Fire Ventilation Systems in platform screen doors equipped Metro Station

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ABSTRACT: Scope of this work is to analyze a way to investigate an admissible solution for fire ventilation systems installed in a metro station equipped with Platform Screen Doors (PSD). Fire ventilation is related to fire scenarios involving generic events on the rolling stock present in the station. In order to evaluate capability and efficiency of desmoking systems, computational fluid dynamics analysis (CFD) have been developed, using Fire Dynamics Simulator software (FDS). Analysis have involved a range of fire simulations in a typical model of station where different system configurations provided during the design stage are applied. In all these models the railway platform area is delimited from the truck area by means of PSD system and all the limits with platform and concourse zone are modeled to investigate smoke interactions with station areas. System configurations assumed during the design provide for the possibility to operate a ventilation from the train side using side and upper ventilation as well as platform level ventilation. Simulation results show differences between smoke behavior using different systems and strategy leading us to the final design choice. According to NFPA 130 Standard, the acceptability of the solutions was defined applying tenability criteria along emergency and evacuation pathways. Final ventilation strategies using under platform ventilation have obtained excellent results in term of smoke and compliance of tenability criteria.

1 INTRODUCTION

The scope of this study is to show a way to investigate an admissible solution for ventilation system to be installed inside a metro station equipped with PSD in order to manage generic fire scenario involving events on the rolling stock. In the study fluid dynamics analysis (CFD) have been used in order to evaluate the efficiency of the proposed ventilation systems with particular reference to its behavior in fire regime.

In particular the study consists in the development of a fire simulation in a typical model of Metro Station in which an Under Platform Extraction system (UPE) is adopted in order to manage the ventilation in case of fire. Preliminary analysis showed that the best results in terms of ventilation efficiency are guaranteed by a UPE system compared to other ventilation systems (such as Over Truck Extraction or Tunnel Ventilation System) and in the following we want to highlight the good results obtained with the simulations concerning to the present case.

2 REFERENCES

Ref. [1] NFPA 92 - Standard for Smoke Control Systems
Ref. [2] NFPA 130 - Standard for Fixed Guideway Transit and Passenger Rail Systems
Ref. [3] Fire Safety Journal 44. Ingason H - Design fire curves in tunnels

Ref. [4] Springer SFPE. Morgan J. Hurley - SFPE Handbook of Fire Protection Engineering”

Ref. [5] SP Technical Research Institute of Sweden. Ying Zhen Li - CFD modelling of fire development in metro carriages under different ventilation conditions

Ref. [6] Proceedings from the Fifth International Symposium on Tunnel Safety and Security (ISTSS 2012). Lonnermark, A., Lindstrom, J., Li, Y. Z., Ingason, H., Kumm, M. - Large-scale Commuter Train Tests - Results from the METRO Project

Ref. [7] Research Institute of Sweden, SP Report 2012:05, Boras, Sweden, 2012. Lonnermark, A., Lindstrom, J., Li, Y. Z., Claesson, A., Kumm, M., Ingason, H. - Full-scale fire tests with a commuter train in a tunnel

Ref. [8] Branz Study Report 185, A.P. Robbins, C.A. Wade - Soot Yeld Values for Modelling purpose – Residential occupancies

Ref. [9] NIST Special Publication 1018-2 Sixth Edition. K. McGrattan, S. Hostikka, R. McDermott, J. Floyd, C. Weinschenk, K. Overholt - Fire Dynamics Simulator Technical Reference Guide. Volume 2: Verification

Ref. [10] NIST Special Publication 1018-3 Sixth Edition. K. McGrattan, S. Hostikka, R. McDermott, J. Floyd, C. Weinschenk, K. Overholt - Fire Dynamics Simulator Technical Reference Guide. Volume 2: Validation.

3 SUBJECT

3.1 *Models and Fire Scenarios*

The fire scenarios, covered by the simulations, refer to a generic event of fire on the rolling stock present in the station. It wants, in fact, to determine the behavior of ventilation systems during an emergency scenario involving this convoy in the station platform.

The railway platform area is delimited from the rail area by means of a system of platform screen doors (hereinafter PSD). The system configurations assumed during the design provide for the possibility to operate a ventilation from the under platform level as shown in the following figure.

