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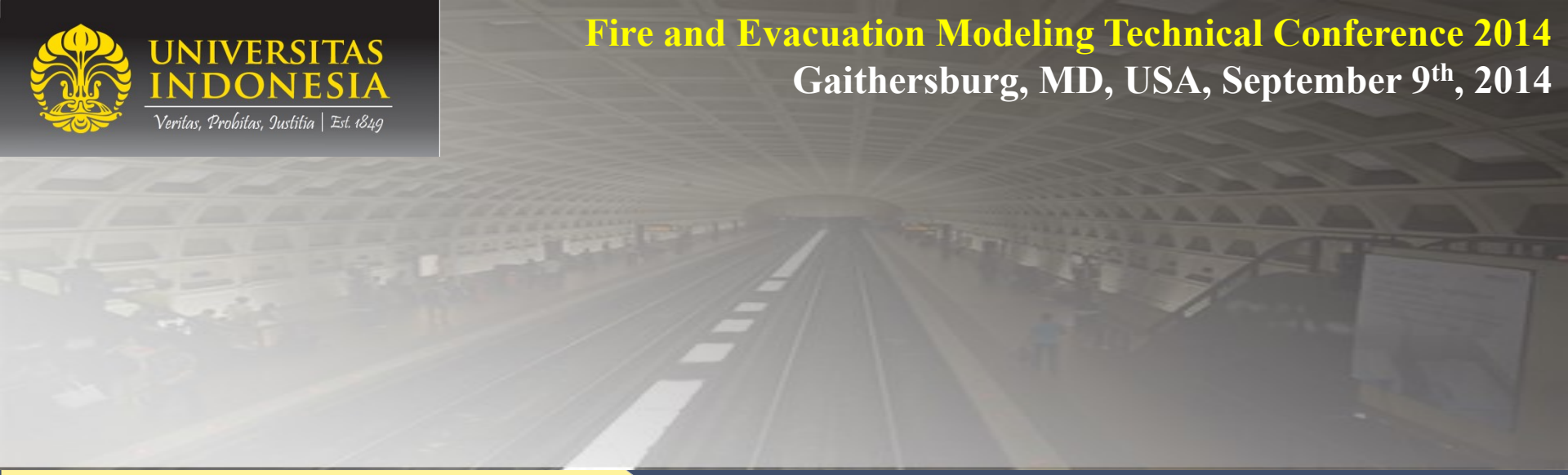

Optimization of Smoke Ventilation Strategy in a Typical Underground Metro Station Fire

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Introduction

- Topics
  - Underground Metro Station
    - Reduce traffic load
    - Effective massive human transportation
    - There are 188 metro system in 53 countries in the world (May, 2013)
    - Occupying up to 2000 passengers (rush hour)
  - Fire accident in underground structure
    - King's Cross Underground Station (London, 1987)
    - "Deutsche Oper" Underground Station (Berlin, 2000)
    - Heinrich – Heine – Allee Underground Station (Dusseldorf, 1991)
    - Daegu Metro Station (Korea, 2003)
  - Fire Hazard in underground station
    - Fire – induced smoke moves to the same direction as evacuation route
    - Smoke properties and CO concentration are the most important parameters affecting human safety
  - Ventilation strategy
    - Keep passengers away from smoke hazard
    - Effectively exhaust and control the movement of fire induced smoke

Research Objective

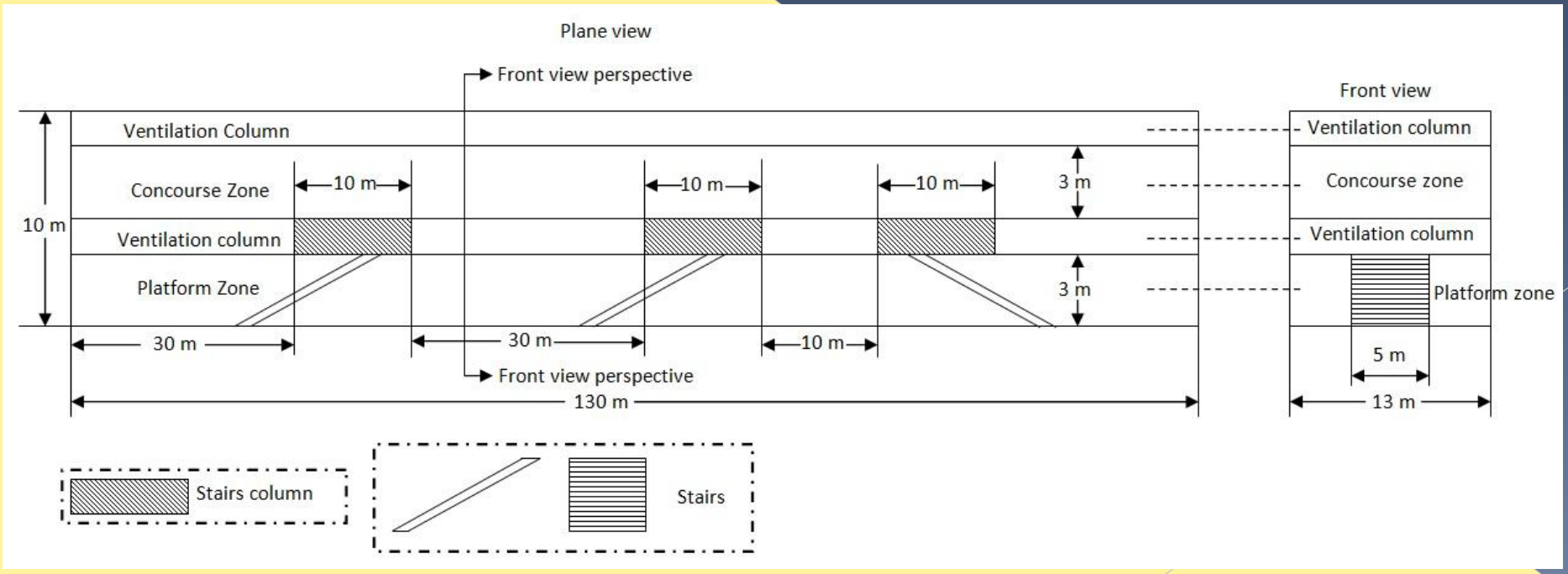
- To find an effective ventilation strategy in underground metro station in case of fire
- To investigate smoke movement and CO distribution across station accordance to various ventilation strategies

Research Methodology

- Fire simulation using Fire Dynamics Simulator Version 6 of National Institute of Science and Technology (NIST).

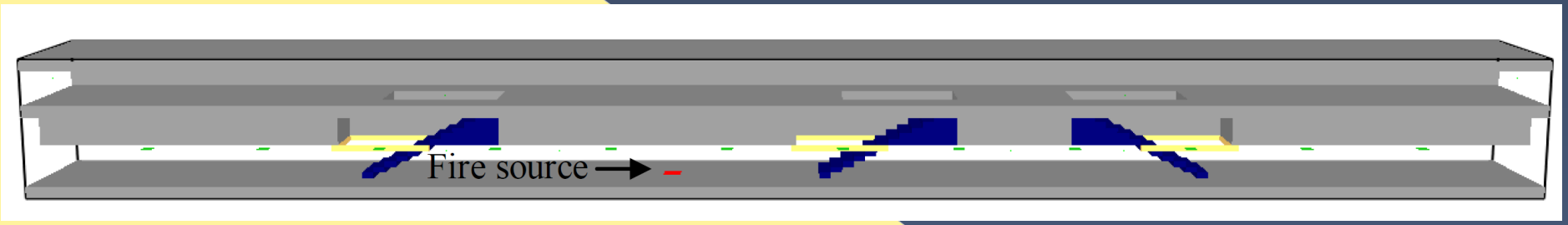
Physical Model

- Two storey underground metro station
  - Length = 130 m
  - Width = 13 m
  - Total height = 10 m
    - Platform level height = 5 m
    - Concourse level height = 5 m



