Integrated CFD Models for Air-sampling Smoke Detection

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ABSTRACT

Computational Fluid Dynamic (“CFD”) modelling is becoming a powerful tool both for sophisticated research by fire scientists, and as a part of the daily design routine conducted by fire engineers and consultants. The NIST Fire Dynamics Simulator (“FDS”) has become a standard computer modelling software in fire safety engineering due to its broad community of support world-wide and the many validations conducted for a range of applications.

Application of CFD has been extended from analysis of fire behaviour, to fire response from the environment, to modelling of other systems such as fire detection. Recently these efforts have been extended in FDS version 5 to model the reaction of Air-sampling Smoke Detection (“ASD”) systems, a high sensitivity and reliable fire detection technology. This new capability of FDS relies on input of key parameters of the ASD system to allow FDS5 to make a realistic prediction of detection performance. Even through major ASD manufacturers have developed special tools to compute those parameters, it’s still a challenge to convert the ASD system designs into FDS modelling, especially for those designs with complicated system layouts.

Working with Worcester Polytechnic Institute (“WPI”), Xtralis AG (“Xtralis”) developed a software tool called AspireSDS which integrates the ASPIRE2 pipe network design software and FDS5. The new tool is capable of converting any existing ASD design (modelled within ASPIRE2) into a standard FDS5 input file. With the improved efficiency of working with the AspireSDS tool fire engineers and consultants can focus on other critical variables that may affect prediction of detection, such as fire source, contents and ventilation.

This paper describes the need for the tool, and how this convenient tool can be used by fire engineers and consultants to more efficiently design ASD systems in any built environment. With the support of such tools and greater awareness by fire engineers, modelling of ASD system will provide immense value for the community.

INTRODUCTION

1. ASD Systems

In their simplest form, ASD systems continually draw air samples from the equipment or area requiring protection, through a network of pipes to a central detector for assessment of the presence of smoke. The sensitivity of an ASD detector is typically hundreds of times greater than conventional point (spot) smoke detectors. Such high sensitivity is required to detect the earliest traces of airborne particles or aerosols released due to the overheating of materials. As an example, Xtralis’s VESDA detectors can reliably provide a very early warning alarm at a smoke obscuration level of 0.005 %Obs/m, compared to a range from 1 to 10 %Obs/m typically claimed by conventional point detectors.

ASD’s “active” sampling mechanism, drawing the smoke into the pipes and to the detector, eliminates many of the uncertainties of the environment surrounding the sampling point and contributes to its reliability. Alternatively, complicated environmental conditions, like obstruction and air flow, adds uncertainty to the smoke entry behaviour in a point type

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detector and results in great variation in their detection performance. Some recent studies of point type detectors reported up to 1000% error on their nominal sensitivities[1]. The combination of very high sensitivity, a broad sensitivity range (from very sensitive to very in-sensitive), reliable performance, plus multiple staged alarms and great flexibility in detection options, is why ASD systems are seen being applied in more and more challenging projects. ASD is commonly used for early warning fire detection ("EWFD") for life safety evacuation and very early warning fire detection ("VEWFD") for asset protection and business continuity. However it is also used for triggering other fire protection and safety systems, such as smoke management and suppression systems, etc.

In an ASD system, a pipe network may consist of multiple sampling pipes and holes through which smoke may enter before becoming entrained in the flow to the detector, as shown in Figure 1. Sampling smoke from multiple points is normally described as "accumulative" or "cumulative sampling". Of course, from the other perspective, in any multi-hole system there is a dilution of any smoke entering some of the holes/points before being analysed at the detector. As discussed by the authors previously[2], soot density ("SD") reported at the central detector unit is a function of time over factors of soot density and flow rate at each hole, and the transport time of each hole (the time for smoke travelling from the hole through the pipe network to the detector unit).

