✗ = unacceptable performance

300 mm Deep Inter-beam Spaces	**Ceiling Height**	**0.81 m² Inter-beam Spaces**	**3.24 m² Inter-beam Spaces**	**13.32 m² Inter-beam Spaces**
NFPA 72 Separation (9.1 m)	3.7 m	-15% ✓	-3% ✗	0% ✗
	5.5 m	-9% ✓	0% ✗	3% ✗
	7.3 m	-12% ✓	-3% ✗	6% ✗
	11.0 m	-24% ✓	-24% ✓	-26% ✓
	15.2 m	-26% ✓	-24% ✓	-29% ✓
Close Separation (7.3 m)	3.7 m	-21 ✓	-12% ✓	-15% ✓
	5.5 m	-21% ✓	-9% ✓	-12% ✓
	7.3 m	-18% ✓	-12% ✓	-15% ✓
	11.0 m	-27% ✓	-27% ✓	-30% ✓
	15.2 m	-32% ✓	-32% ✓	-34% ✓
600 mm Deep Inter-beam Spaces				
NFPA 72 Spacing (9.1 m)	3.7 m	-9% ✓	18% ✗	6% ✗
	5.5 m	-6% ✓	3% ✗	12% ✗
	7.3 m	-6% ✓	3% ✗	12% ✗
	11.0 m	-24% ✓	-18% ✓	-21% ✓
	15.2 m	-29% ✓	-21% ✓	-18% ✓
Close Separation (7.3 m)	3.7 m	-18% ✓	-3% ✗	-12% ✓
	5.5 m	-18% ✓	-9% ✓	-6% ✓
	7.3 m	-15% ✓	-9% ✓	-18% ✓
	11.0 m	-27% ✓	-21% ✓	-24% ✓
	15.2 m	-32% ✓	-24% ✓	-29% ✓

We see from these results that, the ASD system with 7.3 m sample hole separation performed significantly better than the benchmark in every situation; percentages being less than the –5% considered to be an improvement. For the ASD system with sample holes at the NFPA 72-recommended maximum spacing of 9.1 m, the sensitivity of ceiling height and pocket size is obvious; positive percentages indicating poor performance under certain conditions. For ceilings lower than 7.3 m, we recommend reducing the sample hole separation to 7.3 m under the following conditions: where the Inter-beam Spaces are 600 mm deep or more and the Inter-beam Spaces are larger than 3.24 m^2.

In-situ Test Procedures

Test Program

The in-situ test program was developed and conducted in conjunction with the Australian government's Commonwealth Science and Industry Research Organization (CSIRO); representatives from which participated in the experimental work as an independent third party.

A total of twenty real-life tests were conducted, in our warehouse facility, using four different smoke sources and five different mock-up beamed ceiling structures. The numbers and locations of the photoelectric Point detectors and ASD systems are discussed later.

Ceiling Structure Mock-ups

Our Engineers constructed a polystyrene mock-up ceiling that allowed the inter-beam space size and depth to be adjusted. An example is shown below. The ceiling could also be converted to parallel joists.

Example of the mock-up ceiling structure

The five combinations of inter-beam space size and depth tested were as follows:

- Small 300 mm Deep Inter-beam Spaces – 1.25m by 1.25 m.
- Large 300 mm Deep Inter-beam Spaces – 1.25 m by 2.5 m.
- Small 600 mm Deep Inter-beam Spaces – 1.25 m by 1.25 m.
- Large 600 mm Deep Inter-beam Spaces – 1.25 m by 2.5 m.
- 600 mm Deep Joists (No Inter-beam Spaces) running the entire length of the mock-up ceiling 1.25 m apart.

The mock-up ceiling structure dimensions were 7.8 m by 7.0 m. Due to the fact that the mock-up was at an angle of 6.5°, it was higher at one end than the other with an average height of 6.1 m.

Smoke Source

Each of the five ceiling structures were tested with four different smoke sources. Due to the large volume of results that these tests generated, we will consider the results for one smoke source only - the CSIRO Smoke Test Method. The other smoke sources were a timber fire, a paper fire and a 1 m length of smouldering electrical wire. Since these fires were small, the smoke emitter in the CSIRO Test generated more smoke than any of the other sources and was, therefore, easier to detect. The emitted smoke was given the thermal energy needed to ascend to the ceiling by four 6 kW heaters.

As for the CFD simulations, these fire types were low energy so that they could be properly controlled within the size restrictions of the test area.

