Fire Dynamics
Projected flames out of an opening

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Objectives

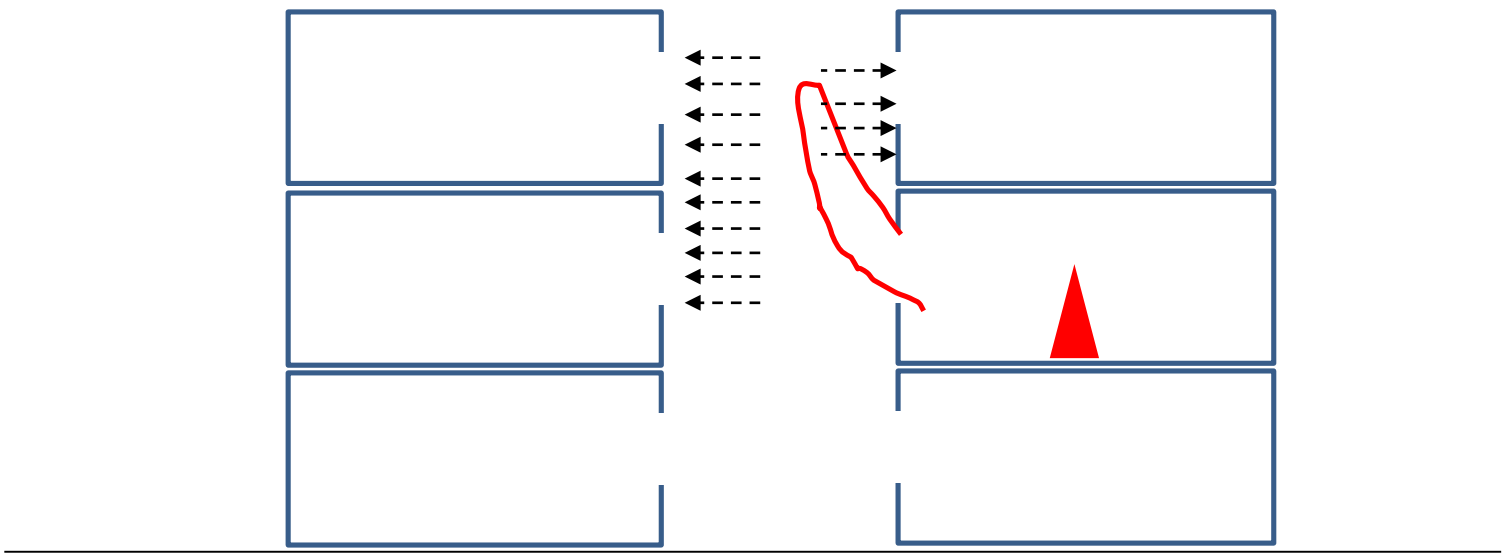
- Understanding fire spread by projected flames out of openings