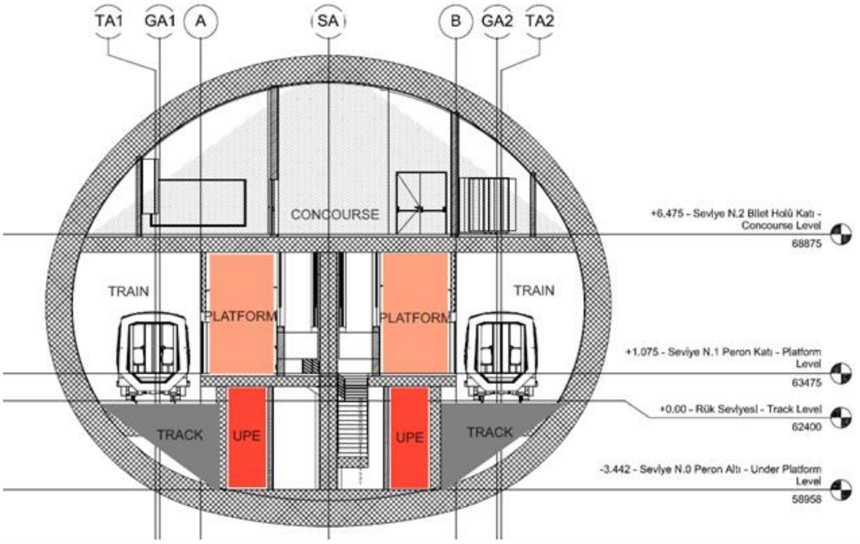

Figure 1 – Typical cross section with main ventilation elements

In particular, there is a train side ventilation system (obtained underneath the seat of the platform tunnel and station), defined UPE (Under Platform Extraction), that provide to extract air or smoke from train areas.

Ventilation strategies adopted in case of fire on train inside station area are schematically described in next figure where main fluxes of UPE system is highlined. Blue dot lines and red arrows show fully airflow path from extraction point to external environment. UPE system provide exhaust ventilation at both ends of the station, in one track side, using ventilation shaft and UPE Duct installed under platform. Extraction at both ends is actuated using two vertical smoke damper installed on train side.

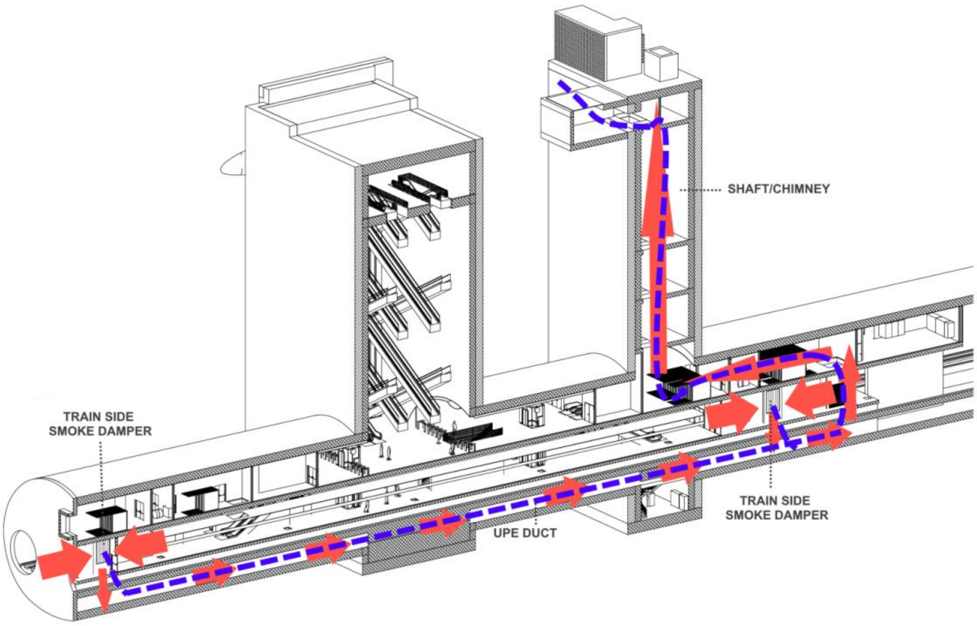

Figure 2 – Typical cross section with main ventilation elements

3.2 *CFD analysis method and objectives*

As mentioned in the previous paragraphs, CFD approach was used in this simulation to evaluate efficiency of smoke management system that are designed for (Ref. [1]):

- Allowing fire department personnel sufficient visibility to approach, locate, and extinguish a fire
- Limiting the rise of the smoke layer temperature and toxic gas concentration and limiting the reduction of visibility
- Maintaining of tenability for people involved.