Simulation Set Up

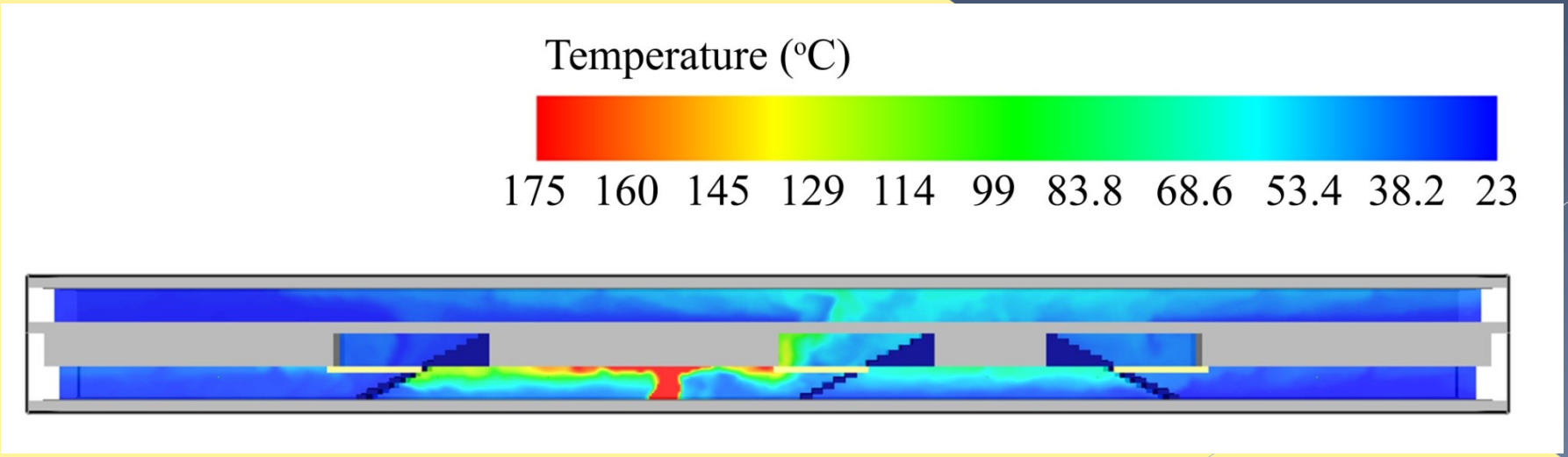
- Modeled geometry in the simulation



- Fire Heat Release Rate = 5 MW
- Materials (Incropera et al, 2007)
  - Concrete for structure
  - Glass pyrex for Platform Screen Door

Fire Scenario

- Fire at Platform level
- t-squared fire, $\dot{Q} = 5\ MW$
  - $\alpha = 0.1876$
- Yield
  - CO = 0.1
  - Soot = 0.01



Mesh Resolution

- Cell size = (0.25 x 0.25 x 0.25) m^3
- Characteristic diameter of fire = 1.8 m

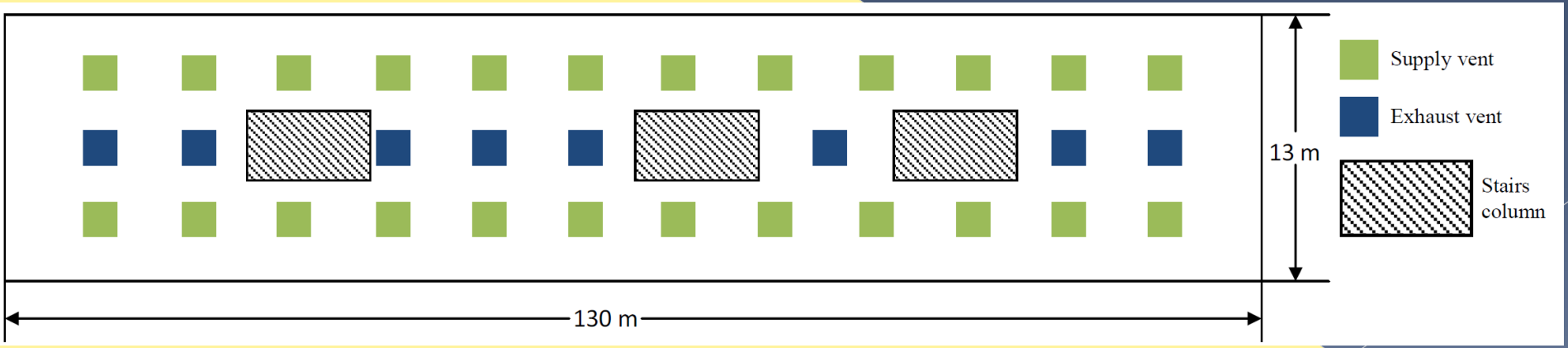
$$D^* = \left(\frac{\dot{Q}}{\rho c_p T_\infty \sqrt{g}}\right)^{2/5}$$

- Mesh resolution = 7.23

$$\frac{D^*}{\delta x}, \frac{D^*}{\delta y}, \frac{D^*}{\delta z}$$

Vents Configuration

- Air Change per Hour = 10
  - Supply = 50,700 m^3/hour
  - Exhaust = 50,700 m^3/hour