External fire spread

https://www.youtube.com/watch?v=bRMSqSf1rFM

External fire spread

- Fire safety concerns

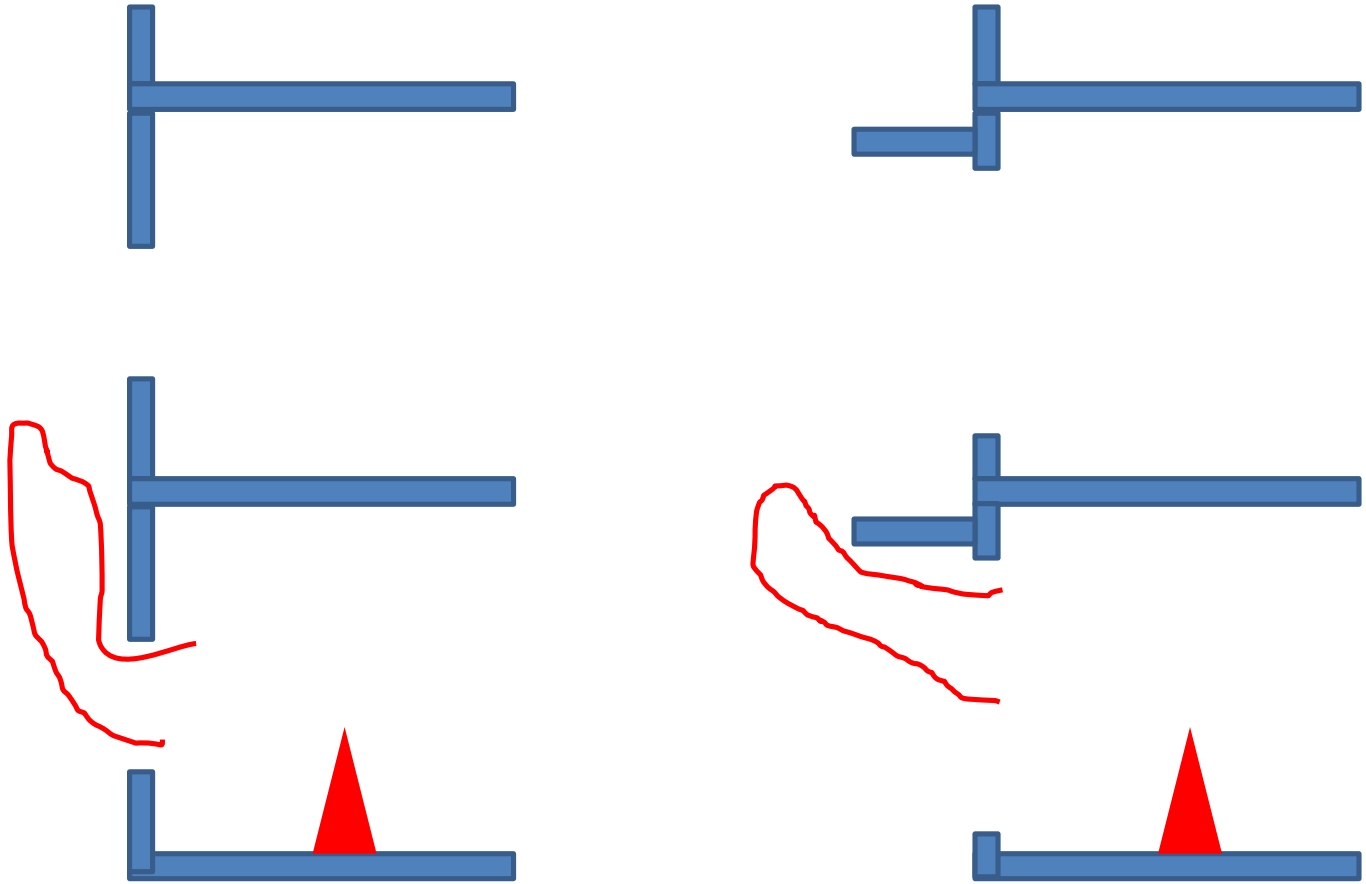


  - Vertical fire spread to upper floors
  - Horizontal fire spread to adjacent buildings

Fire engineering approaches

- Automatic sprinkler systems
  - Wall surface
  - Within compartments
- Separation between buildings & openings
- Wall surface ignition / fire spread limitation
- Long enough spandrels
- Projected aprons

