# Method of determining smoke detector spacing in high ceiling applications

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## Introduction

Simple tools for the application of smoke detectors in commercial spaces with high ceilings and/or complex geometries do not exist due to the complexity in accurately estimating smoke densities and smoke detector response and activation. A method for predicting smoke detector activation has been sought for some time. Initially, a fuel dependent temperature change correlation was envisioned as an acceptable method by Heskestad and Delichatsios [1]. Other metrics like the Heskestad characteristic detector length [2] and later Davis and Cleary dwell and mixing time model [3] for predicting smoke detector activation time in the presence of a ceiling jet were introduced. A detector material response characteristic was envisioned by Bukowski and Averill [4]. Watanabe and Tanaka [5] developed maximum optical smoke density equations using buoyant plume theory and ceiling jet correlations. Davis and Reneke [6] developed similar correlations that predict smoke concentration in an unconfined ceiling jet. These methods do not incorporate findings that indicate different detector types respond to smoke in different ways [7] even though they are evaluated by the same criteria for listing purposes [8,9], nor do they incorporate the proprietary activation algorithms often included with modern smoke detectors by the equipment manufacturer in an attempt to compensate for false stimuli.

In order for a commercial smoke detector to be listed for use in Canada, it must pass both a smoke box test and room tests in accordance with the standard ULC S529 “Standard for Smoke Detectors for Fire Alarm Systems” [8]. In room tests, a paper fire with a maximum obscuration of 29 %/m, a liquid fuel fire with a maximum obscuration of 35 %/m as well as a smouldering fire with an approximately uniform obscuration of 20 %/m are used to test smoke detectors. The flaming tests require response of the detector within 4 minutes, and the smouldering test requires smoke detector response prior to smoke obscuration per meter reaching 20 %/m within 15 ± 3 minutes. In addition to these tests, UL 268 [9] requires that the test sample pass a wood fire test. The ULC standard test facility is an enclosed room approximately square in plan view with nominal side dimensions between 6 m and 7.6 m. The room height is nominally between 2.4 m and 3 m. The test samples are installed on the ceiling at a radial distance from the test fires of 4.9 m.

Given the lack of a correlation between fire size and smoke characteristics and the height of the enclosure used in standard tests, guidelines for the placement of smoke detectors are limited to normal height ceiling applications [10,11]. Notwithstanding these limitations, smoke detectors are often found in larger rooms with higher ceilings. The intent of this research is to provide further guidance to designers to facilitate the design of smoke detectors in such applications.

## Experiments

To test the ability of commercial smoke detectors that have been listed in accordance with ULC S529 to detect smoke at elevations higher than 3 m and in rooms that are larger than the test enclosure described in the standard, an experimental facility was designed and built at Carleton University’s fire research laboratories. A flat wood platform measuring approximately 10 m x 10 m was used to simulate the ceiling of a large enclosure. The floor area of the test facility is approximately 20 m x 20 m. Light scattering type photoelectric smoke detectors were place in 8 rows of 3 detectors along the diagonal of the platform. The platform was suspended above the floor of the test facility and it could be raised in increments of 3 m up to an elevation of 21 m. The three standard test fires from ULC 529 [8] and UL 217 [9] were used to evaluate the detector performance at the various elevations. Custom test fires using the liquid fuel were also developed to test detector response at elevations above 15 m. For each fuel package and each elevation, tests were repeated 3 times. In all 72 tests were conducted.

## Modeling

Three types of models were used to predict smoke obscuration values at the locations of the smoke detectors. The first method used algebraic equations developed using empirical data, combined with buoyant plume theory and ceiling jet correlations [5,6]. The other methods were the two-zone computer model CFAST [12] and the fluid dynamics simulator computer model FDS [13]. Model inputs included the experimental heat release rates, smoke yield data and environmental data. The peak heat release rate was used for the algebraic models, but the time averaged values of heat release rates were input to both computer models use. The heat release rates from the Smoke Characterization Project [7] were used as model inputs for the paper and wood fire tests and for the liquid fuel fire tests the heat release rates were estimated from plume temperature measurements taken during the experiments.