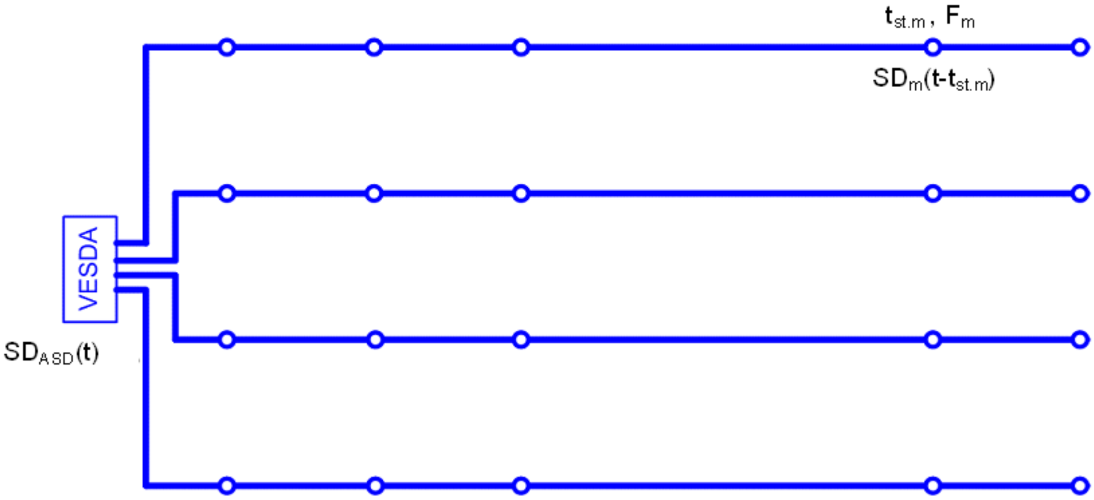


Figure 1: Parameters affecting reported Soot Density in an ASD System

This function can be described as below:

$$SD_{ASD}(t) = \frac{\sum_{m=1}^{s} SD_m(t - t_{st,m}) \times F_m}{\sum_{m=1}^{s} F_m} \qquad (1)$$

where,

SD_{ASD}, soot density in the detector, in kg/m^3;
SD_m, soot density at sampling hole/point *m,* in kg/m^3;
s, total number of sampling holes of the detector;
$t_{st,m}$, transport time from hole *m* to the detector, in second;
F_m, flow rate through sampling hole *m,* in m^3/s.

This formula is similar to the one presented in the User Guide for FDS5's[3].

Using a conversion from soot density to percentage obscuration, more commonly used to define smoke detector sensitivities, the formula can be expressed as follows:

$$OBS_{ASD} = 100 \times \left(1 - \exp\left(-SD_{ASD} \times 8700 \times L\right)\right) / L \qquad (2)$$

where,

OBS_{ASD}, obscuration level in the detector, in %/m;
L, beam path length inside detector chamber, in m.

2. Modelling ASD Detectors in FDS

Modelling of detection performance of fire detectors is becoming an important reason to apply computer models in fire safety engineering designs, especially in performance-based designs ("PBD") where qualitative and quantitative proofs of performance are a prerequisite. Modelling of conventional fire detectors, including point type smoke detectors, heat detectors and beam-type smoke detectors has been possible in previous versions of FDS. However, the accuracy of predicted detection performance of those detectors continues to be under questioning[1][4]. Uncertainty in predicting smoke entry behaviour into the point detector detection chamber and errors in choosing soot yields of various fuel materials have been identified as two major factors causing the low accuracy in the FDS prediction of these detectors[5].

As with the modelling of the other smoke detectors mentioned above, the response of ASD to a fire is predicted by the soot density at the sampling holes calculated in FDS plus transportation inside the pipe network. While soot density distribution can be modelled in FDS, parameters as described in Formula (1) have to be provided to calculate transportation in the pipe network as well as the accumulation/dilution effects. Fortunately, commercial modelling software is available to perform ASD pipe network design and computing to derive such parameters. ASPIRE2 is a leading example of such pipe network modelling software. Calculation of the smoke transportation inside the pipe network and the effect of accumulation/dilution can be manually performed by utilizing FDS simulated soot density results in the previous versions of FDS (FDS4 and former). Thanks to the recent development in FDS version 5, such calculation has been built into simulations for ASD ('Aspiration Detection'), with the key parameters computed from the ASD pipe network modelling software.

Due to its high sensitivity, active sampling mechanism, and well modelled/computed transportation behaviours, a much higher degree of prediction accuracy can be achieved for ASD using FDS, as confirmed by a number of recent studies[6][7]. Application of FDS modelling of ASD detection technology includes various type of building environments, such as large open spaces ("LOS"), high-rise office, multi-story apartment, etc. As validated by in-situ tests from many projects, modelled ASD performance has been widely applied in fire safety engineering designs, including PBDs where proven quantified performance is required.