Spandrel and apron

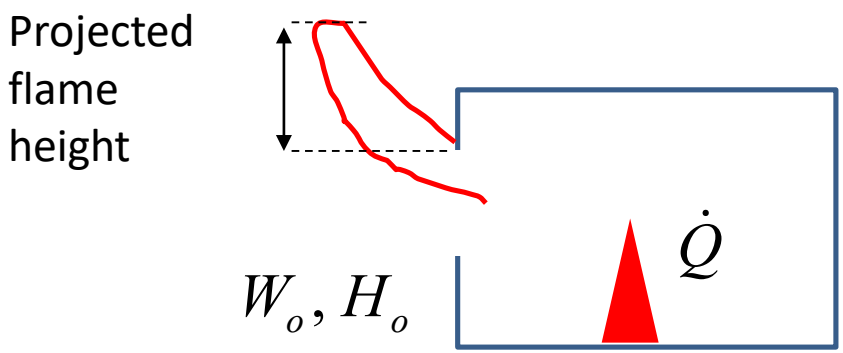


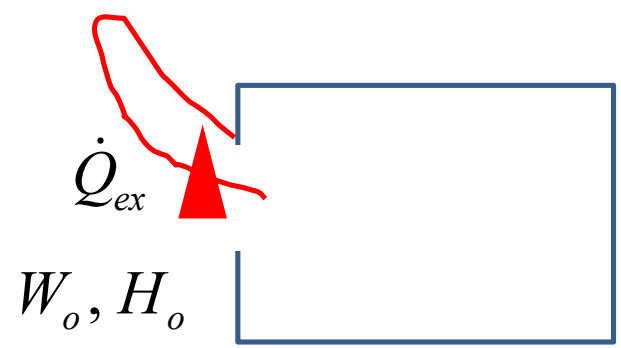
Key parameters

- Projected flame height outside an opening
  - The higher the flame, the higher the probability of fire spread
- Heat flux [kW/m^2] on the potential fuel surface in upper floors or on the wall surface
  - 20 kW/m^2 for the minimum ignition heat flux

Previous research

1960s	1970s	1990~
Yokoi, Webster, Seigel	Thomas, Law	Quintiere, Ohmiya, Delichatsios





$$\dot{Q}_{ex} = \dot{m}_{fuel}\Delta H_{c,fuel} - \dot{m}_{air}\Delta H_{c,air}$$

$$\approx \dot{m}_{fuel}\Delta H_{c,fuel} - 1500 A_o \sqrt{H_o}\ [kW]$$

Correlations

- Thomas and Law (1978)

$$z_f = 12.8\left(\frac{R}{W_o}\right)^{2/3} - H_o$$

where,

$$R = A_o\sqrt{H_o}\left(\frac{W_{wall}}{D}\right)^{\frac{1}{2}}(0.18)\left(1 - e^{\frac{-0.036 A_T}{A_o\sqrt{H_o}}}\right)$$

R: burning rate [kg/s]

z_f: flame height from the top of an opening[m]

W_{wall}: the width of the wall containing openings[m]

D: the compartment depth [m]

A_T: total area of floor, ceiling, and wall excluding opening area[m^2]

Correlations

- Quintiere and Cleary (1994)

$$z_f = 0.0165\left(\frac{\Delta H_c R}{\sqrt{\frac{2A_o}{\pi}}}\right)^{2/3} - H_o$$

- Ohmiya et al.(2000)

$$z_f = 0.65\left(\dot{Q}_{W_o}{}^*\right)^{2/3} W_o, \quad \dot{Q}^*_{W_o} = \frac{\dot{Q}_{W_o}}{\rho_a c_p T_a \sqrt{g} W_o^{5/2}}$$

$$\dot{Q}_{W_o} = 0.5 c_p A_o \sqrt{H_o}\Delta T + R\Delta H_c - 150 A_o \sqrt{H_o}\eta^{2/5}$$

Correlations

- Delichatsios et al.(2007)

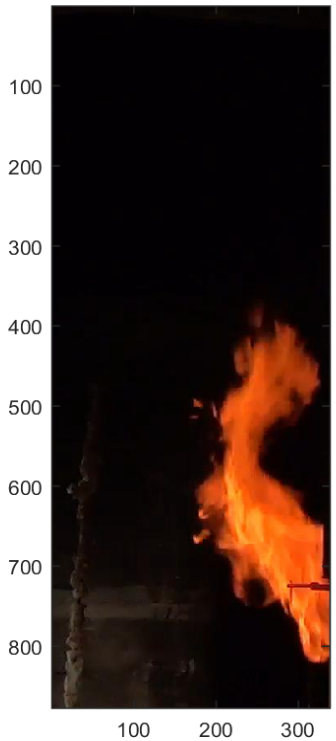
$$\dot{Q}_{ex}^{\ *} = \frac{\dot{Q}_{ex}}{\rho_a c_p T_a \sqrt{g}(A_o\sqrt{H_o})}$$