Simulation results allow to understand, in a qualitative and quantitative way, the behavior of the ventilation systems during an event of fire in accordance with the ventilation strategy chosen. Factors that should be considered in a tenability analysis include the following:

- Heat exposure
- Smoke toxicity
- Visibility.

4 DESIGN FIRE SIZE

4.1 *HRR*

Fire scenarios are characterized by a designed fire scenario. The design of fires is most easily and commonly expressed in terms of a Heat Release Rate (HRR) versus time curve for the progress of the fire. A HRR curve is a simple approximation of real fire behavior and according to Ref. [1] and [2], is generally represented, in CFD models, with an unsteady fire with a heat release rate that varies with time.

The growth phase of the fire shall be described using t-squared fire (Ref. [3]) growth model with $Q = \alpha t2$ where α is the fire intensity coefficient; α value can be considered as 0.012 kW/s^2 as well as for Medium growth up fires.

The radiative portion of the heat release rate of the fire is in general determined from equation Q / Qr = ξ, where Q is the total heat release rate of the fire, Qr is its radiative portion (kW) and ξ is its radiative fraction (dimensionless). In practice a value of 0.35 should be used for the radiative fraction and it has been used in these simulations. Given the above, we considered in our CFD simulations, following parameters for design the train fire size:

- peak HRR = 12 MW
- peak specific heat flux = 240 kW/m^2 (train geometry)
- peak Time = 1000 s
- α growth rate = 0.012 kW/s^2
- ξ radiative fraction = 35%.

4.2 *Fuel and Exhaust*

The fuels inside the carriage mainly consisted of floor, walls, ceiling, seats and luggage Ref. [5]. The metro carriage is made of steel. A thin steel plate with a insulation board behind mostly existed beneath the interior combustible materials.

For the simulation at issue is provided the use of a combustion reaction that uses as a reference fuel of a polymeric nature composition. The polyurethane is a plastic material used in the inner linings of motor vehicles and in the form of foam also for the upholstery of chairs and generic furnishings and contributes to a considerable production of smoke combined with an equally important production of carbon monoxide. The soot and CO yields, produced by fuel during fire reaction, are estimated according to experimental test made and descripted in Ref. [5] and [8]. Both soot and CO yields vary significantly during the tests but can be approximated, to the purpose of this analysis, to values represented below:

- CO Yield = 0.10 kg/kg_{fuel}
- Soot Yield = 0.07 kg/kg_{fuel}.

5 CFD CALCULATION DOMAIN

5.1 *Geometrical and Physical model*

As part of the train fire simulations the following geometric model has been implemented (see figures below). In calculation domain are represented, in order:

- tunnel an station geometry (platform level)
- train geometry
- second platform geometry
- elevator, escalators and stair in concourse areas (and their open connections with upper level)
- fire geometry and conditions
- open condition at tunnel boundaries
- open condition at PSD boundaries (second platform)
- smoke ventilation design parameters.