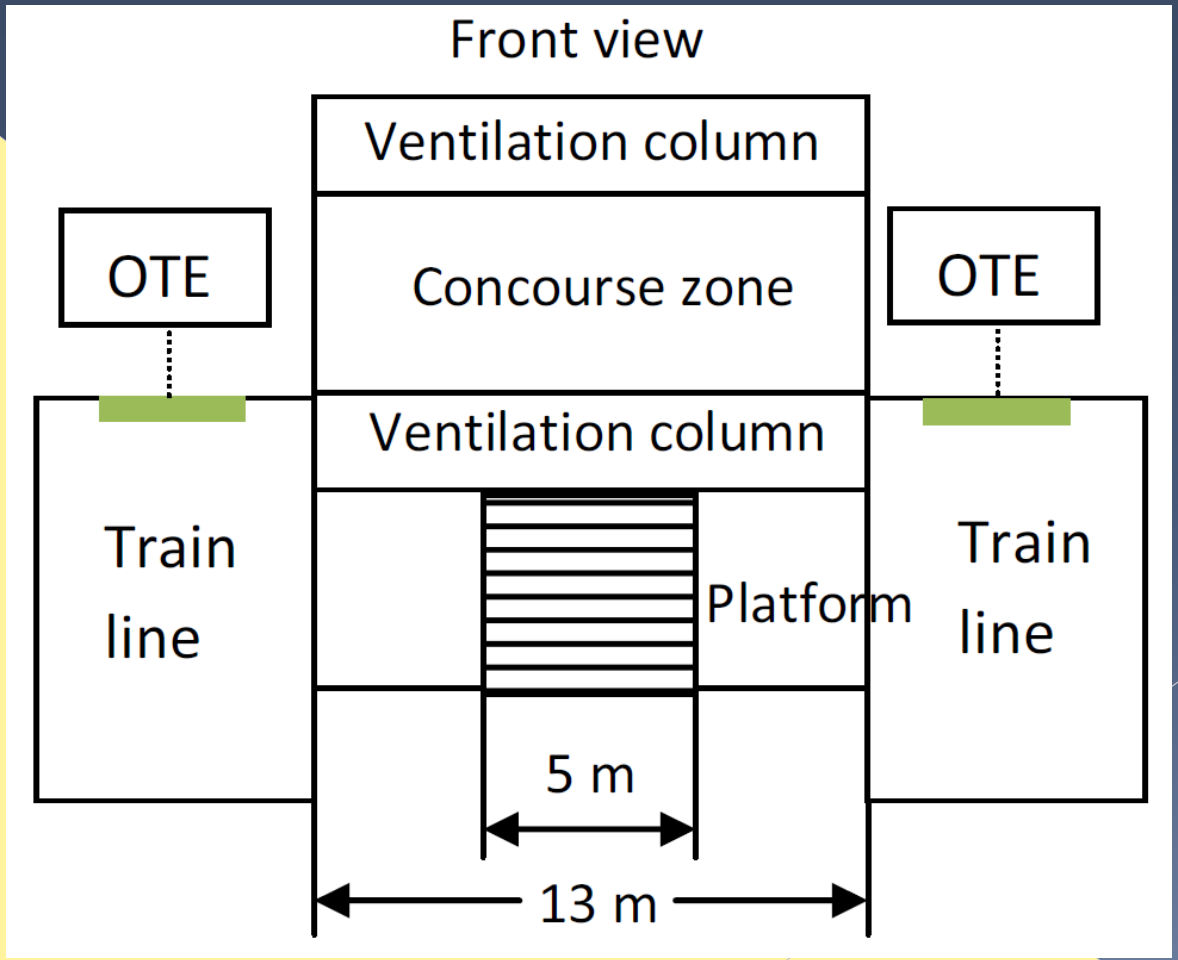
Ventilation Strategy

The following investigation were carried out to study the most optimum ventilation strategy:

- Arrangement of platform and concourse ventilation direction
- The role of Overhead Track Exhaust (OTE) inside the tunnel
- The addition of auxiliary smoke exhaust in platform level
- The addition of natural ventilation effect via atria structure
- The investigation of platform opening position impact on smoke distribution

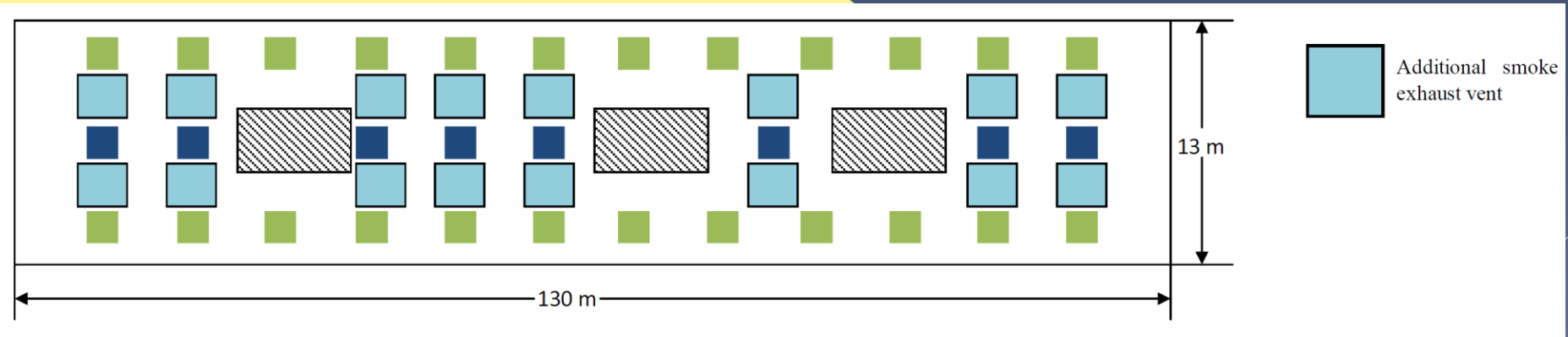
The role of Overhead Track Exhaust (OTE) inside the tunnel

- Air Change Rate per Hour per train line = 10
  - Exhaust 29,575 m^3/hour
- Tunnel train line dimension
  - Length = 130 m
  - Width = 3.5 m
  - Height = 6.5 m



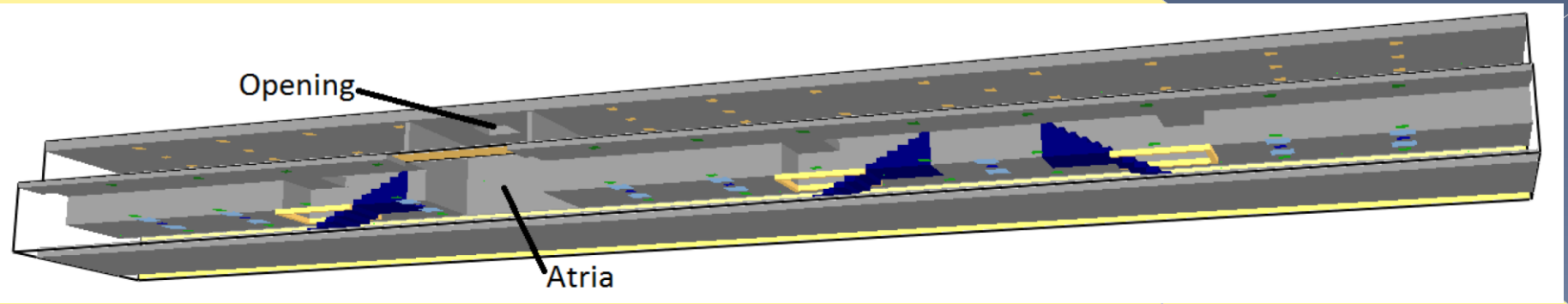
Additional Smoke Exhaust

- Located at platform
- ACH = 5 (Exhaust capacity of 25350 m^3/hour)



