A Numerical Study on the Effect of Ceiling Slope on Sprinkler Activations and Spray Transport

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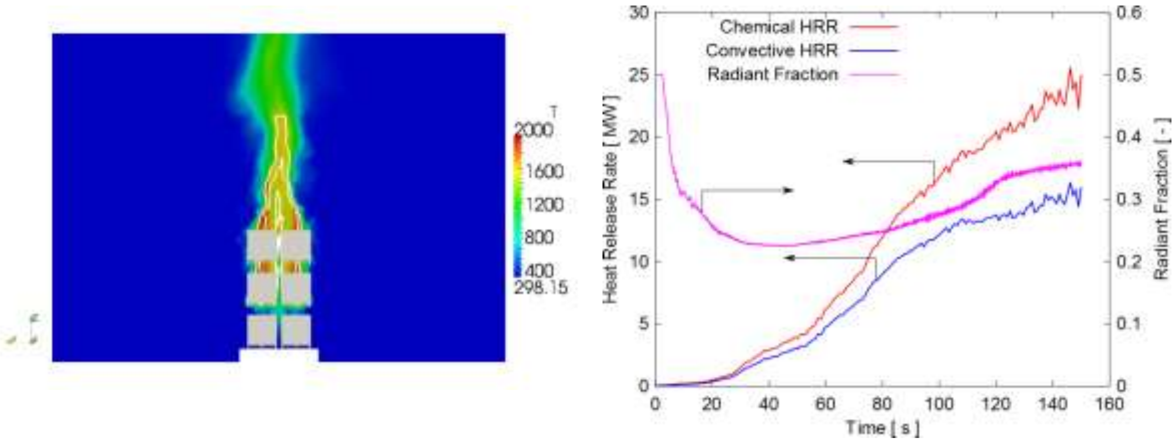
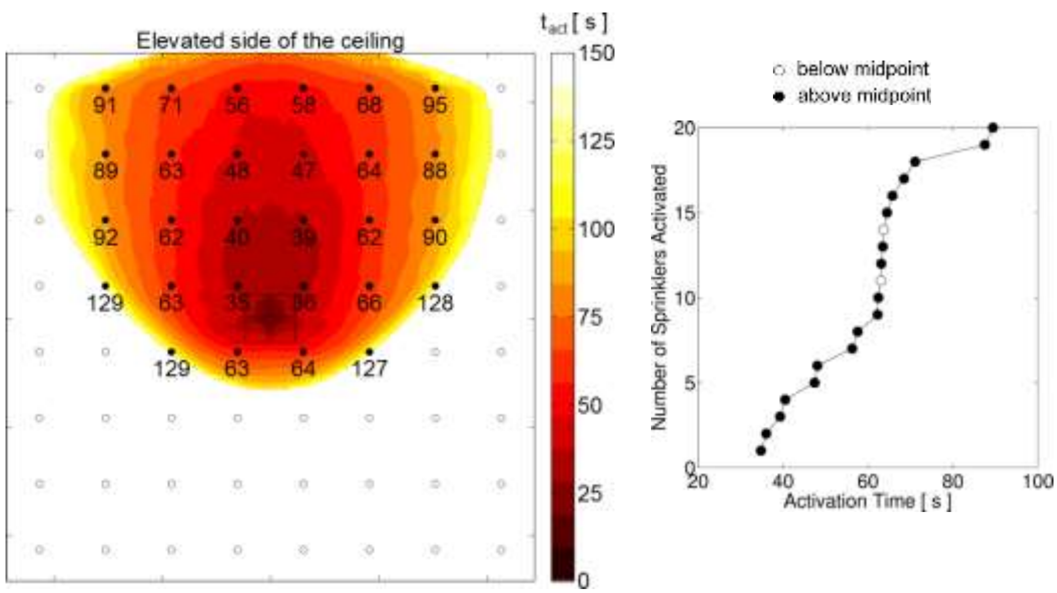
Working in partnership with the NFPA-FPRF, a numerical modeling study was conducted to facilitate understanding of the impact of sloped ceiling on fire protection challenges. The study applied the computational fluid dynamics (CFD) code FireFOAM [1,2]. Ceiling jets resulting from growing fires were simulated to evaluate sprinkler activation patterns under ceilings having a range of slopes. A growing fire on a 3-tier high rack storage array of Cartoned Unexpanded Plastic (CUP) commodity was simulated (see Fig. 1). Ceiling inclinations between 0° and 33.7° were considered and ceiling clearance directly above the ignition location was kept fixed at 3.05 m (10 ft). Activation patterns under the inclined ceilings were compared against horizontal ceiling results. Comparisons were also made between quick-response, ordinary temperature (QR/OT) and standard-response, high temperature (SR/HT) sprinkler responses. For the particular fire scenario investigated, simulation results involving QR/OT sprinklers showed that ceilings up to and including 18.4° inclination had similar activation times and patterns as horizontal ceilings for the four sprinklers immediately adjacent to the fire source. Increasing the inclination to 26.6° produced significant delays in activations on the lowered side of the ceiling (see example in Fig. 2). The number of sprinklers activated on the elevated side also greatly exceeded the number of activations on the lowered side when the ceiling inclination was ≥ 26.6°. For SR/HT sprinklers, several activations occurred on the elevated section before the sprinklers below the lowered side activated, indicating the activation pattern skewness is accentuated with the use of SR/HT sprinklers.