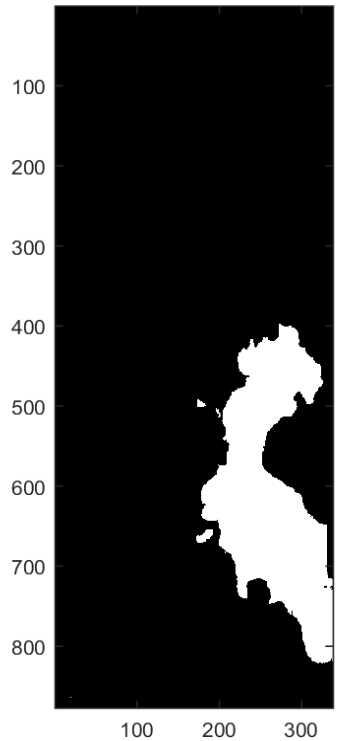
$$\dot{Q}_{ex}^{\ *} < 1.3, \quad z_f = 3.03(A_o\sqrt{H_o})^{2/5}\left(\dot{Q}_{ex}^{\ *}\right)^{2/3} - 0.6H_o$$

$$\dot{Q}_{ex}^{\ *} \geq 1.3, \quad z_f = 3.45(A_o\sqrt{H_o})^{2/5}\left(\dot{Q}_{ex}^{\ *}\right)^{2/5} - 0.6H_o$$