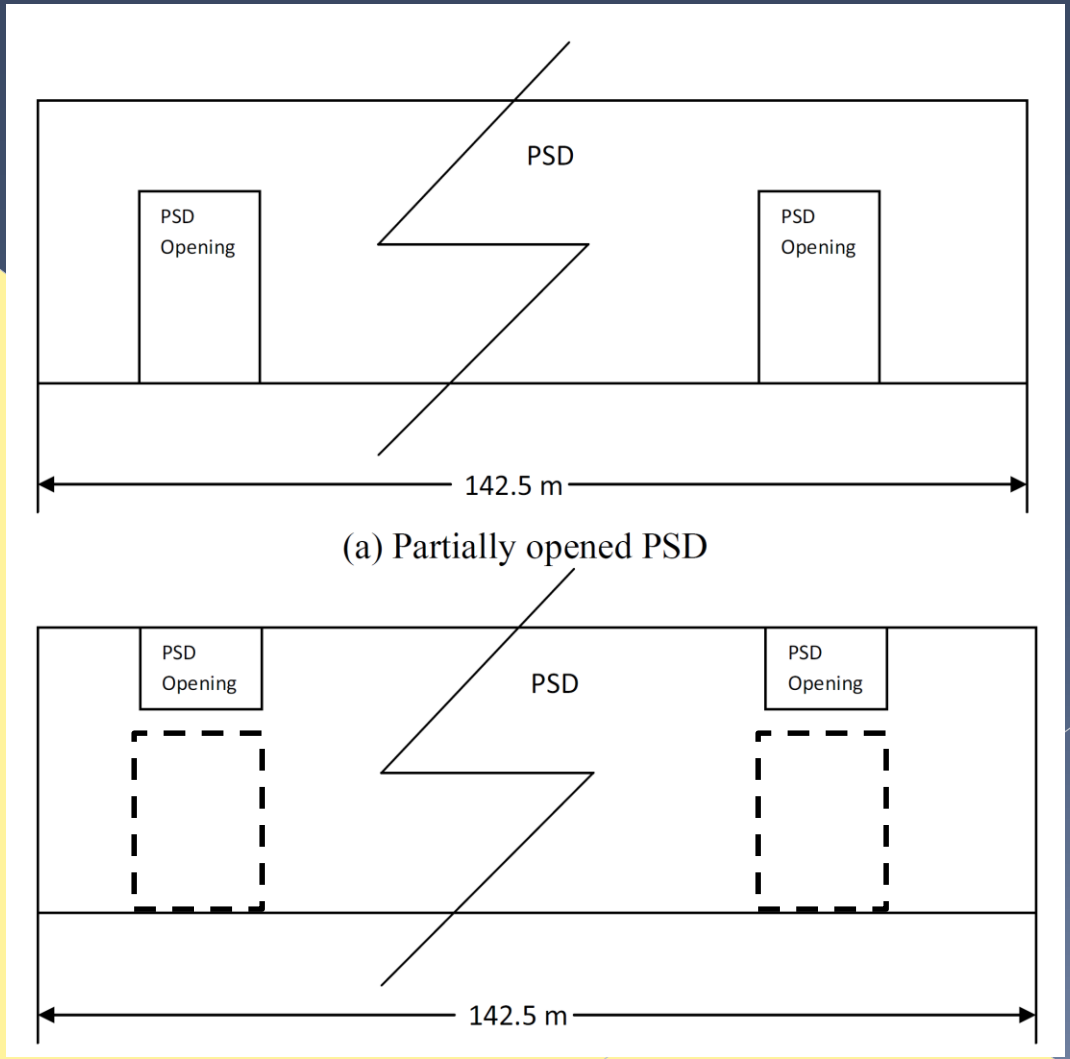
The impact of Atria Structure

- Attached to the station
- 42 m from the left end side of the station
- Atria dimension
  - Length = 12.5 m
  - Width = 13 m
  - Height = 10 m
- Ceiling opening = (3.5 x 3.5) m^2



Platform Opening Position

- Normal opening position
  - Opening for passenger to onboard the train
- Fire emergency opening position
  - PSD opening located on top



Operating Parameters

Case	Ventilation Mode				PSD	OTE	Additional smoke exhaust	Atria structure
	Platform Supply	Platform Exhaust	Concourse Supply	Concourse Exhaust				
Case 1	ON	ON	ON	ON	Closed			
Case 2	Become exhaust	ON	Become exhaust	ON	Closed			
Case 3	Become exhaust	ON	ON	Become supply	Closed			
Case 4	Become exhaust	ON	OFF	OFF	Closed			
Case 5	ON	ON	ON	ON	Partially opened	ON		
Case 6	Become exhaust	ON	Become exhaust	ON	Partially opened	ON		
Case 7	Become exhaust	ON	ON	Become supply	Partially opened	ON		
Case 8	Become exhaust	ON	OFF	OFF	Partially opened	ON		
Case 9	Become exhaust	ON	OFF	OFF	Partially opened	ON	ON	
Case 10	Become exhaust	ON	OFF	OFF	Partially opened	ON	ON	Exist
Case 11	Become exhaust	ON	OFF	OFF	Partially opened on top	ON	ON	Exist

Results and Discussion

Base ventilation condition (Case 1)

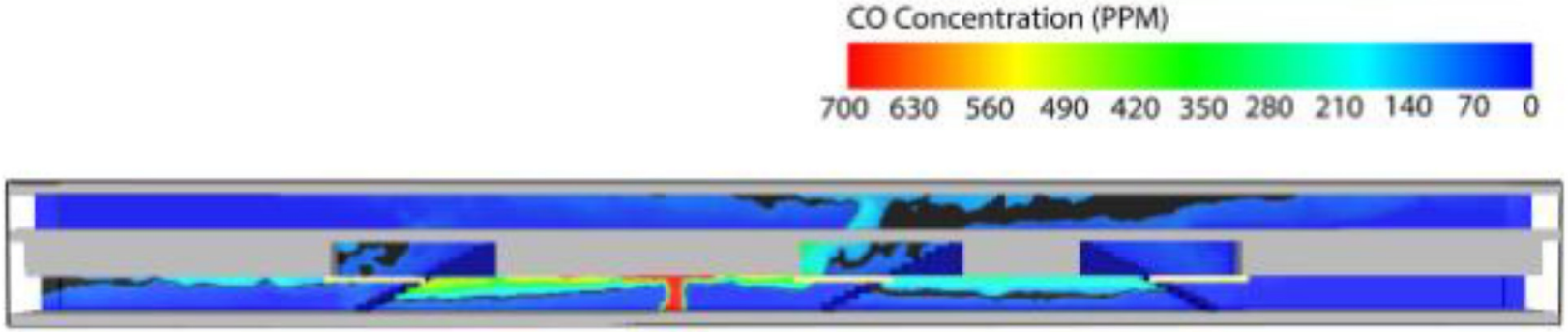


Figure 9. CO distribution of case 1 at 200 s (black color represents CO concentration of 85 ppm)

Results and Discussion (Con't)

- All ventilation exhaust (case 2)

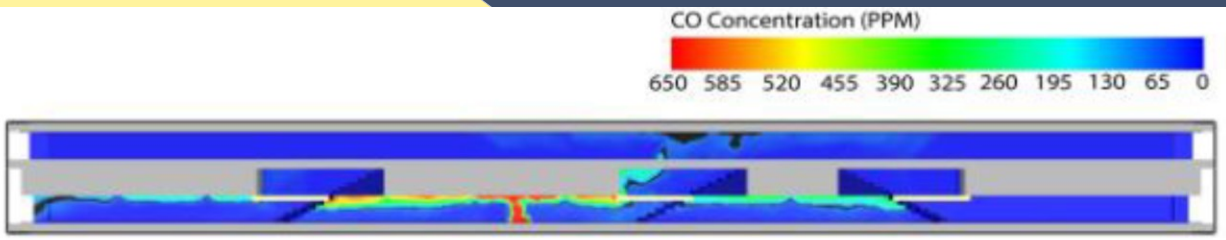


Figure 10. CO distribution of case 2 at 200 s ((black color represents CO concentration of 84 ppm)

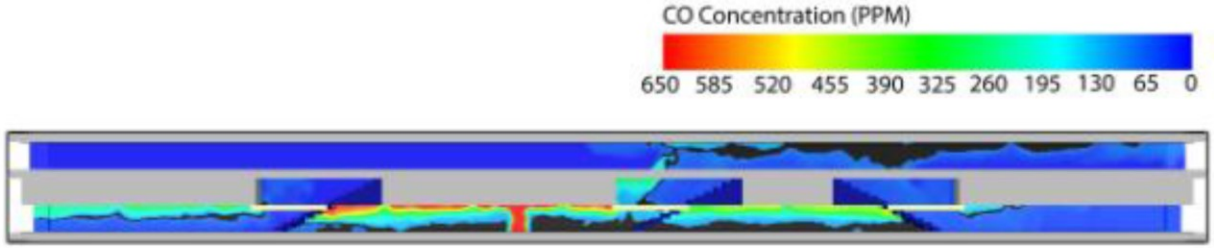


Figure 11. CO distribution of case 2 at 600 s (black color represents CO concentration of 84 ppm)

Results and Discussion (Con't)

- Platform's ventilation exhaust – Concourse's ventilation supply (Case 3)

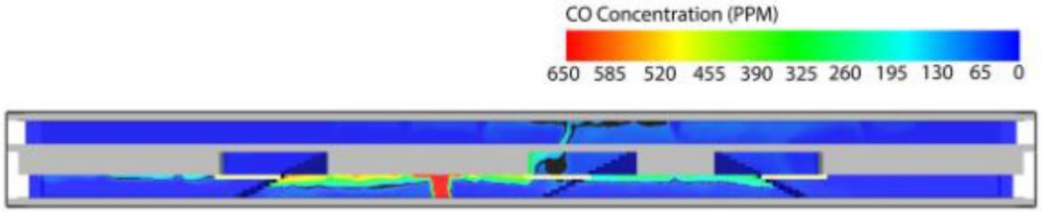


Figure 12. CO distribution of case 3 at 200 s (black color represents CO concentration of 84 ppm)