Smoke Detection Devices

A number of different smoke detection devices were located on the mock-up ceiling structure as follows:

- Thirty Type A Photoelectric Point detectors were placed at the centre of every inter-beam space. Alarm thresholds for these detectors were 0.8%obs/m (*level 1*) and 1.8%obs/m (*level 2*).
- Four pairs of Photoelectric Point detectors (one Type A and one Type B) were placed on the undersides of beams at the points where the beams cross, as shown below. Two different distances from the smoke source were assessed in this case; close to the smoke source and 4.57 m away from the smoke source (that is, half of the NFPA 72 recommended detector separation for a flat ceiling). Alarm thresholds for the Type A detectors were as before, thresholds for the Type B detectors being 0.6%obs/m (*level 1*) and 1.67%obs/m (*level 2*).

- Two VESDA LaserPLUS VLP000 ASD systems were also placed on the undersides of beams; one with a sample hole separation of 4 m and the other with a sample hole separation of 1.25 m. The VESDA pipes were located 4.57 m from the smoke source (that is, half of the NFPA 72 recommended detector separation for a flat ceiling). Alarm thresholds for these detector systems were 0.08%obs/m (*alert*) and 0.14%obs/m (*action*).

Again, the point detector thresholds were low to compensate for the low energy fires and smoke production methods used.

The VESDA systems had to be significantly scaled down; their sample hole separations being greatly reduced, from the usual 9.1 m, so that they would fit within the smaller dimensions of the mock-up beamed ceiling (7.8 m by 7.0 m).

The following key explains the symbols used to represent the various smoke detection devices in the diagram below:

SD 32–35 - Standard Photoelectric Point detectors under beams.
SD 2–31 - Standard Photoelectric Point detectors inside Inter-beam Spaces.
SD 36–39 - High Sensitivity Laser-based Point detectors under beams.
● - VESDA LaserPLUS Unit with 4 m (4 m) sample hole separation.
● - VESDA LaserPLUS Unit with 1.25 m (1.25 m) sample hole separation.
○ - VESDA LaserCOMPACT Unit reference.

○ ▬ - CSIRO Obscuration Meter reference.

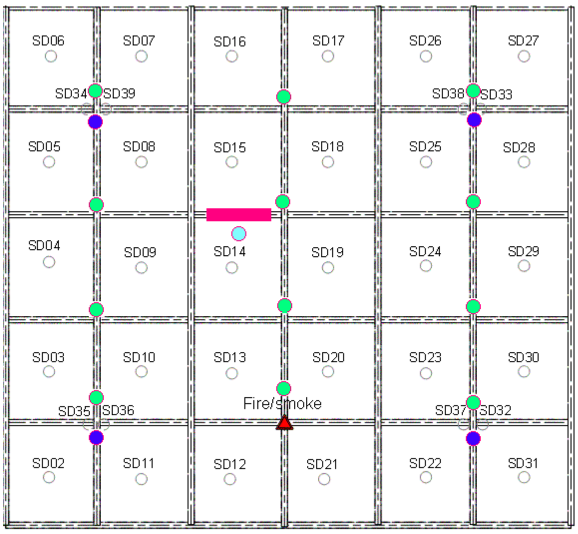


Diagram showing the positions of the Point detectors and ASD pipe sampling holes on the mock-up beamed ceiling.

Alarm Response Times for each device were recorded on a stop-watch during each test run. The start of the test was defined as the instant smoke became visible at the smoke source. All tests were halted after five minutes; any alarms occurring after this point being ignored. All detectors were reset prior to each test run and smoke remaining in the test area was cleared before proceeding.

How The In-situ Test Results Were Analysed

As for the CFD Models, Alarm Response Times for all detector types and positions, were converted into percentages related to a performance benchmark. In the in-situ tests, the benchmark Alarm Response Times were established by the first point detector to issue an alarm. Only negative percentages (better performance than the benchmark) were deemed to indicate appropriate fire protection.

Note: The raw Alarm Response Time data can be found in the Appendices of the In-situ Test report.

In Pocket Detector performance Assessment

In order to assess whether a detection point is needed in every inter-beam space, a 'Zone Concept' was devised to categorize the Inter-beam Spaces according to their positions with respect to the smoke source. As the smoke plume ascends to the ceiling, it spreads out in all directions. In a still air environment, the smoke plume will be more or less circular; the diameter of this circle, at any height, being equal to half of that height (smoke plume diameter = height/2). We superimposed a circle of the appropriate diameter for the height of the ceiling, as shown in the diagram of the small inter-beam space ceiling structure mock-up below.