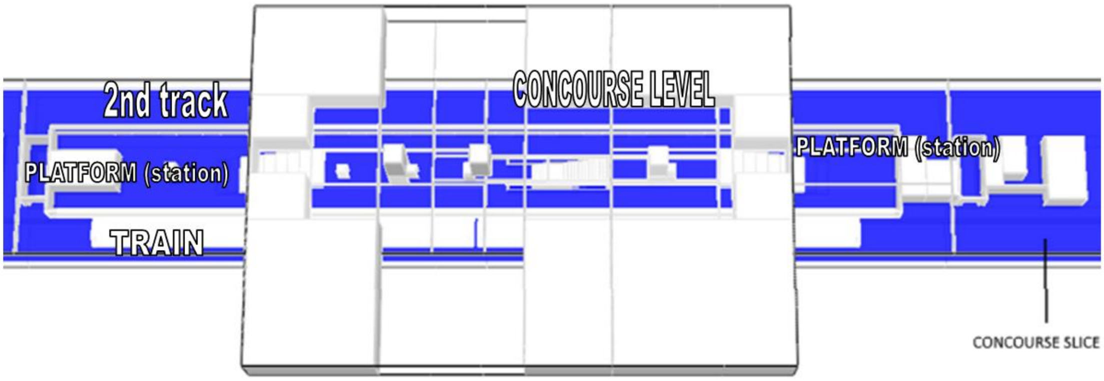

Figure 3 – FDS Calculation Domain

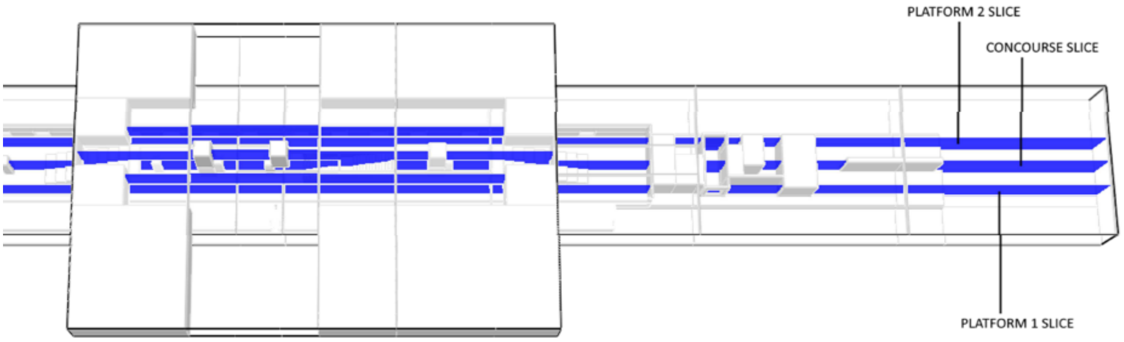

Figure 4 – FDS Calculation Domain (vertical slice view)

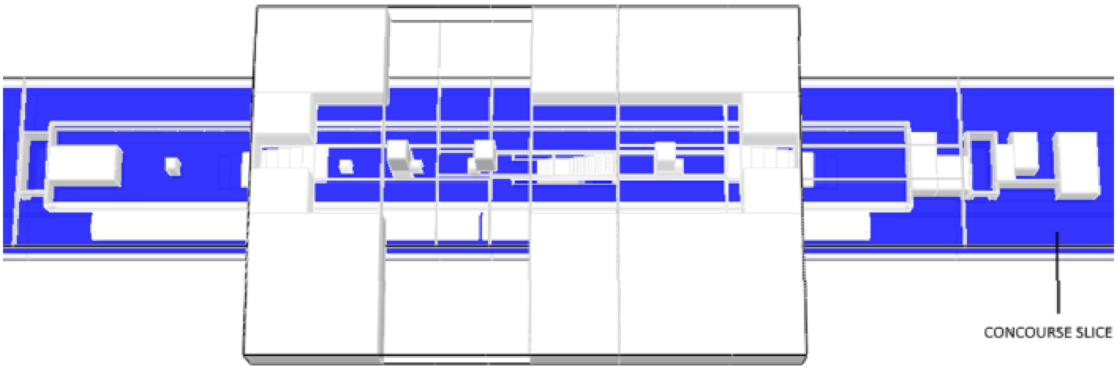

Figure 5 – FDS Calculation Domain (horizontal slice view)

In the geometrical and physical model, following parameters are been considered and setted in the processor code.

- Height of ceiling inside tunnel and station zones
- Size and location of fire in plane underneath the train with surface = 50 m^2
- Open vents at tunnel boundaries
- Open vents at concourse interface (stairs, escalators, …)
- Open vents at PSD interface in the second train platform (to consider failure)
- Inert condition for model wall and ceiling
- Initial temperature of 20° C
- Initial tunnel air velocity = 1.5 m/s (train running direction).

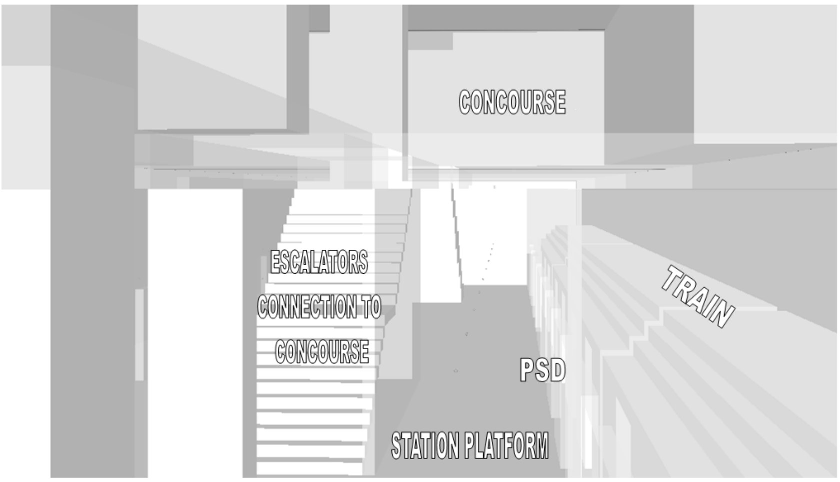

Figure 6 – View from inside model

The inclusion of platform edge screens is a design option that is effective for comfort control in stations as well as for smoke control in tunnels. For that reason, PSD system at both platform has been included in model geometry to evaluate ventilation system efficiency. At simulation time = 0 s (initial state), train is stopped at station platform; its doors and station PSD are opened.