3. Challenges and Development Requirements

Modelling ASD detection is a challenge for fire consultants and engineers with limited knowledge about this technology, even when utilising FDS5. While further accuracy of the predicted detection performance of ASD systems should always be sought, ensuring the proper and efficient construction of a simulation remains a greater issue in most applications. The industry requires the existing tools be made easier to use.

Though the required parameters of the ASD system can be obtained from the pipe network modelling software (when available), how to convert a complicated ASD system design into the FDS simulation domain remains a difficult task. For example, an ASD detector in an IT server room may have multiple sampling pipes to protect various areas, like under ceiling, inside floor void, in front of air return grille, and even inside server cabinets. To achieve such comprehensive protection, a combination of various ASD pipe network components, such as elbow bends, branches, tees and capillary tubes, etc. may be required in a space stretched in three dimensions. To calculate the coordinates of each component of such a pipe network and enter the required system parameters into FDS input files manually and correctly is laborious and prone to error and therefore limits the broad application of ASD detection modelling in fire safety engineering ("FSE").

Some efforts have been made to assist FDS users to set input files more easily through graphical tools[8] and convert building design in AutoCAD format into the FDS's obstructions automatically[9]. This is certainly a step in the right direction, but no safe or practical tool to perform such conversions for ASD systems is available today. One ASD-pipe-model-to-FDS4 converter, as discussed by one researcher[10], evidences the market demand and need for further development. This tool's serious and unrecorded assumptions on fire source, geometry and ventilation conditions do not allow it to be used as a serious fire safety engineering design tool. Furthermore, the lack of any capability to perform computations of smoke transportation in the pipe network (i.e. only able to provide soot density information at individual sampling holes), prevents it from being compatible with NISTS's latest and supported version of FDS.

To help more fire engineers, consultants and distributors to conduct computer modeling of ASD system, including pre-design modelling for choice of suitable detection technologies, Xtralis, with the cooperation of WPI, has developed an integration tool between the ASPIRE2 pipe modelling software and the FDS input function. This new software aims to enable experienced FDS users to set FDS simulations for ASD designs through an ASPIRE2 calculation. Most of the other functions in FDS can also be set through this graphical user interface ("GUI") based tool as well. Rather than persisting with the time consuming manual input of numerous lines of statements, users can now access a tool that improves their efficiency and the accuracy of FDS settings, avoiding most typos. In addition to providing sophisticated support for ASD designs, the tool also provides support for various other detection technologies to make the tool the one tool required for all FDS input tasks.

MAJOR FEATURES OF ASPIRESDS

1. General Functions

General functions of AspireSDS can be described by following flow chart.