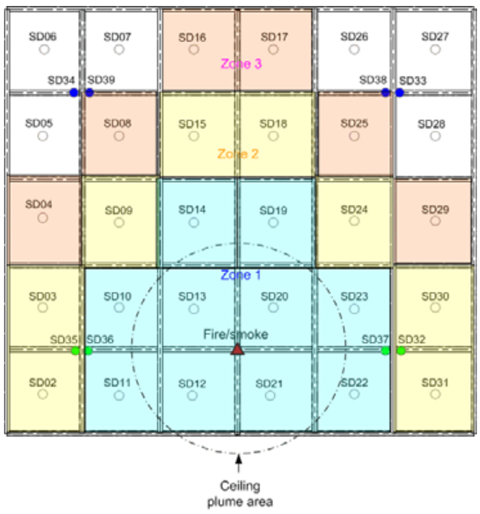


Illustration of the Zone concept for the small Inter-beam Spaces used in the in-situ tests and the computer model of one of these tests.

Zone 1 contains all Inter-beam Spaces for which the smoke plume covers at least one quarter of the area of the inter-beam space. Zone 2 Inter-beam Spaces border those in Zone 1, Zone 3 Inter-beam Spaces border those in Zone 2and so on.

By investigating the performance of Point detectors in each Zone, it is possible to assess whether a Point detector is really needed in every pocket or whether every second or third pocket would suffice. If the detectors in Zone 2, that is further away from the fire source, perform well it can be concluded that the every pocket requirement is unnecessary.

For example, suppose that Zone 1 has a diameter such that it covers four Inter-beam Spaces (two on either side of the fire source). If the detectors in Zone 2 perform satisfactorily, compared with the benchmark, it is not necessary to put a Point detector in every pocket. Since Zone 2 is three pockets away from the fire source, a Point detector in every third pocket may be adequate; a more cautious approach would be to place a detector in every second pocket.

Out Of Pocket Detector performance Assessment

In order to determine whether placing point detectors and ASD systems on the undersides of beams provides adequate fire protection, the performances of these detectors were compared to that of the benchmark Zone 1 point detector.

What The In-situ Test Results Revealed

Point detectors Inside Inter-beam Spaces

The table below shows the percentages of performance, for the first Zone 2 in-situ test point detector to issue an alarm. Percentages are relative to the benchmark Zone 1 in-situ test point detector. Negative percentages indicate better than benchmark performance, positive percentages indicate worse than benchmark performance.

Relative percentages of performance for point detectors inside Inter-beam Spaces on the in-situ test ceiling mock-ups

	Small Inter-beam Spaces 300 mm Deep	**Large Inter-beam Spaces 300 mm Deep**	**Small Inter-beam Spaces 600 mm Deep**	**Large Inter-beam Spaces 600 mm Deep**	**600 mm Deep Joists**
Zone 2 Point detector	139%	46%	80%	50%	Not Detected

From these results, we see that the point detectors in Zone 2 performed significantly worse than the Zone 1 benchmark for all ceiling mock-up structures. Since Zone 1 for both inter-beam space sizes is never more than three Inter-beam Spaces wide, Zone 2 is always less than two Inter-beam Spaces away from the smoke source. Hence, we can conclude that placing a point detector in every second inter-beam space will not provide adequate fire protection in the situations tested.

Point detectors On The Undersides Of Beams

The table below shows the performance percentages for the fastest responding point detectors placed on the undersides of beams. Results are for detectors both close to and at half of the NFPA 72 recommended spacing (that is, a distance of 4.57 m) from the smoke source. Percentages are relative to the benchmark Zone 1 in-situ test point detector. Negative percentages indicate better than benchmark performance, positive percentages indicate worse than benchmark performance.

Relative percentages of performance for Point detectors on the undersides of beams on the in-situ test ceiling mock-up.

Point detector Under Beams	**Small Inter-beam Spaces 300 mm Deep**	**Large Inter-beam Spaces 300 mm Deep**	**Small Inter-beam Spaces 600 mm Deep**	**Large Inter-beam Spaces 600 mm Deep**	**600 mm Deep Joists**
Near Smoke Source	178%	Not detected	52%	88%	29%
4.57 m Away	Not detected	Not detected	184%	Not Detected	25%

Regardless of the distance from the fire, we can see from these results that placing point detectors on the undersides of the beams will not provide even an equivalent level of protection to the Zone 1 benchmark. It is, therefore, not advisable to do so.