## Results

Results of the tests using different types of fuel with the ceiling platform located at a height of 6 m are compared with the model predictions in Figures 1 – 3. Each figure shows a plot of maximum obscuration values averaged for all tests conducted at the 6-m elevation (6 m Average) as well as results from the Davis and Reneke algebraic model (D+R), the Watanabe and Tanaka algebraic model (W+T), CFAST and FDS. As the Figures show, for the liquid fires FDS over predicted obscuration values near the fire but the difference decreased with radial distance from the fire centreline. The results of CFAST for the liquid fire compare well with the experimental values at the centre of the fire plume. The results of the algebraic models compare well with the experiments. For both other fuels the models under predicted the measured values closer to the fire source, but as the radial distance increase the difference decreases. This under prediction may be due the turbulence and swinging of the plume, which was observed during the experiments. Another reason for the paper fire is the ignition method of this fire, which resulted in an initial dense smoke followed by flaming combustion which then lifted smoke upwards.

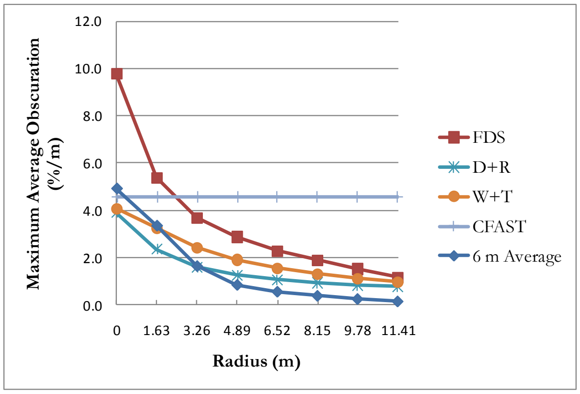

**Figure 1 - Maximum obscuration vs. radius for 20-ml liquid fuel fire at 6 m elevation**

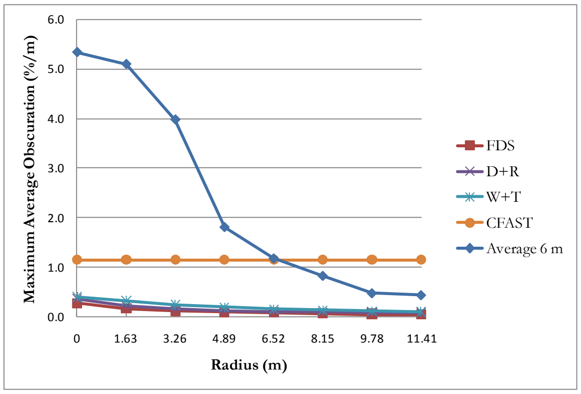

**Figure 2 - Maximum obscuration vs. radius for newsprint fire at 6 m elevation**

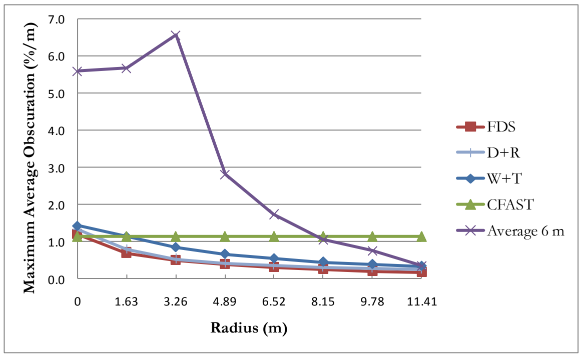

**Figure 3 - Maximum obscuration vs. radius for wood crib fire at 6 m elevation**

Although the standard describes the fires as flaming fires, the method of combustion is actually a combination of smouldering and flaming for the paper and wood fires. Only the liquid fuel fire produces true flaming combustion from the start until the end of the test. The models did not account for smoke development during the early stages of fire development since they are only provided with smoke yield data for the flaming portion of the fires.

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[3] William D. Davis, Thomas Cleary, Michelle Donnelly and Samuel Hellerman, "Prediction Smoke and Carbon Monoxide Detector Response in the Ceiling Jet in the Presence of a Smoke Layer", NISTIR 6976, National Institute of Standards and Technology, July 2003

[4]Richard W. Bukowski and Jason D. Averill, "Methods for Predicting Smoke Detector Activation", Proceedings of Fire Suppression and Detection Research Application Symposium, Research and Practice: Bridging the Gap, February 1998

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[9]ANSI/UL 268-2006 "Standard for Smoke Detectors for Fire Alarm Signaling Systems", 5th Edition, September 2006

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