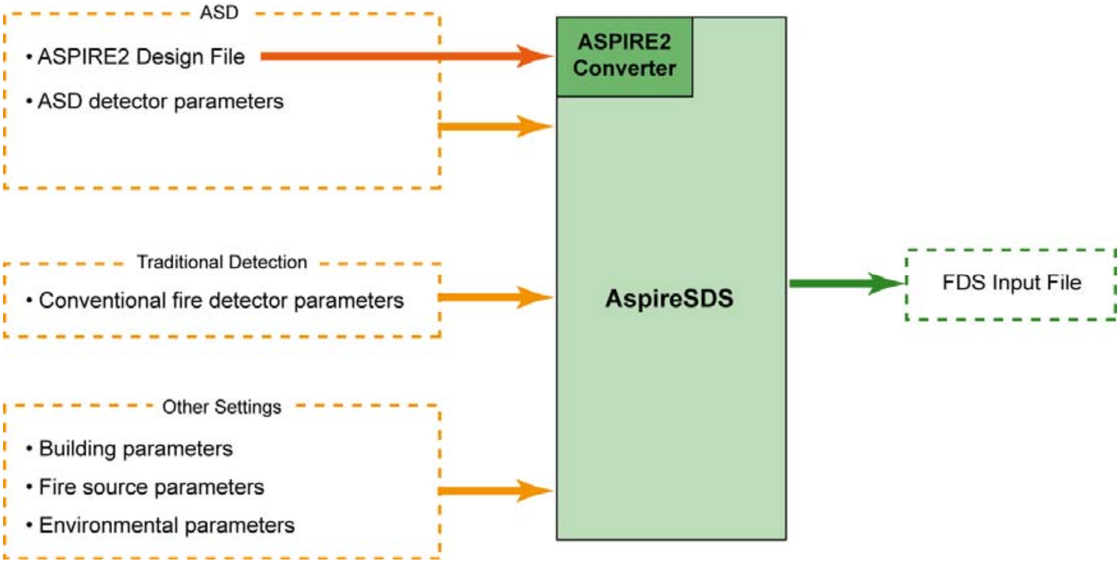
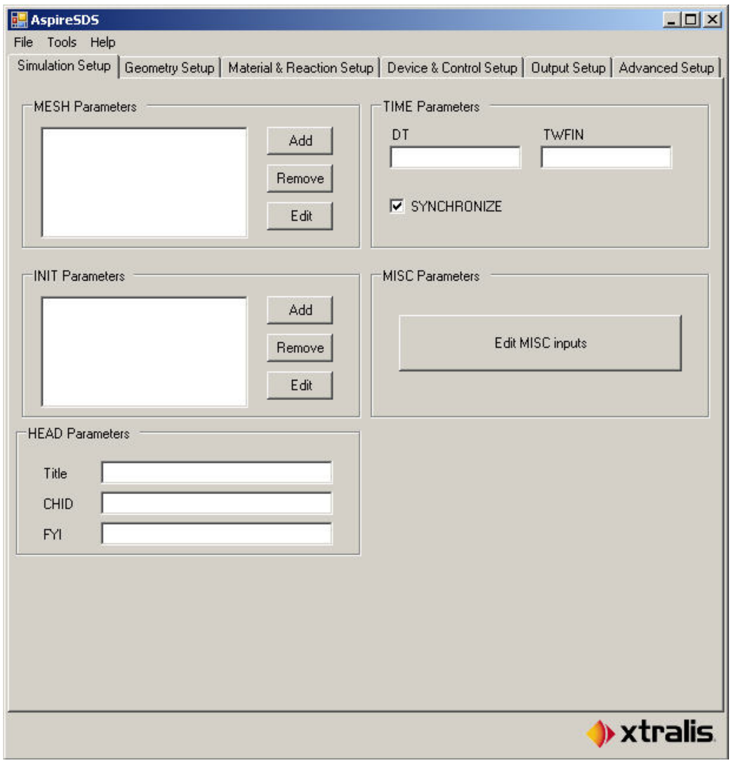


Figure 2: Flow Chart of AspireSDS

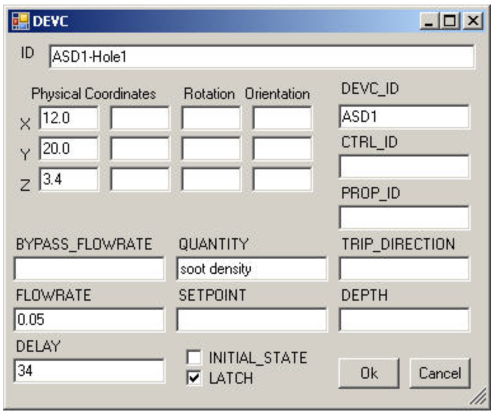
Like other existing FDS input tools mentioned in the previous section, the AspireSDS functions as a GUI tool to allow users to set all parameters for the FDS simulation. All such settings, as inputs shown on the left hand side in Figure 2, can be specified through several tabbed groups: Simulation Setup, Geometry Setup, Materials & Reaction Setup, Device & Control Setup, Output Setup, and Advance Setup. The main window of AspireSDS is shown in Figure 3.



☑ SYNCHRONIZE

Figure 3: Main Window of AspireSDS

Fire Detectors, including ASD systems, can be specified manually in a Device parameters edit window, as shown in Figure 4. The ASD systems are able to be inserted into FDS simulation domain automatically through a ASPIRE converter, which will be introduced in the next section.



ID: ASD1-Hole1

X: 12.0
Y: 20.0
Z: 3.4

DEVC_ID: ASD1

QUANTITY: soot density

FLOWRATE: 0.05

DELAY: 34

☐ INITIAL_STATE
☑ LATCH

Figure 4: ASD Input Window

2. Set ASD System From ASPIRE2 Design

When an existing ASPIRE2 design is available, the parameters of the ASD system can be imported into the FDS input file automatically through the ASPIRE converter.

Below is the converter input window, to allow users to specify coordinates of the detector. By entering the coordinates of the detector and ASD pipe network sampling holes can be placed at desired locations in the simulation domain.

