EVALUATION OF ENGINEERED SMOKE MANAGEMENT SYSTEM FOR AN INTERNATIONAL AIRPORT EXPANSION PROJECT USING PYROSIM/FDS

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ABSTRACT

The passenger terminal building (PTB) of a modern international airport consists of high-rise, large volume, undivided public spaces for circulation. While local code governing high-rise buildings requires fire and smoke compartmentation, full compliance to the code is not practical due to the nature and use of passenger terminal building. Hence, performance-based fire engineering approach in conjunction with the local code provision is adopted for fire safety, using CFD analysis for the design of smoke management system for control of fire and smoke spread. In this project case study, smoke management system design adopts static smoke extraction i.e., automatic openable natural smoke vents for smoke exhaust and automatic openable louvers/doors for make-up air. In order to limit the smoke spread, the space is divided into a number of smoke zones. PyroSim/FDS is used for CFD modelling and analysis of smoke extraction system. Proposed smoke management system consists of smoke zones, smoke down stands/smoke curtains and natural smoke vents. Smoke vents are proposed on the façade for arrival area i.e., baggage reclaim area and on the roof for departure areas. CFD model is created based on actual building geometry, number of vents, vent spacing and locations, and worst-case fire scenarios for departure and arrival areas of passenger terminal building. Design fire sizes include check-in hall fire, retail fire and baggage fire. Wind effect on smoke exhaust has been modelled for baggage reclaim area. CFD results of smoke visibility and smoke temperature demonstrate that smoke spread is limited to the smoke zones of fire origin. Tenable conditions for life safety are ensured throughout the passenger terminal building and hence proposed smoke management system in terms of number of vents and openable louvers is found to be adequate to evacuate and exhaust smoke in case of fire in the passenger terminal building spaces.

KEYWORDS

Life safety, Performance-based fire engineering, Smoke management, PyroSim/FDS.

INTRODUCTION

Life safety in the event of fire is the key parameter in the design of a large public space such as the passenger terminal building (PTB) of an international airport. The smoke management strategy is one of the main features of the fire safety strategy for the airport PTB. The fire safety strategy adopts performance-based engineering approach in conjunction with local code. Control of fire spread in the event of fire is achieved by sprinkler protection, compartmentation or control of fire load. Control of smoke spread is achieved via smoke management system where in smoke zones are provided and separated. Smoke is contained and vented out in order to prevent spread of smoke to adjacent zones. Departure and arrival areas of the airport PTB are of significant importance and a powerful CFD tool – PyroSim/FDS is used to evaluate the smoke management system design to ensure that tenable conditions are maintained throughout the evacuation for life safety.

BUILDING DESCRIPTION

The International Airport is undergoing an expansion for passenger capacity roughly 3 times of existing capacity. The existing terminal is a T-shaped building (Refer Figure 1) across 7 levels and 2 piers. As a part of this project, the existing PTB and Piers (West and East Wing) will be extended to increase the processing capacity. PTB has multi levels, with the proper escape routes and smoke management system to curtail the smoke spread between the compartment zones, for the life safety of occupants. In this study, Level D for Baggage reclaim area and Level F for Check-in hall are considered.