Experiments

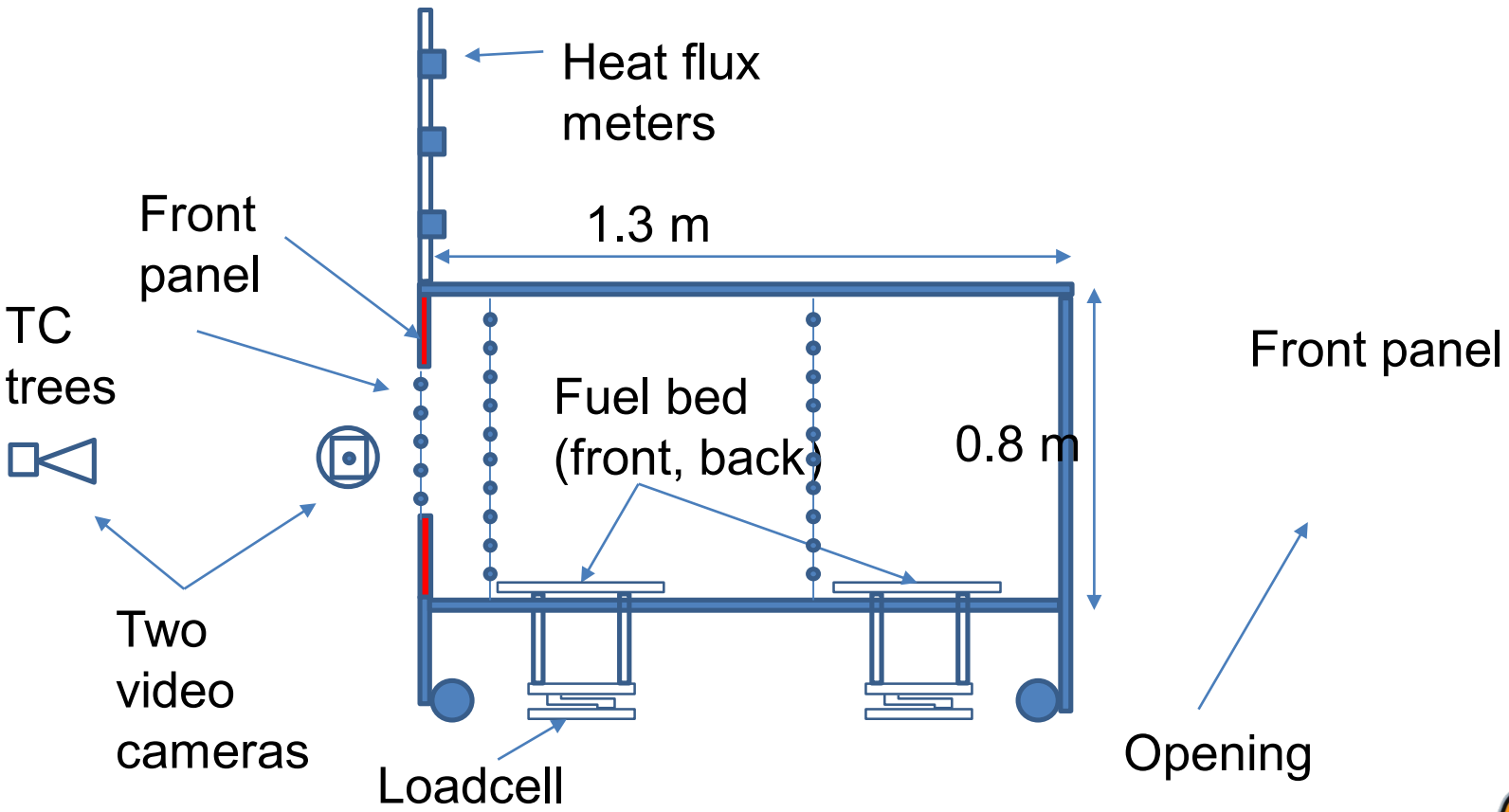
Extraction of flame regions



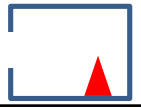


- Image processing
- Flame height averaged for every 20 sec.
- 50 % intermittency