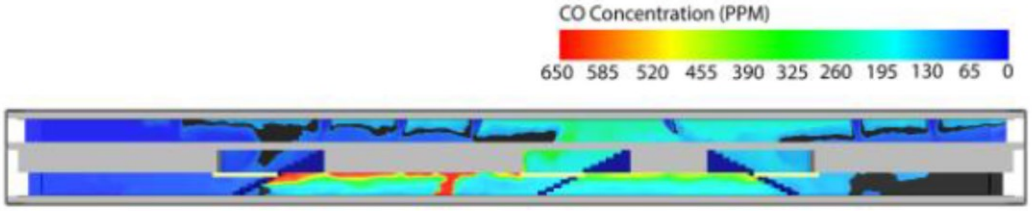
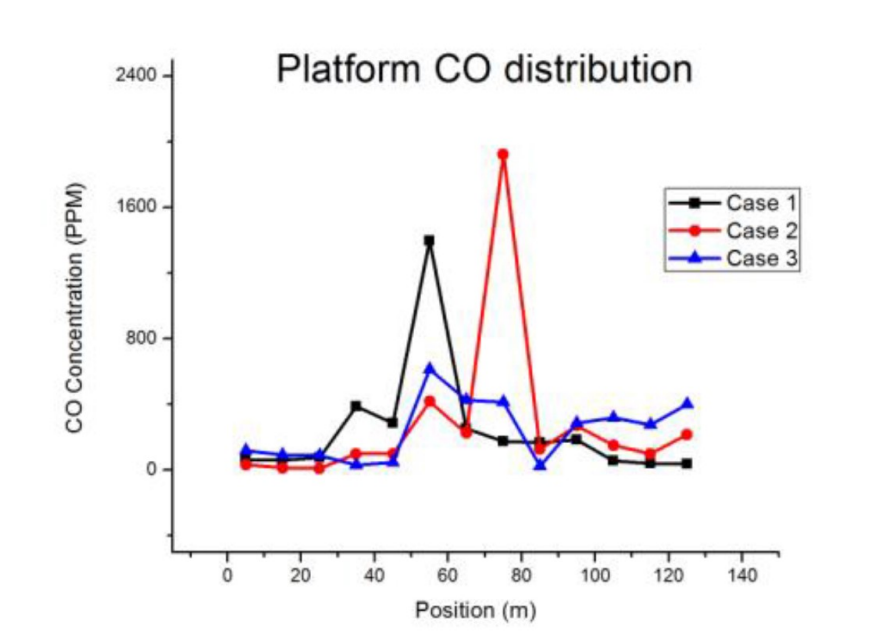
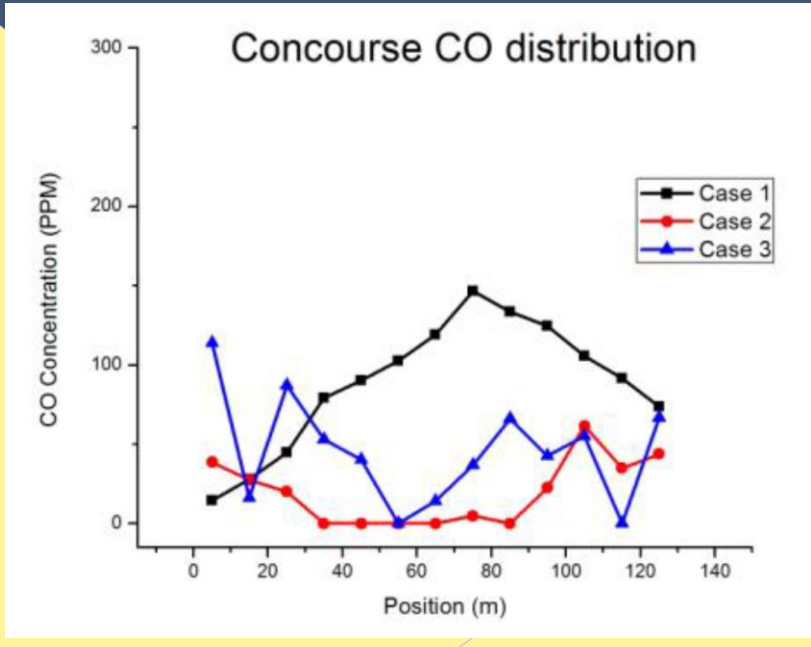


Figure 13. CO distribution of case 3 at 600 s (black color represents CO concentration of 84 ppm)

Results and Discussion (Con't)

- CO distribution between case 1, case 2, and case 3





Results and Discussion (Con't)

Base ventilation condition

Platform – exhaust
Concourse - exhaust

Platform – exhaust
Concourse - supply

Platform – exhaust
Concourse – not operated

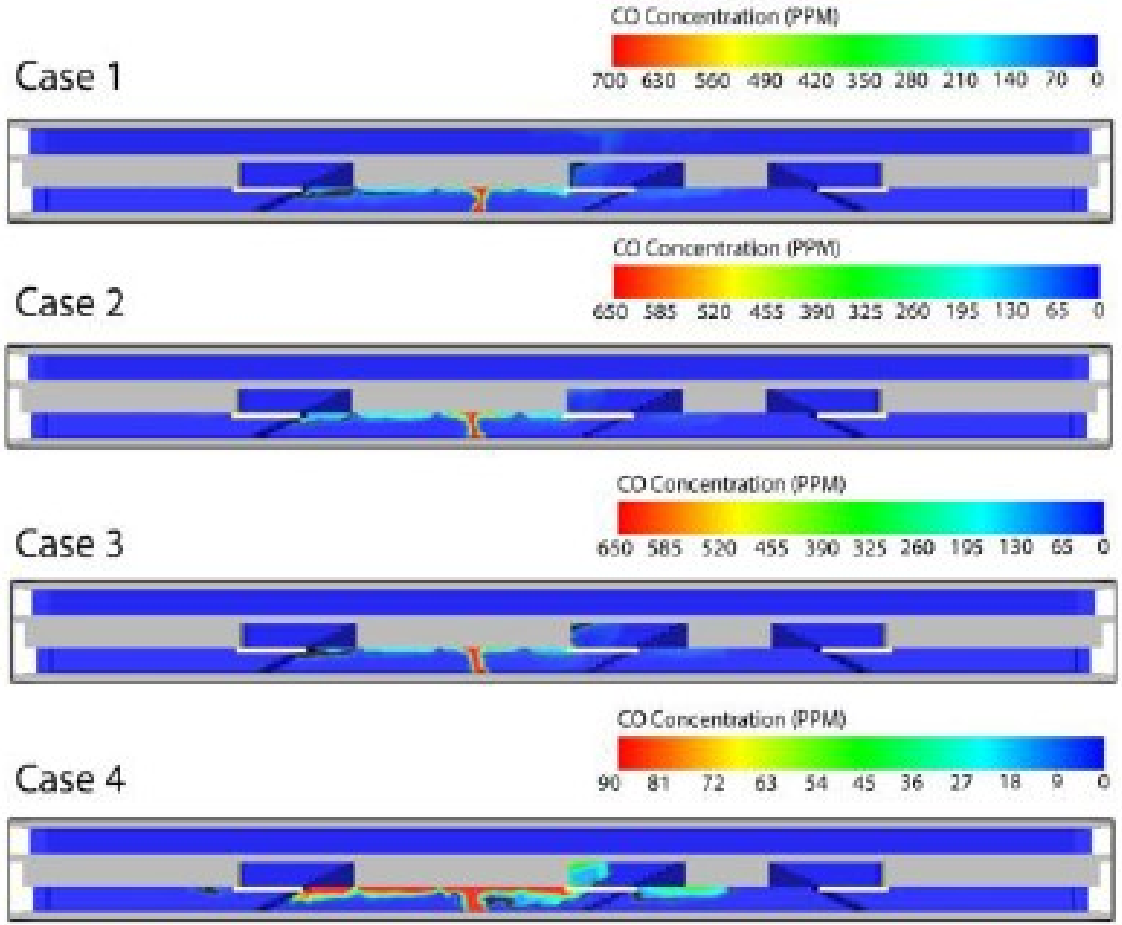


Figure 16. Comparison of CO distribution of the ventilation mode of case 1, case 2, case 3, and case 4 at 100 second while fire growth (black color indicates CO concentration of 85 ppm)