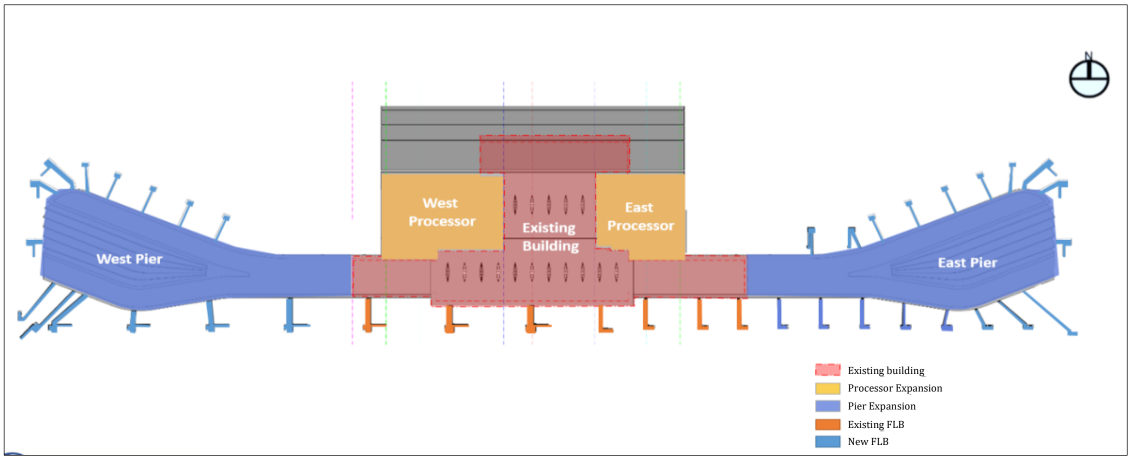


Figure 1: Proposed PTB and expansion

METHODOLOGY

Smoke management system

The smoke management system for the PTB is primarily via natural vents (i.e., static smoke extraction system). In the event of fire, hot smoke will rise to the ceiling and will be confined within the smoke reservoir before flowing out via the vents. The purpose of a smoke management system is to achieve a smoke free zone of specified height and level of safety.

The static smoke ventilation is provided based on controlled fire sizes. Therefore, use of the sprinkler protection and compartmentation in high-risk areas such as retail will control the worst expected incident and enable the smoke to be dealt with efficiently.

Natural smoke vents are provided for each zone in order to achieve the following performance criteria:

- Maintain tenable conditions within the smoke zone of fire origin.
- Prevent wide spread of smoke, resulting smoke to lose its buoyancy before vented out.
- Limit smoke spread so that occupants within the non-fire zone are not affected by smoke and heat. The non-smoke zone can be utilized as a place of relative safety if necessary.
- Limit smoke damage to reduce the impact of disruption within PTB extension and maintain business continuity.

The use of natural vents is chosen over mechanical extract system so that the flexibility of the PTB for future development is maximized.

Provisions of smoke zones

As per local code, all the buildings need to be fire compartmented to have control on spread of fire and airport buildings which come under assembly occupancy require every 2000 sq.m area to be compartmented. As per local code, number of compartments required for PTB would be large and will not serve the intended use as PTB requires large open spaces for easy wayfinding. Instead, smoke management system with smoke zones is provided. Smoke zones are separated by down stands to contain and vent out the smoke.

Spread of smoke between different zones is limited to allow people to remain within the building in a place of relative safety while an incident in another zone is being dealt with.

Smoke zones with down stands and interconnected circulation spaces between levels protected by smoke curtains is shown below:

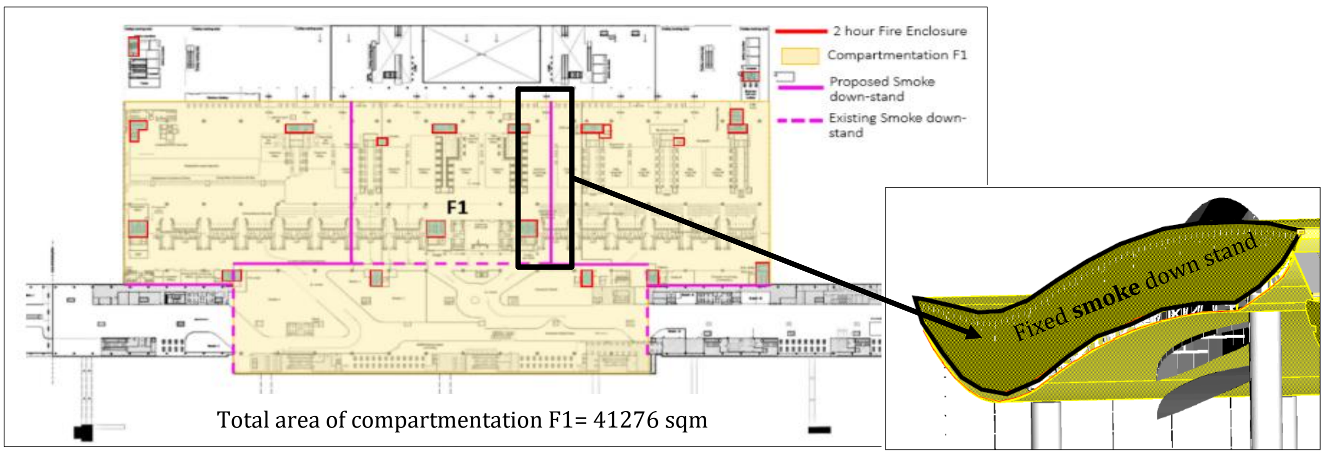
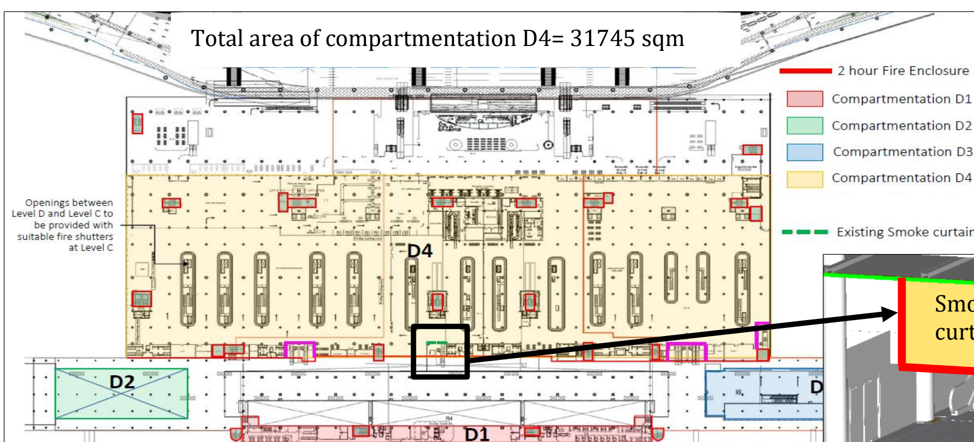