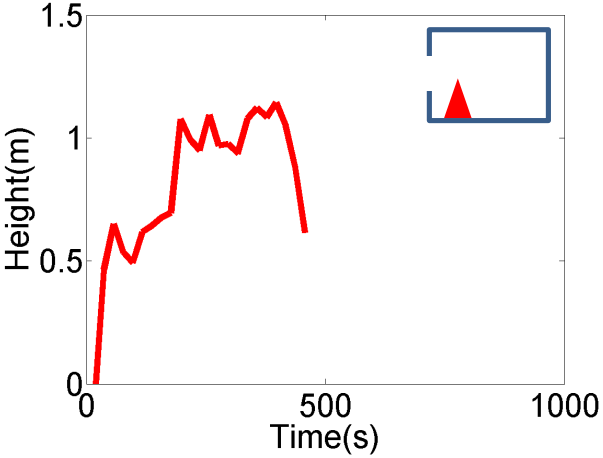
Compartment fire experiments

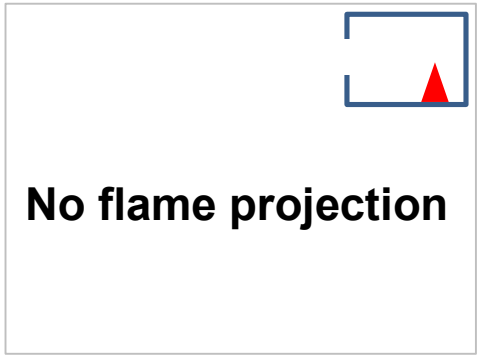


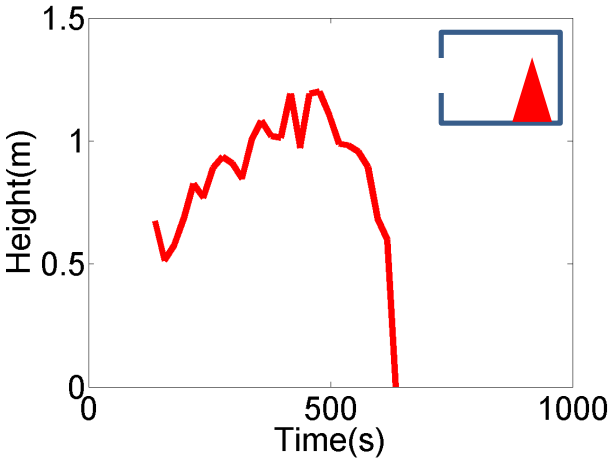
Compartment fire experiments

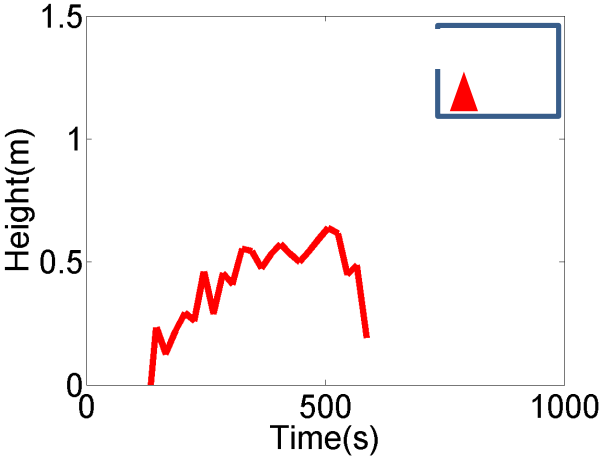
Opening location	Fuel location	Fuel surface area	configuration
	Back	0.3 m by 0.3 m pan	
	Back	0.4 m by 0.4 m pan	
	Front	0.3 m by 0.3 m pan	
	Back	0.3 m by 0.3 m pan	
	Back	0.4 m by 0.4 m pan	
	Front	0.3 m by 0.3 m pan	