The effect of Partially opened PSD and OTE

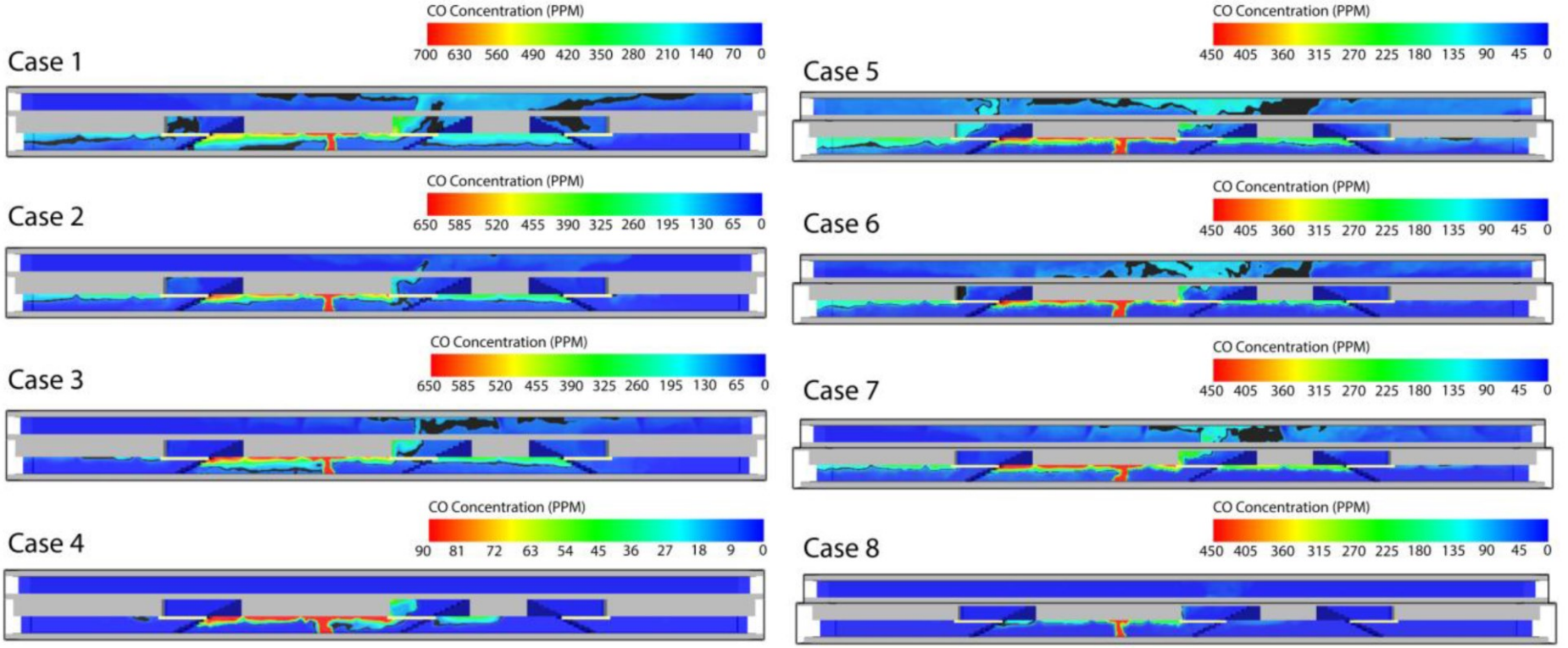


Figure 17. Comparison of the impact of partially opened PSD and OTE on CO distribution (black color indicates CO concentration of 85 ppm)

The effect of Partially opened PSD and OTE (Con't)