Figure 2: Compartmentation - Level F (Processor)



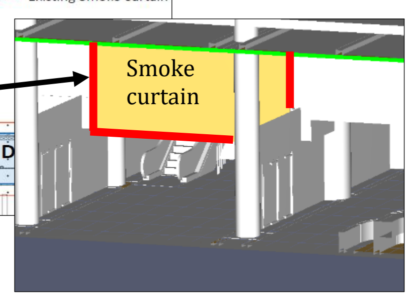
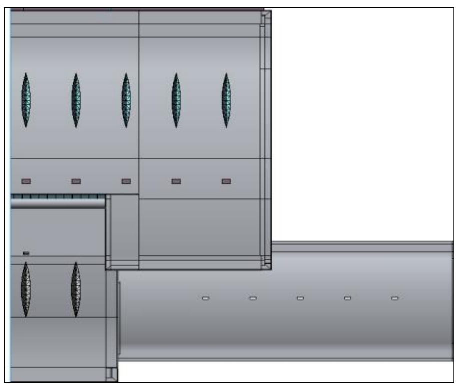


Figure 3: Compartmentation – Level D (Processor)

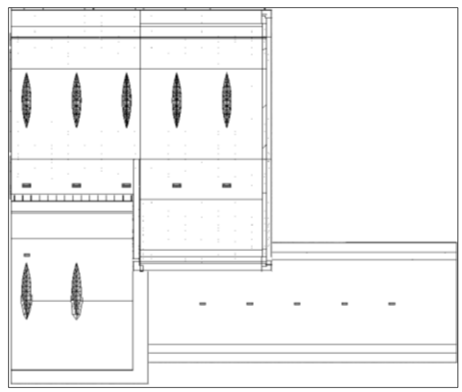
Smoke extraction system

Level F East Processor – Check-in hall area

- Static smoke extraction using automatic openable roof vents (smoke vents) are used for smoke management system. In the event of a fire, hot smoke will rise to the ceiling and is confined within a smoke zone before venting out via the roof vents in the departure level.
- Make-up air will be provided via the entrance doors and automatic openable panels on the facade.
- Fixed down stand is provided between each smoke zone in the processor. Suspended ceiling is provided underneath the roof for aesthetic purpose and hence the fixed down stand will drop from the roof to 450 mm above the ceiling.
- The smoke vents, automatic openable panels and smoke curtain will be activated immediately on activation of smoke detection. The smoke vents and automatic panels/door within the smoke zone receiving activation signal will open together.
- Smoke curtain between two compartment zones, will drop till 2.5m from floor to restrict the smoke spread.