Summarizing in table below, main geometrical characteristics of domain has been shown.

Table 1 – CFD Domain Characteristics

Domain Characteristics*	Tunnel	Station	Other platform	Concourse area
Geometry	5.2 x 5.8 x 160 m	9.8 x 5.8 x 130 m	5.2 x 5.8 x 160 m	40 x 5.4 x 20 m
Volumes	4 800 m^3	7 400 m^3	4 800 m^3	4 300 m^3
Medium cell dimension	20 cm	20 cm	20 cm	20 cm
Medium cell volume	0.008 m^3	0.008 m^3	0.008 m^3	0.008 m^3

*Total number of cells approx. 5 millions

5.2 *Ventilation Systems and Equipment for smoke control*

The emergency ventilation system shall be designed (according to Ref. [2]) to do the following:

- Provide a tenable environment along the path of egress from a fire incident in enclosed stations and enclosed railway
- Be capable of reaching full operational mode within 120 seconds.

The design shall also encompass, among others, the following:

- The heat release rate produced by the combustible load of a vehicle and any combustible materials that could contribute to the fire load at the incident site
- The fire growth rate
- Station and railway geometries
- A system of fans, shafts, and devices for directing airflow in stations and railway.

For this purpose, an under-platform (UPE) ventilation system has been considered, in the model, for the extraction of heat from the traction and braking devices and for de-smoking. UPE system is located below the platform level. UPE System is designed considering a concentrated extraction system with vertical exhaust dampers installed at both ends of the metro stations as shown in the next figure.

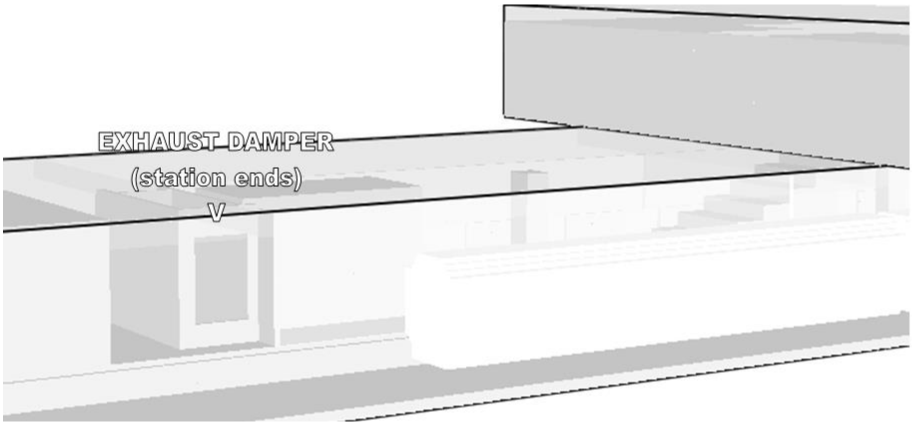

Figure 7 – Vertical exhaust damper at station ends

Activation of ventilation systems (active for every scenarios – see below) has been performed with a fixed delay time (from outbreak of fire start) equal to 60 s. Used Delay Time is the minimum time required for the detection of fire with the HRR used (t^2 growth). Fully development (regime) of the ventilation systems is reached using a 30 s ramp and thus nominal flow rate value is achieved 90 s from the beginning of the simulation.

Table 2 – Ventilation system characteristics

Ventilation system	Tunnel
Nr. of exhaust dampers	2
Dampers Geometry	3 000 x 2 000 mm
Distance between dampers	105 m (approx.)
Total vent area	11.2 m^2
Nominal flow rate (total)	360 000 m^3/h

6 TENABLE ENVIRONMENTS

The effects of a fire are crucial to the assessment and management of evacuation procedures. Both the flames that its combustion products can seriously damage persons undergoing evacuation causing a total incapacity of movements up to the death.