(a) (b)

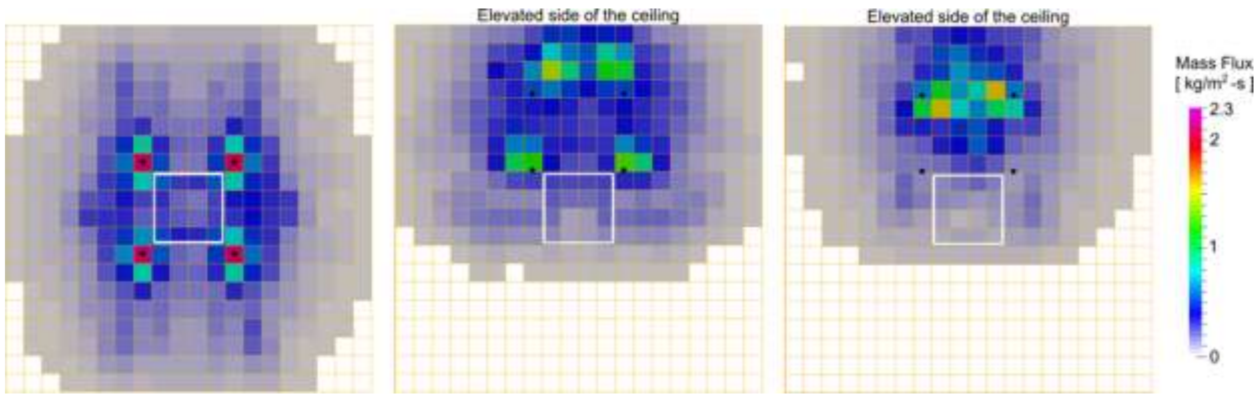
Figure 1: Fire growth on a 2 x 2 x 3 CUP rack-storage array – (a) instantaneous temperature contours, and (b) modeled heat release rates (chemical and convective) and radiation fraction variation in time.



(a) (b)

Figure 2: Activation of QR/OT sprinklers located 0.33 m (13 in.) below a ceiling inclined at 33.7° with its midpoint located 3.05 m (10 ft) above the CUP array: (a) activation time contours, and (b) number of sprinklers activated plotted against activation time.

The effect of ceiling inclination on water mass flux distributions over the rack-storage commodity was also evaluated. Specifically, the effect of sprinkler orientation was investigated by performing spray simulations keeping the sprinkler deflector parallel to the ceiling or parallel to the floor. A K-200 lpm/bar$^{0.5}$ (K-14.0 gpm/psi$^{0.5}$) pendent sprinkler was used in the simulations, as its injection properties are well characterized by measurements [3] and available as model inputs. Sprinkler spray simulations were conducted by selecting fixed fire source sizes for two scenarios: when ignition occurs under one sprinkler, and when ignition occurs among four sprinklers. Water mass flux distributions on top of the rack storage array were compared for various ceiling inclinations and sprinkler deflector orientations. For spray calculations involving a single sprinkler located directly above the ignition location, it was found that the deflector orientation strongly affects the water flux that reaches the fire source and the pre-wetting region. As the ceiling inclination was increased, the water flux on top of the commodity was found to reduce when the sprinkler deflector was kept parallel to the ceiling. No such reduction in water flux was observed when the deflector was kept parallel to the floor. For a fire plume located among four sprinklers, it was observed that the skewed activation pattern for higher ceiling slopes adversely impacts the spray density on the fire (see Fig. 3 for details).



(a) 0°, parallel-to-floor (b) 33.7°, parallel-to-floor (c) 33.7°, parallel-to-ceiling

Figure 3: Droplet mass flux distribution is shown for four sprinklers below ceilings inclined at (a) 0°, (b) 33.7° (sprinkler deflectors parallel-to-floor) and (c) 33.7° (sprinkler deflectors parallel-to-ceiling), located 3.05 m (10 ft) above the CUP array. Mass flux is computed at sampling squares of 0.37 m^2 (4 ft^2) area located 0.3 m (1 ft) above the top of the CUP rack storage array. A fire with a constant 2.6 MW convective HRR is present. Projected sprinkler locations on the collection plane are indicated by black dots and the footprint of the CUP array is shown by the white square.

References

[1] FireFOAM: available from http://www.fmglobal.com/modeling
[2] Y. Wang, P. Chatterjee, and J. L. de Ris, *Proc. Comb. Inst.*, **33**(2):2473-2480, 2011.
[3] X. Zhou, S. P. D'Aniello, and H.-Z. Yu, *Fire Safety Journal*, **54**:36-48, 2012.