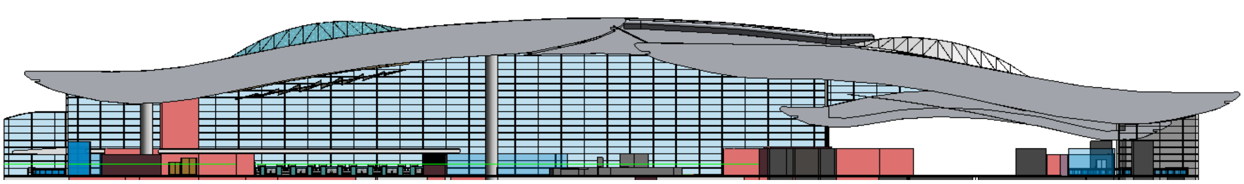


Revit model

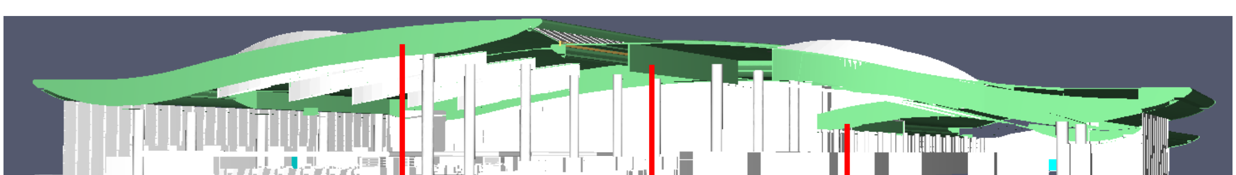


PyroSim/FDS model

Figure 4: Roof smoke vents - Level F (Processor)



Revit model



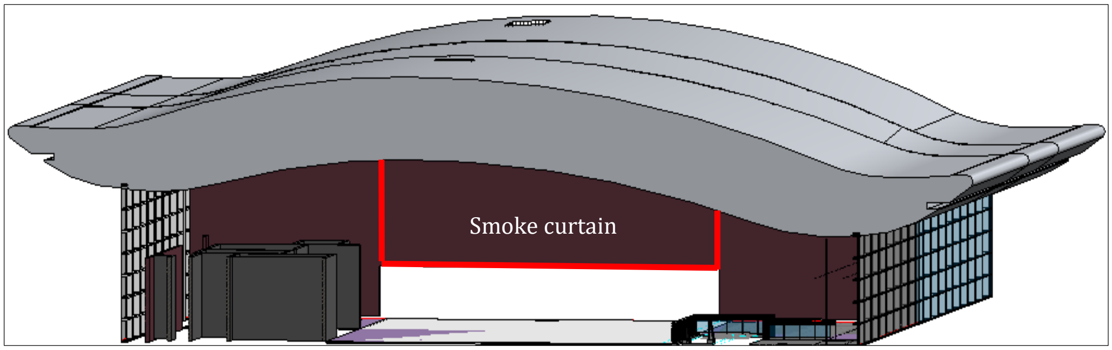
Smoke down stand

Smoke down stand

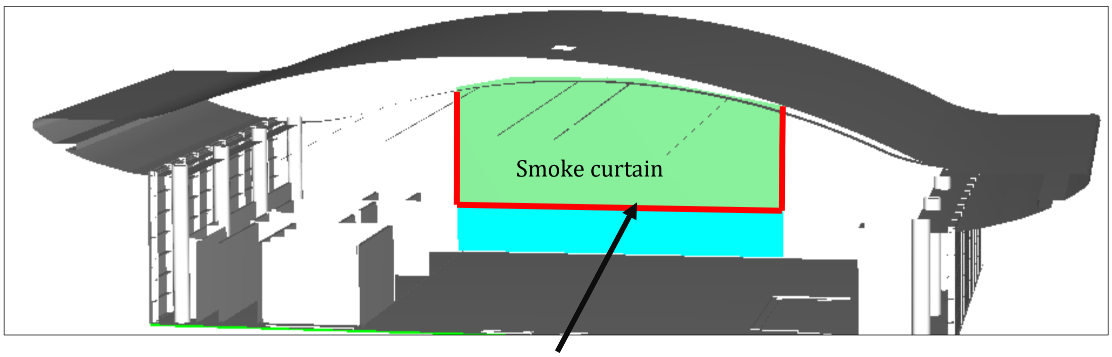
Smoke down stand (Pier)

PyroSim/FDS model

Figure 5: Smoke down stands - Level F (Processor)



Revit model



Smoke curtain in the passage between existing building and proposed pier. Smoke curtain drops up to 2.5m from floor.