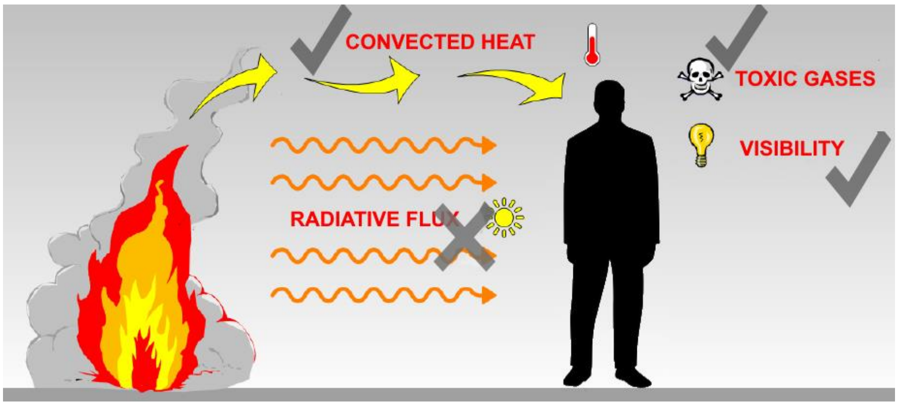

Figure 8 – Adopted design tenability criteria

According with Ref. [2], some factors that should be considered in maintaining a tenable environment for periods of short duration can be defined as follows:

- Air temperatures as follows: Maximum allowed temperature during evacuation was estimated by NFPA 130 using Fractional Effective Dose (FED) criteria that consists in a calculation of the time to incapacitation under conditions of exposure. Limit value for incapacitation are fixed (in NFPA) equal to 80°C per first few minute (3.8 minutes) and 60°C for first 10 minutes during fire. This value (60°C) is adopted in our scenario to evaluate human capacity to perform the evacuation during the entire duration of the simulation (1200 s)
- Air carbon monoxide (CO) content as follows: as well as for temperature maximum values for CO exposition during fire is fixed to of 2000 ppm in first few minutes and 1000 ppm for the first 10 minutes. For these reasons 1000 ppm value is fixed for maximum reference value during evacuation
- Smoke obscuration levels that are continuously maintained below the point at which doors and walls are discernible at 10 m.

Other main tenability criteria regard Heat exposure due to radiation but this effect is ignored in these simulation because of geometry model and presence of screens (i.e. PSD) and design evacuation time.

7 FINAL RESULTS

To give full understanding of the results some graphical representations of the main variables examined within the computational domain have been reported, over time, in the following figures. The representations are provided in the form of section planes (SLICE plane) longitudinal and transversal with respect to the domain, in which the reproduction of the results (scalar values or vectors) is expressed in the form of color gradation. Graph trend of most important variables along platform are also represented.

In particular, the analysis of temperature and visibility on the median planes station allows, qualitatively, to demonstrate fully compliance of fire ventilation strategy with design tenability criteria. The results allow to determine in graphical form and among others, the thermal stress produced by the fire along the walkways of the platform and the visibility along the said walkways.

7.1 *Qualitative Results – Slices colored contours*

In order to better clarify the full compliance of the tenability criteria during fire scenario guaranteed by the adopted ventilation strategy, in the next figures final results relative to 600 s time simulation are shown.