Smoke movement in tunnel

- Platform's ventilation exhaust
- Concourse ventilation exhaust

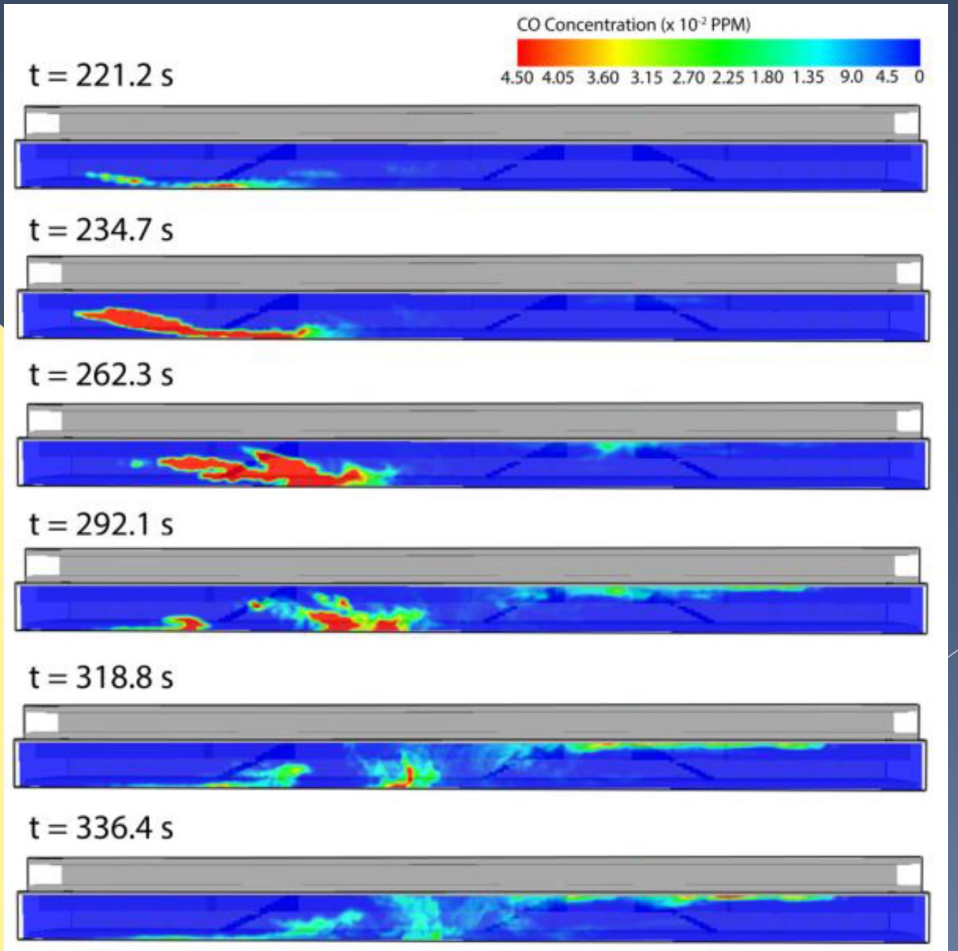
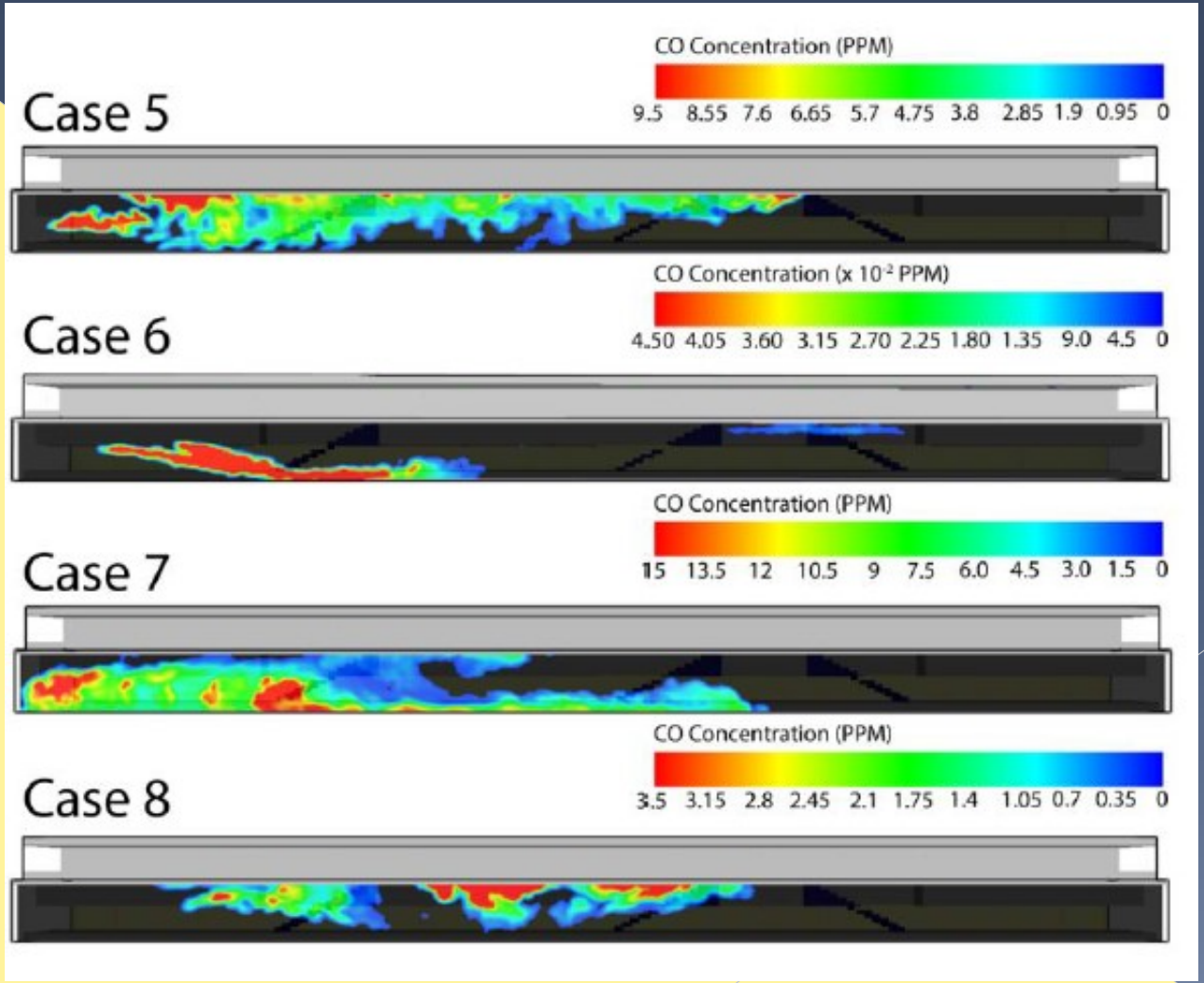


Figure 19. Fraction of smoke pulled from the left end side of the station and pulled back inside the station

The effect of Partially opened PSD and OTE

CO distribution in tunnel



The benefit of additional smoke exhaust

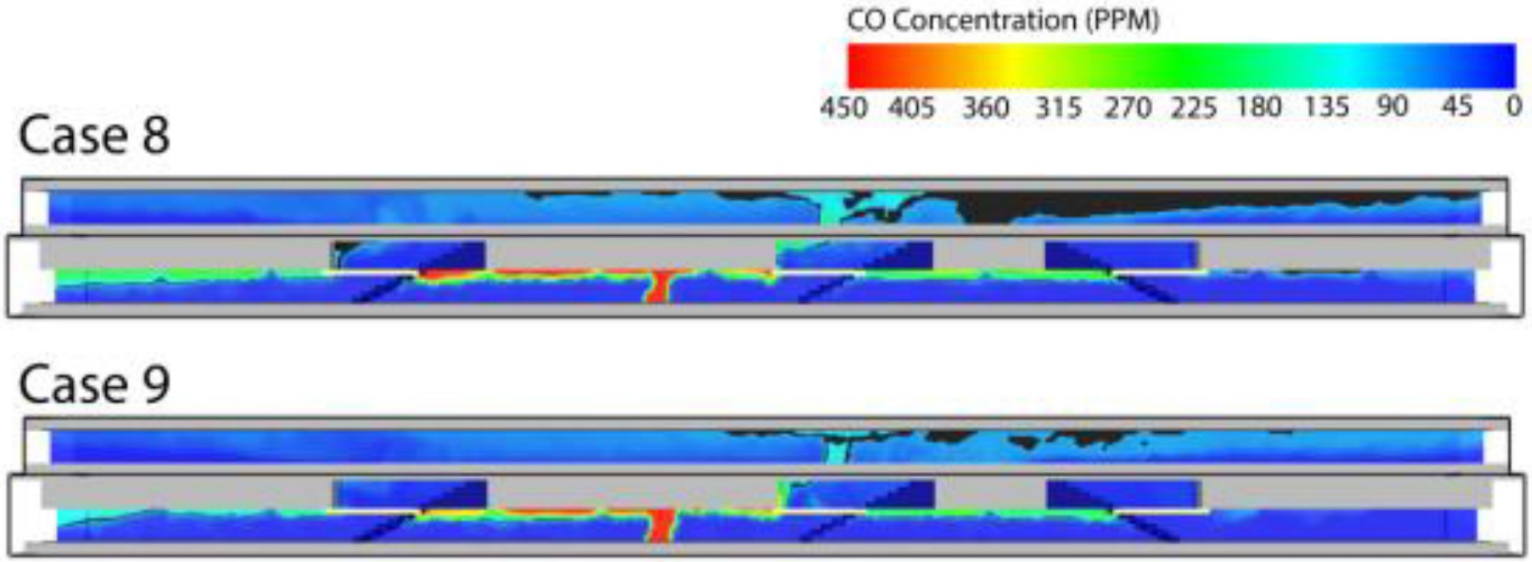


Figure 20. The effect of additional smoke exhaust at 289.3 s (black color indicates CO concentration of 85 ppm)

The effectiveness of natural ventilation (Hybrid ventilation strategy)