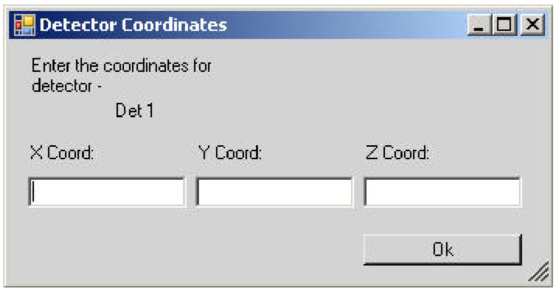


Figure 5: Specification of ASD Detector Position

3. Components of ASD Pipe Network

All pipework components used in the ASPIRE2 design can be handled by AspireSDS. Below is an example of various components and sampling hole types, that are used to compose various complicated ASD pipe networks through AspireSDS. A combination of those components and the hole types was designed and calculated in ASPIRE2 and then smoothly converted into an FDS5 input file.

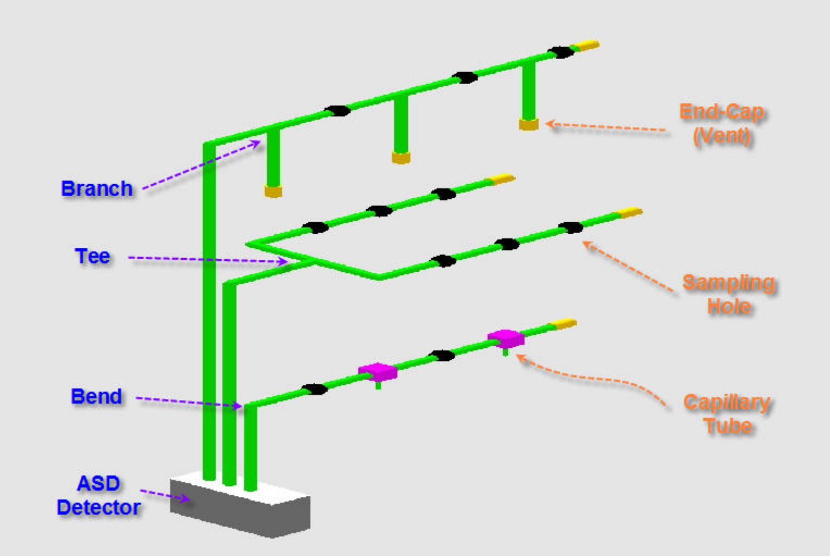


Figure 6: Components and Sampling Hole Types from an ASPIRE2 Design

APPLICATIONS OF ASD SIMULATION

1. Multiple Detectors in Simulation

Multiple ASD detectors can be created in the ASPIRE2 design, and then converted into a FDS input file simultaneously, or by executing the conversion operation for multiple ASPIRE2 files which contain designs of single ASD detectors. Modelling of multiple ASD detectors in a single FDS simulation enables assessment of ASD detection performance with the detectors at different locations or at the same location with various sampling hole spacings, under the same fire scenario. Therefore, prediction of performance from the various protection options can be achieved and the ASD system design can be optimised. Furthermore, this function allows quick assessment of a possible total solution consisting of a number of protection areas as illustrated previously for the IT server room. In this way, verification and optimisation, of a design comprising a mix of ceiling protection, raised floor void protection, air return protection and in cabinet protection can be achieved quickly and with good reliability.

The exact pipe network location for each detector is able to be optimised via adjustment of the detectors’ coordinates through the ASPIRE to FDS converter window that is presented for each detector, as shown in **Figure 5**.

2. Normal and Worst-Case Detection Scenarios

The normal and worst case scenarios assessed in a fire safety design by adopting conventional fire detectors usually relate to fire and environmental conditions. However, for an ASD system, the smoke transportation delays inside the pipe network must also be taken into consideration. In practice, the worst case situation is one where the smoke enters through the last holes of the sampling pipes, i.e. at the farthest point from the ASD detector unit. In this case, the maximum transport time will be applied as the detector’s response time. The more likely situation, where smoke enters through holes located in the middle of the pipe network, may be is treated as the normal case scenario, in which case the average transport time is counted as the detector’s response time.