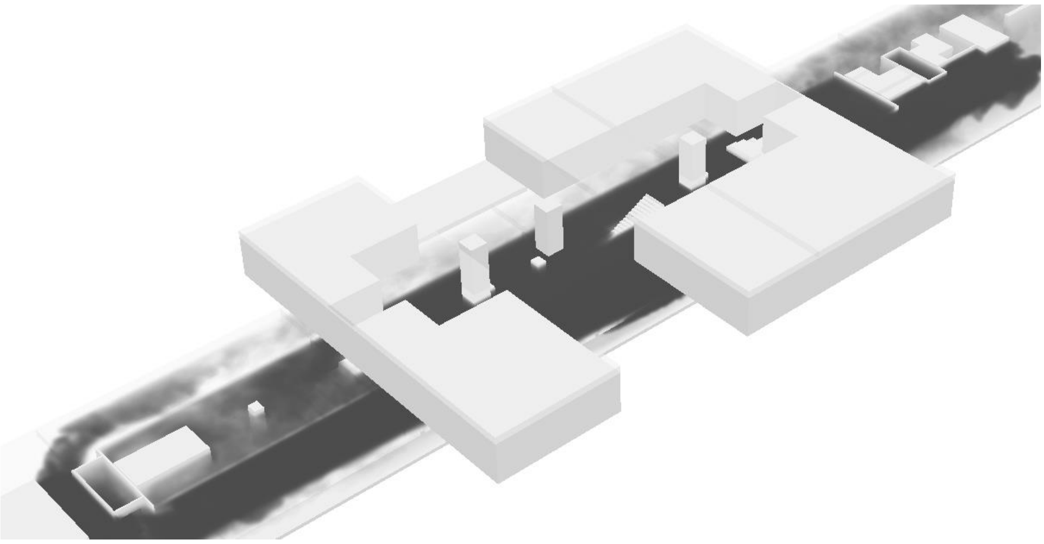

Figure 9 – Spread of smoke at platform level (perspective view)

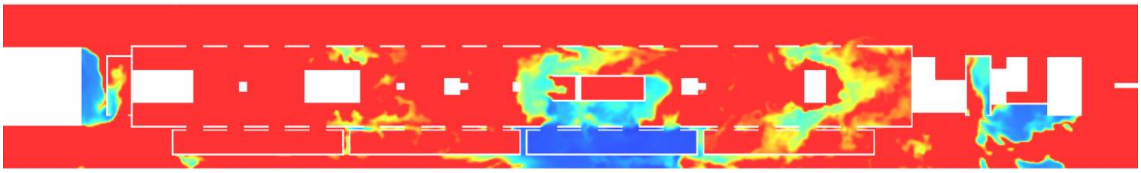

Figure 10 – Visibility contours along platform areas in the horizontal slice (scaled from 0 – blue contours – to 10 m and above – red contours)

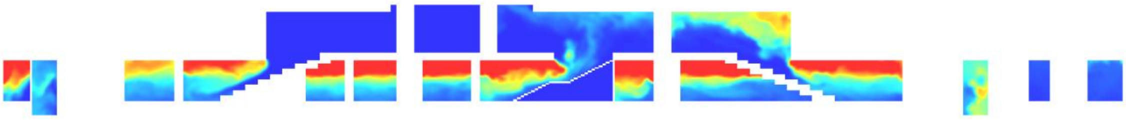

Figure 11 – Temperature contours along platform and concourse areas in the vertical slice (scaled from 20 – blue contours – to 60 °C and above – red contours)

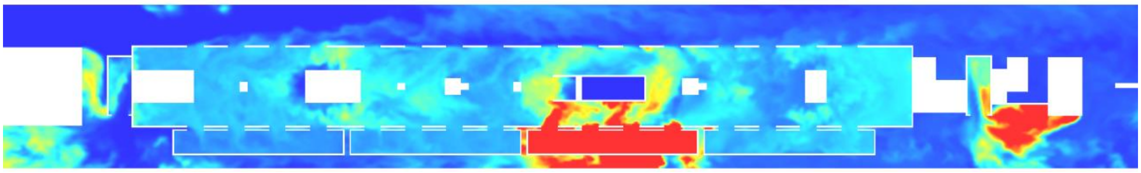

Figure 12 – Temperature contours along platform areas in the horizontal slice (scaled from 20 – blue contours – to 60 °C and above – red contours)

7.2 *Quantitative Results – Graphical trends*

In the next we underline the graphs related to the main quantities and variables disclosed along tunnel, station platform and escape walkways. Values of interest are the ones highlighted in the following image.

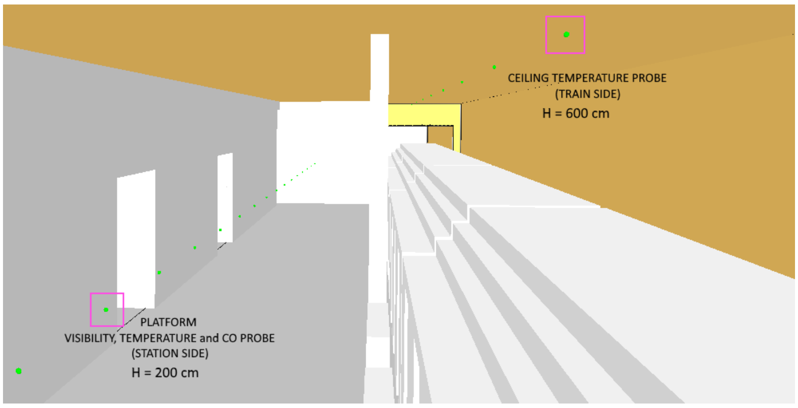

Figure 13 – Thermocouple and probe position inside domain

In particular in the next graph you can analyze registered values, during simulation, related to maximum temperatures and toxic gases concentrations along station platform and its walkways. Graphlines confirm qualitative results analyzed above and shows that maximum values assumed in order to maintain tenability criteria inside station area were not exceeded during first 600 s of simulation.