ASD Pipes On The Undersides Of Beams

The table below shows the performance percentages for both sample hole separation VESDA ASD units at the NFPA 72 recommended distance of 4.57 m from the smoke source. Percentages are relative to the benchmark Zone 1 in-situ test point detector. Negative percentages indicate better than benchmark performance, positive percentages indicate worse than benchmark performance.

Relative percentages of performance for VESDA units on the undersides of beams on the in-situ test ceiling mock-ups.

NFPA 72 Distance (4.57 m)	**Small Inter-beam Spaces 300 mm Deep**	**Large Inter-beam Spaces 300 mm Deep**	**Small Inter-beam Spaces 600 mm Deep**	**Large Inter-beam Spaces 600 mm Deep**	**600 mm Deep Joists**
VESDA (4 m Hole Separation)	4%	12%	-8%	-4%	18%
VESDA (1.25 m Hole separation)	-35%	-4%	-12%	-38%	-18%

The positive percentages for 300 mm deep Inter-beam Spaces and 600 mm deep joists indicate that, under these circumstances, it would be advisable to reduce the VESDA ASD sample hole separation. Note that the VESDA system with 1.25 m sample hole separation performed significantly better than the benchmark Zone 1 point detector in all cases.

In-situ Test/CFD Model Comparison

A CFD simulation of one of the in-situ tests (small 600 mm deep Inter-beam Spaces) was generated to verify our findings. A CSIRO Smoke Test method was used for the modelled fire as it consistently produced more smoke during in-situ tests and hence better Alarm Response Time results.

When we compared all detector Alarm Response Times for the small 600 mm deep inter-beam space in-situ test and the corresponding computer simulation, we found an average difference between results of 4.5%. This low percentage difference indicates very good correlation between the real and modelled results for an identical situation.

Conclusions

Design Recommendations

As a result of our research, Vision Systems recommend the following when designing a fire protection system for an enclosure with the types of ceiling structures investigated here:

- Regardless of inter-beam space dimensions, it would be advisable to place a point detector in every inter-beam space, as stipulated in the NFPA 72 code. Although, some of our simulation results indicated that every second pocket would suffice, the bulk of the data suggested otherwise.
- Regardless of ceiling structure, it is never advisable to place point detectors on the under sides of beams or joists.
- Regardless of ceiling structure, placing ASD pipes with the appropriate sample hole separation on the undersides of beams or joists will always provide the required level of fire protection. Our results indicated that sample hole separation reductions were needed for ceiling heights of less than 7.3 m where Inter-beam Spaces were larger than 1.8 m by 1.8 m (3.24 m^2) and 600 mm or more deep.

How Relevant Are These Results Under UK Regulations?

The British Standards BS5839 part 1 (2002) recommends that, where inter-beam space width is equal to or less than four times inter-beam space depth, point detectors should be located on the undersides of the beams regardless of ceiling height or beam depth. The maximum, detector separations specified depend on ceiling height but never exceed the flat ceiling limit of 10.6 m. Our studies revealed that, under no circumstances, was it advisable to place point detectors on the undersides of the beams. Between the in-situ test and computer simulations, we covered ceiling heights from approximately 3.7 m to 15.2 m, inter-beam space widths of 1.25 m to 3.6 m and inter-beam depths of 300 and 600 mm; all of which is within the ranges outlined in the BS5839 code.

We also discovered, in both of our studies, that it was necessary to place a point detector in every inter-beam space; even with point detectors in the centre of every second inter-beam space, a suitable level of performance could not be achieved. Under the BS5839 code of practice, point detectors are placed inside inter-beam spaces where inter-beam space width is greater than four times beam depth. Again, detector separation varies according to ceiling height with out exceeding the flat ceiling limit of 10.6 m. This code also specifies inter-beam space depths in terms of greater or less than 10% of ceiling height. It is possible, therefore, for inter-beam spaces to miss out on a point detector as a result of the relationship between its dimensions and the height of the ceiling.

For example, suppose the ceiling height is 15m and the inter-beam space depth is more than 10% of the ceiling height (more than 1.5 m). The BS5839 code states that for inter-beam spaces with widths of more than four times inter-beam depth (more than 6 m in this case), point detectors should be inside the inter-beam spaces with a separation of 13 m. It is obvious, when comparing inter-beam space width with detector separation (6 m versus 13 m), that only every second inter-beam space would require a detection point to comply with the regulations. Remembering that the beams themselves have unspecified width to be accounted for in the detector separation.