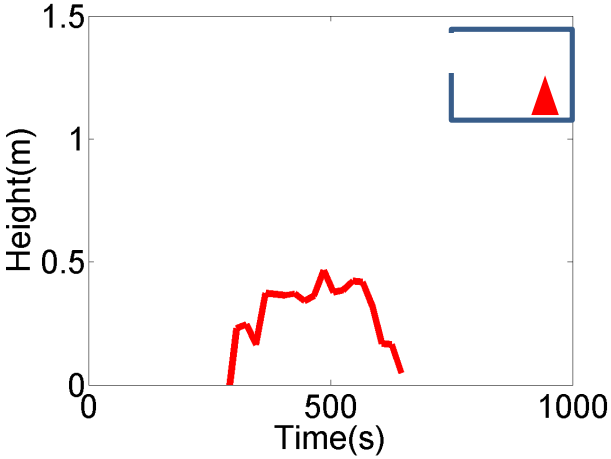
Projected flame heights

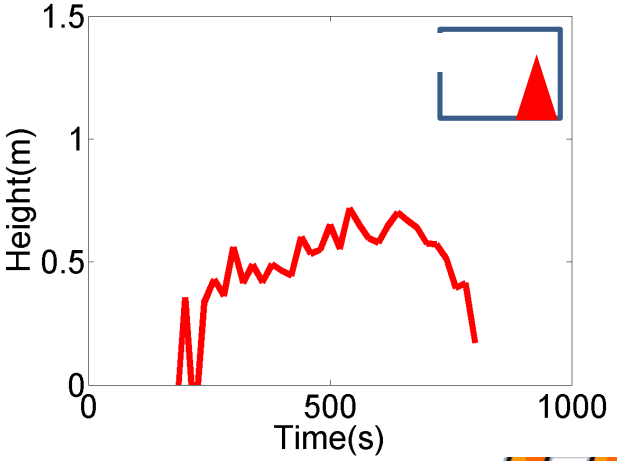




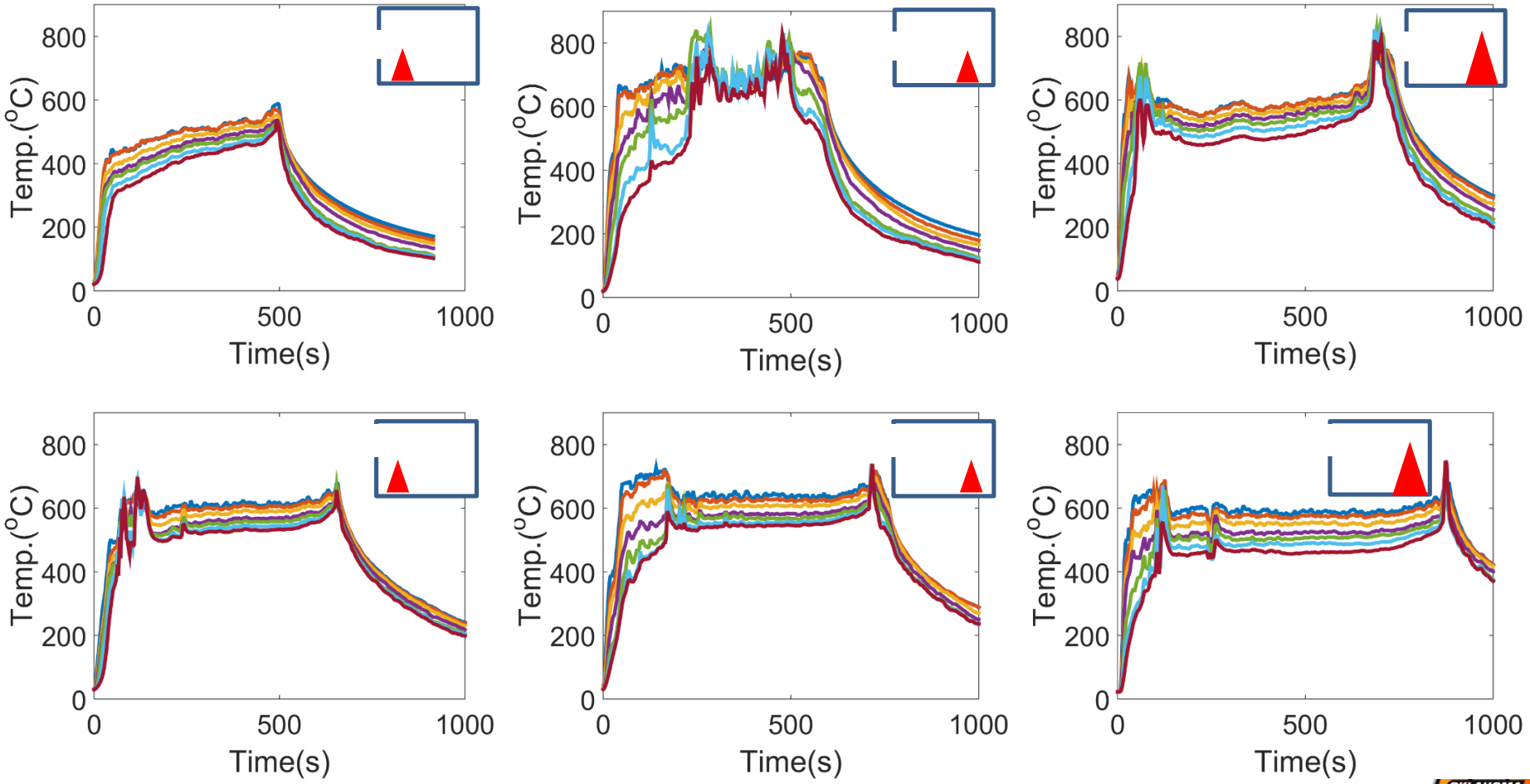




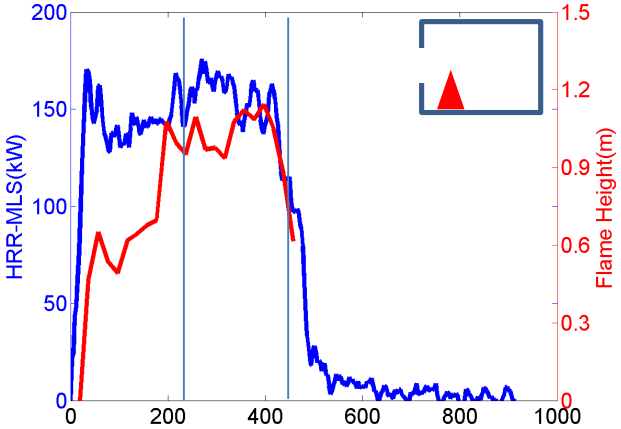
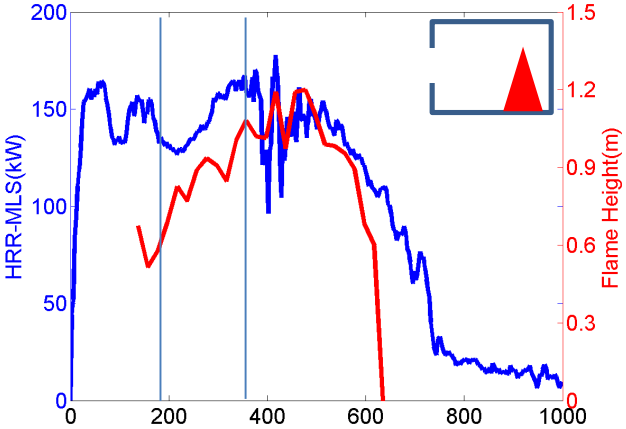