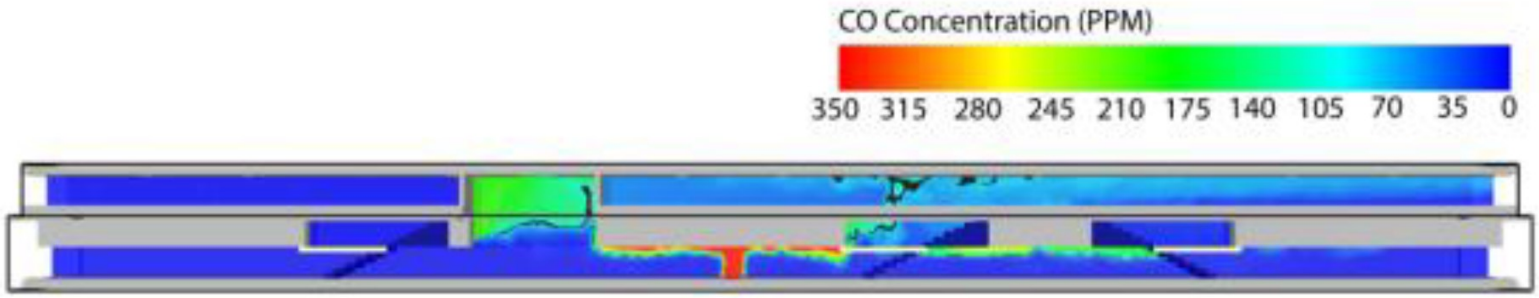
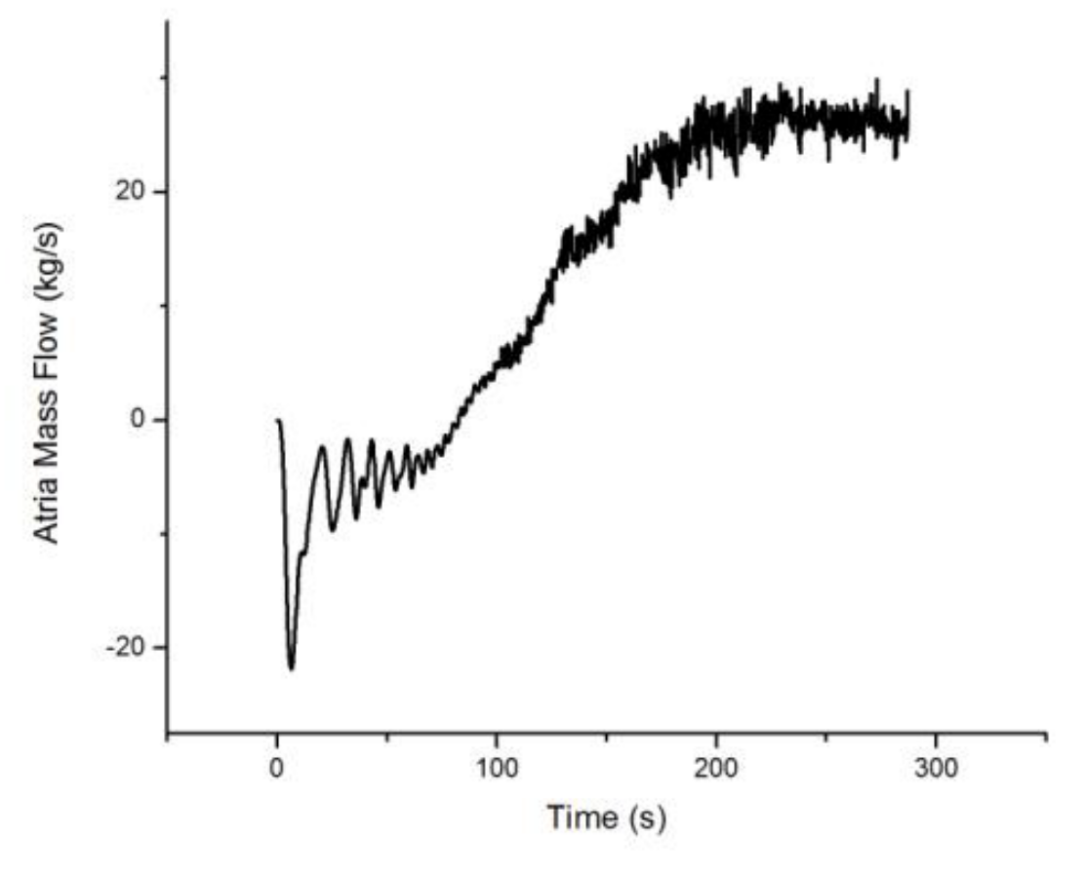


Figure 21. The impact of atria structure on the overall CO concentration distribution (black color indicates CO concentration of 85 ppm)

The effectiveness of natural ventilation (Con't)

- Mass flow at atria ceiling opening



The effective position of PSD opening position in case of fire

Normal PSD opening

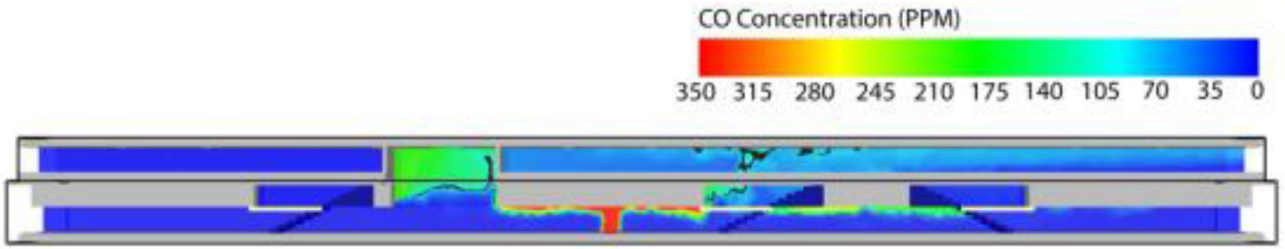


Figure 21. The impact of atria structure on the overall CO concentration distribution (black color indicates CO concentration of 85 ppm)

PSD opening on top

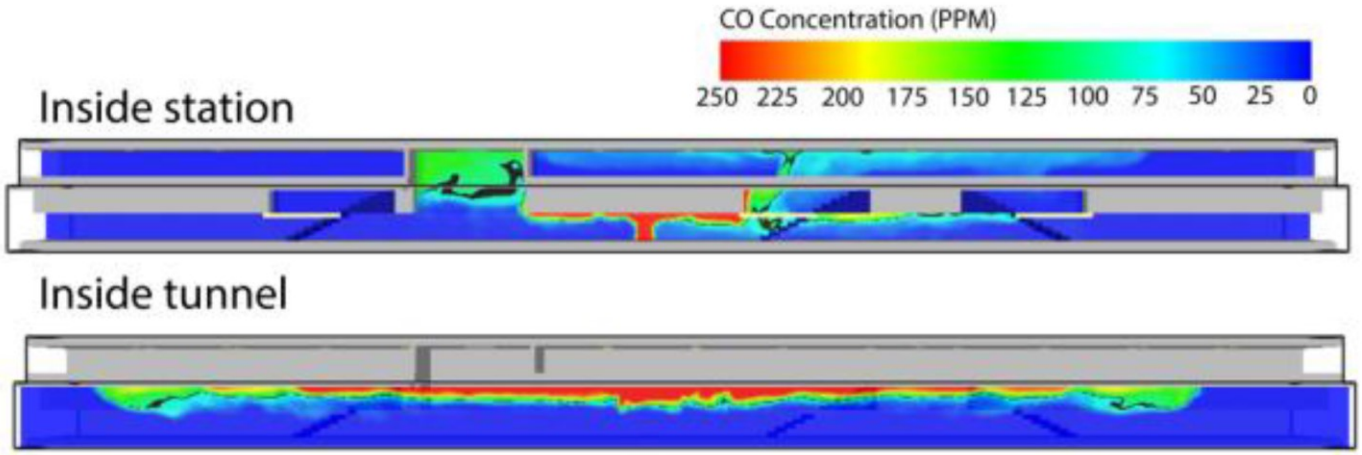


Figure 23. The impact of partially opened PSD on top (black color indicates CO concentration of 85 ppm)

Conclusions

- The most effective ventilation strategy is when platform's ventilation exhaust and concourse's ventilation set off
- The addition of natural ventilation effect (hybrid ventilation strategy) proved to effectively control smoke movement inside the station
- The proposed additional smoke exhaust is indeed needed to provide more effective smoke management
- PSD opening on top effectively maximize the utilization of OTE

Question and Answer