For ceilings with joists, detector location (on the undersides of beams or inside inter-beam spaces) is unspecified. Detector separation is, once more, dependant on ceiling height, hence depending on the distance between joists, point detectors could be both on the undersides of beams and in some inter-beam spaces but not necessarily all inter-beam spaces.

It is clear that placing a VESDA pipe on the undersides of beams, with an appropriate sample hole separation, would greatly simplify the problem of designing a fire protection system to the British standards.

Smoke Detection Performance

As stated in the introduction, the purpose of this white paper is to present a cost effective, high performance, fire protection solution for enclosures possessing ceilings with beams or joists. It is obvious, on examination of both the CFD models and in-situ results, that the VESDA system with closer spaced sample holes consistently detected smoke significantly sooner than point detectors inside Inter-beam Spaces. Situations where the NFPA 72 recommended spacing was insufficient are easily categorized into certain ceiling heights and inter-beam space sizes.

For practical reasons, we only included one set of in-situ test results in this white paper; those of the CSIRO Smoke Test Method. With the exception of the 1 m smouldering wire test, the other two fire sources (timber and paper) yielded comparable results to the ones presented above. Even although the point detector alarm thresholds were lower than usual, they were unable to detect the small amounts of smoke emitted by the smouldering length of wire. Conversely, in 40% of cases, both VESDA systems succeeded in registering the presence of the sub-threshold level of smoke emitted by the smouldering wire.

Cost Comparisons

Our two studies show that the only viable options are either to place a spot detector in every beam pocket or to install a VESDA ASD system on the undersides of the beams. So, how would the purchase and installation costs of these two options compare?

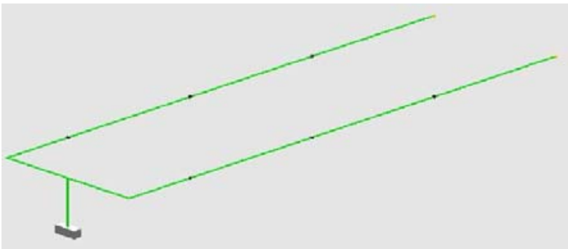
To answer this question, we created a hypothetical storage area with the following dimensions:

- Length 40 m
- Width 15 m
- Height 8 m
- Beam Depth 600 mm
- Beam Pocket Size 2 m by 2 m
- Number of Beam Pockets 96

There are two possible fire protection systems for this space:

1. To comply with the NFPA 72 code, it would be necessary to purchase, install and maintain 96 spot detectors plus the electronics, cabling, conduits etc which accompany them.
2. According to our findings, it would only be necessary to purchase, install and maintain a single VESDA LaserCOMPACT 800 with a total pipe length of 85 m and 10 sample holes 9.1 m apart as shown in the diagram below.

Either of these options could be integrated with a standard Fire Alarm Control Panel and any other components of a Fire Protection System.



VESDA ASD solution for the hypothetical storage area

To determine the difference in cost between the two systems, we sought the experience and expertise of an Australian fire consultancy company (Blue Fire Systems) who provided an estimate of the comparative cost of purchasing and installing both systems.

It was calculated that the VESDA option would cost a mere 16% of the point detectors option; a massive saving of 84%. The costing for the point detectors included conduits to conceal the electrical cabling. Even without conduits, leaving the wires exposed, the VESDA solution still represented a saving of 73%. Staff in our US office also did a cost comparison, with very similar results (a saving of 85% including conduits, 75% with out).

One of the major contributors to these enormous differences in price was the labour; the time needed to install 96 point detectors and their accessories.

Note: Percentages are used for comparison in respect of Blue Fire Systems’ request that commercially sensitive pricing information not be made public.

The Cost-of-Ownership difference between the two systems would also be significant. Having to climb up and down a ladder 96 times to test and maintain each point detector would take much longer than testing one VESDA detector installed at shoulder height. Imagine doing this each year for the lifetime of the building and you begin to see the longer term savings involved.

So, not only did the VESDA solution outperform the point detectors on ceilings with beams or joists, it is also cheaper.

The VESDA Advantage

In summary, the advantages of the VESDA solution include:

- Lower overall cost - when considering long-term ongoing maintenance as well as purchase price and installation, A VESDA system would be more economical than numerous point detectors.
- Very early warning – as can be seen from the tables of results for the VESDA systems, at least one of the two sample hole separations tested was sufficient to out perform the fastest responding point detector in every case.
- Easy access for testing and maintenance – VESDA pipes and other components can be tested at the detector unit located on the wall rather than it being always necessary to access the ceiling components as would be the case for multiple point detectors.

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Document Number: 11847
Version: 00

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