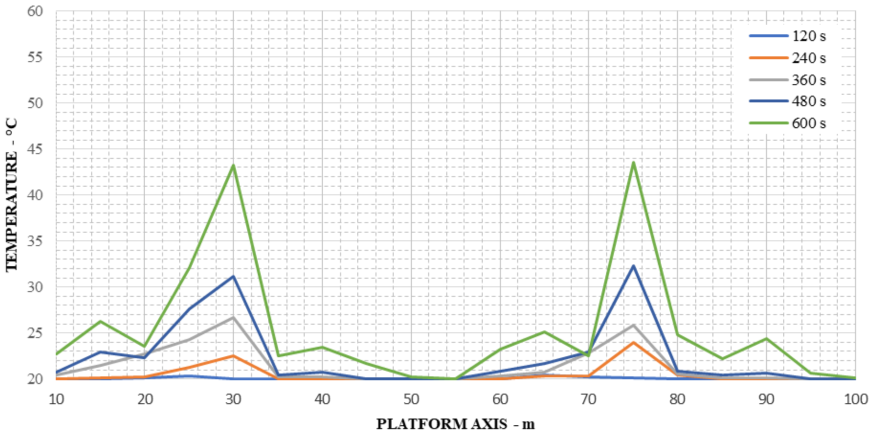

Figure 14 – Temperature trend above station platform (h = 2.00 m)

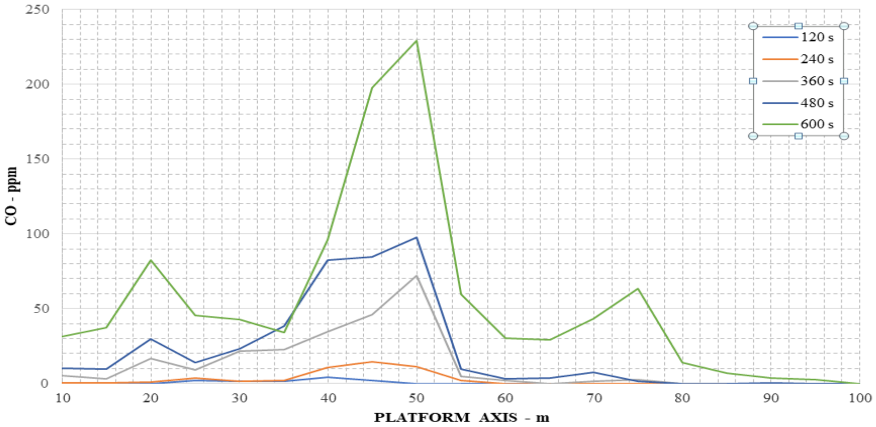

Figure 15 – Monoxide carbon concentrations trend above station platform (h = 2.00 m)

7.3 *Confidence on results*

The objective of this kind of study is to achieve a high level of credibility and confidence in the results in order to consider CFD analysis as a part of the design of the ventilation system. Credibility and confidence are obtained by demonstrating acceptable levels of error and uncertainty as assessed through verification and validation. Determining this precisely is often difficult, but in general CFDS simulation are however affected by intrinsic error, produced by as example:

- Errors exist because continuum flow equations and physical models represented in a discrete domain of space (grid) and time but can be reduced by user analysis and model settings
- Level of error is function of interactions between the solution and the grid and boundary conditions that can change during real phenomena.

Other errors can be introduced during the programming phase but Verification and Validation Guide (as mentioned in Ref. [9] and Ref. [10]) demonstrate that FDS software fulfills the fire test and other real application result.

8 CONCLUSIONS

In conclusion and referring to the above, it can be stated that the Model and Fire Scenario has been realized in a congruent manner with the shared technical choices related to the CFD methodology, and in particular to the boundaries conditions of the design fire size, HRR and tenable environments.

The insertion of this model into the selected ventilation system has demonstrated, throughout the final simulation, that this ventilation system is effective in the management of smoke produced by the fire.

Results demonstrate fully capability of the investigated system to maintain tenability criteria for the entire duration of the analysis.