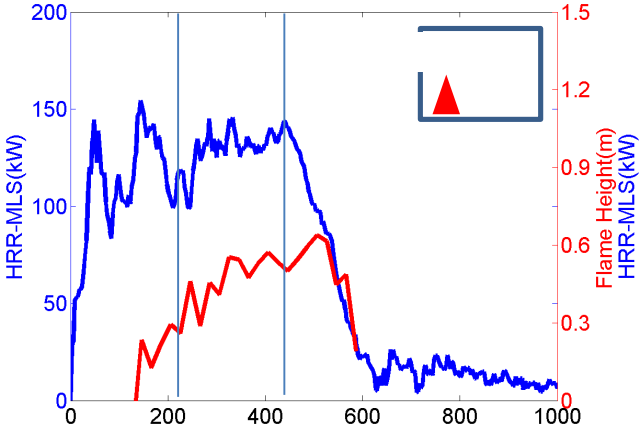
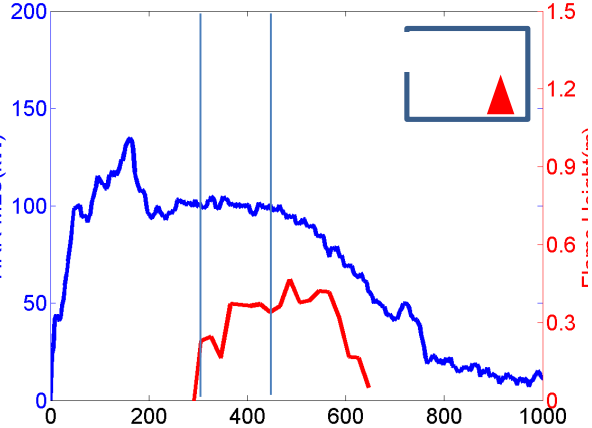
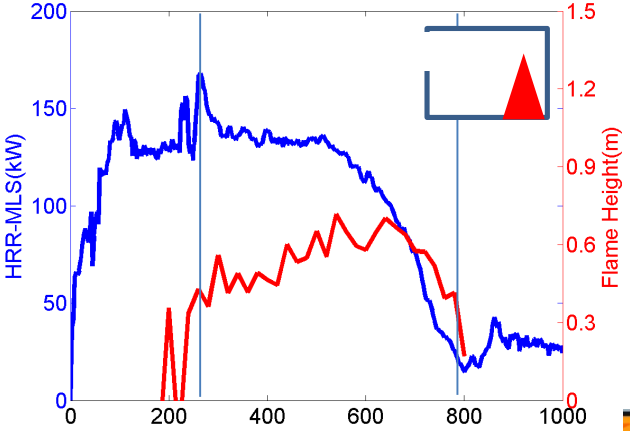




Projected flame heights



Projected flame heights



No flame projection