In FDS5, the predicted detection performance of an ASD system is derived from a simulation scenario with a specified relative location between the fire source and the detection system along with space geometry and ventilation conditions. In a fire safety engineering design, having regard to the relative locations, the prediction may be different from the normal-case and worst-case scenarios mentioned above, To achieve such simulations, the transport times computed by the ASPIRE2 design need to be replaced manually by the average (normal case) and maximum (worst case) transport times through the Device & Control window in AspireSDS.

3. Protection of Multiple Zones

When multiple zones are protected by one ASD detector, such as with the 4-pipe addressable VESDA VLS, different alarm thresholds may be set for each zone to meet various required protection levels for the zones. Therefore, the ASD setup can not be performed by converting from the ASPIRE2 file directly.

The desired ASD simulation can be achieved by following two alternative methods. (1) Split the ASD detector as multiple detectors with different threshold setups in the protection zones. Then build the multiple detectors into the modelling domain as discussed in the previous section. (2) After conversion of the ASPIRE2 file into the FDS input file, manually split the sampling holes into different ASD detectors in AspireSDS and specify the thresholds for the multiple detectors according to the value set for the zones. Either method is satisfactory.

4. Detection of Other Gases

Detection of gases, such as CO and CO2, is being added into Xtralis ASD systems to utilise their sampling capability through the pipe network. Such gas detection capability can both improve fire detection accuracy by discriminating against dust (and hence reduce false alarms), improve fire detection performance (or provide environmental monitoring) through safer lower thresholds and is anticipated to reduce maintenance and improve ease of networking and monitoring.

The gas detection can be simulated through the aspiration detector function in FDS5 by replacing “soot density” by the gas desired to be monitored, such as “carbon monoxide”. Certain computations must be applied to convert the simulated gas density (usually in mol/mol unit) to the unit that the gas detector supports, such as ppm or %. Meanwhile, a reverse calculation has to be applied manually to compensate the computation from point values to the detector level. For normal ASD detectors, the embedded formula, shown in Formula (2), is applied to compute obscuration level from soot density. In gas monitoring, no such conversion or compensation is required.

5. Accuracy in ASD Detection Simulation

Though improved accuracy has been achieved from ASD detection simulations compared to conventional smoke detectors, certain factors may still affect the quality of the prediction. Over-predicted soot density from FDS is a common source of error for all smoke detection simulations. The over-estimated soot density appears to have a greater impact on the prediction of detection performance of conventional point type smoke detectors due to their relatively lower sensitivity, i.e. they are responding to a higher level of soot density, complicated by uncertainties caused by their passive detection mechanism.

ASD detectors are capable of detecting a significantly lower smoke level than conventional systems. Modelling of VEWFD systems to provide predictions in the incipient stage of fires is challenging but worthwhile. To perform such simulations, more attention should be paid to modelling of geometry details and environmental conditions. As reported from a recent Firegrid test[7], the smoke plume from smouldering cotton braid was affected by a 500W halogen lamp placed in the corner of the test room - an ASD detector sampling from a nearby corridor responded to the smoke earlier than a similar detector sampling in the test room. By modelling the lamp properly, this phenomenon in detection order was simulated successfully. Such results indicate the importance of modelling both fire source and the environment and the excellent potential to achieve good EWFD and VEWFD simulations with ASD.

CONCLUSION

ASD is an advanced detection technology capable of detecting very low levels of smoke. Reliable detection performance resulting from its active sampling and proven pipe network transportation calculations makes it an ideal technology in fire safety engineering designs, including PBDs.

Progress has been achieved in FDS modelling of ASD detection, especially from version 5. Xtralis's AspireSDS meets the market needs for a sophisticated yet user-friendly automated conversion of ASD pipe network design parameters into FDS input files for a broad range of applications. This tool increases the “programming” speed and efficiency, and eliminates syntax errors & typos greatly. By doing so, it allows users, fire consultants and engineers, to model ASD technology in many complicated applications more accurately and with greater confidence, allowing them to devote more focus on the important matters of fire configuration and environmental settings.

FUTURE WORK

For those users with limited knowledge of ASD, it is considered helpful to provide built-in templates supporting a range of typical applications and detailing specific detector coverage. Such templates could also comply with various fire codes/standards in terms of zone size and spacing requirements. Results of simulations from those templates could also be useful to enable comparisons of the detection performance of different ASD products under “standardised” cases. Market interest is being evaluated.

ACKNOWLEDGEMENT

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