PyroSim/FDS model

Figure 6: Smoke curtain - Level F (between processor & pier)

Level D Processor (Existing & Expansion) - Baggage reclaim area

- Static smoke extraction using automatic openable panes (smoke vents) are used for smoke management system. In the event of a fire, hot smoke will rise to the ceiling and is confined within a smoke zone before venting out via the smoke vents located on façades, not more than 1m below soffit level.
- Make-up air will be provided via the entrance doors.
- Automatic openable panels (smoke vents) will be activated immediately on activation of smoke detection. The smoke vents and automatic door within the smoke zone receiving activation signal will open together.
- Smoke curtain between two compartment zones will drop till 2.5m from floor to restrict the smoke spread.

<u>Fire loads</u>

For the PTB, two major types of fires considered are:
- High fire load area
- Low fire load area

High fire load area is categorized as high ability of materials catching fire, these areas are protected by the sprinkler system.
e.g., Retail area etc.

Low fire load area is categorized as less ability of materials catching fire, these areas need not protected by the sprinkler system.
e.g., Check-in counter, circulation space, seating space and baggage reclaim area etc.

- Various fire sizes at different levels are considered for evaluation of smoke management system.
- Steady design fire is considered. The design fire will grow at a fast growth rate and remain at the peak heat release rate throughout the simulation.
- Effect of sprinkler system on the fire and smoke is ignored.

Table1: Design fires details

S.no	Level	Design Fire	Fire Size (MW)	Soot yield (kg/kg)
1	Level F - Processor	Check-in Hall	3.6	0.1
2	Level D - Processor	International and domestic baggage claim area	2.5	0.1

External wind details

Based on average statistics for wind speed and monthly wind direction percentage, maximum wind velocity of 5.2m/s from West direction is considered for CFD analysis. Refer section PyroSim/FDS MODELS (Level D Processor (Existing & Expansion) with wind effect).

Tenability Conditions

Table 2: Tenability Criteria

Criterion	Tenability limit
Smoke layer height	Smoke to be kept at 2m above floor*
Visibility	Occupants will not be exposed to smoke with visibility of 10m or less**
Temperature	If smoke is maintained at 2m above floor level, the smoke temperature should be kept at 185 ^{0}C or less*** If smoke drop to 2m or less, smoke temperature should be kept at 60^{0}C or less****

* When the hot layer is at or below 2.0m above the floor level and simultaneously the hot layer temperature exceeds 100°C, the occupants will feel their lives are being threatened on such conditions (CIBSE Guide E).

** Where there is a clearly defined escape route a visibility of 10 m is normally considered reasonable (CIBSE Guide E).

*** When the hot layer is at 2 m above the floor and the temperature exceeds 185°C, the radiation emitted from the hot smoke layer will cause severe skin pain. (CIBSE Guide E)
*** As shown in SFPE Handbook, 80°C is the thermal tolerance for human for long time exposure in dry air and 60°C is for the humid air. A temperature of 60°C is also the reportable highest temperature at which 100% water-vapor saturated air can be breathed. Therefore, 60°C is considered to be conservative tenability criteria.

Life safety assessment

Egress calculations are carried out to determine the egress of occupants in terms of RSET (Required Safe Egress Time). PyroSim/FDS has been used to simulate fire scenarios and evaluate safety i.e., tenability in terms of smoke visibility, smoke layer height and smoke temperature and hence ASET (Available Safe Egress Time). Using the RSET and ASET values, compliance for life safety requirements is demonstrated. Acceptance criteria = ASET/RSET > 1.5 has been considered to evaluate adequacy of smoke management system.

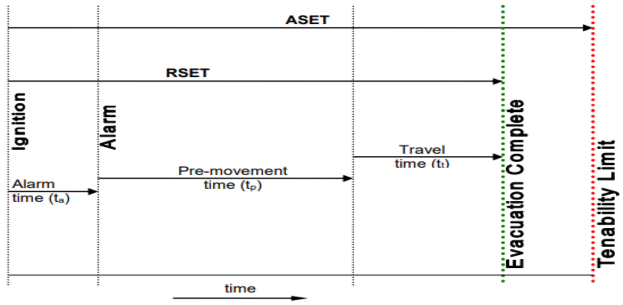


Figure 7: Safe egress assessment

PYROSIM/FDS MODELS

PyroSim/FDS 6.7.0 has been adopted for the case studies on various levels of PTB.

Level F East Processor

Level F East Processor has check-in hall, international and domestic departures, concourse and retail areas. Worst fire scenario considered is Check-in counter workstation. Real fire tests carried out on workstation at the Building and Fire research Laboratory provides information on peak heat release rate

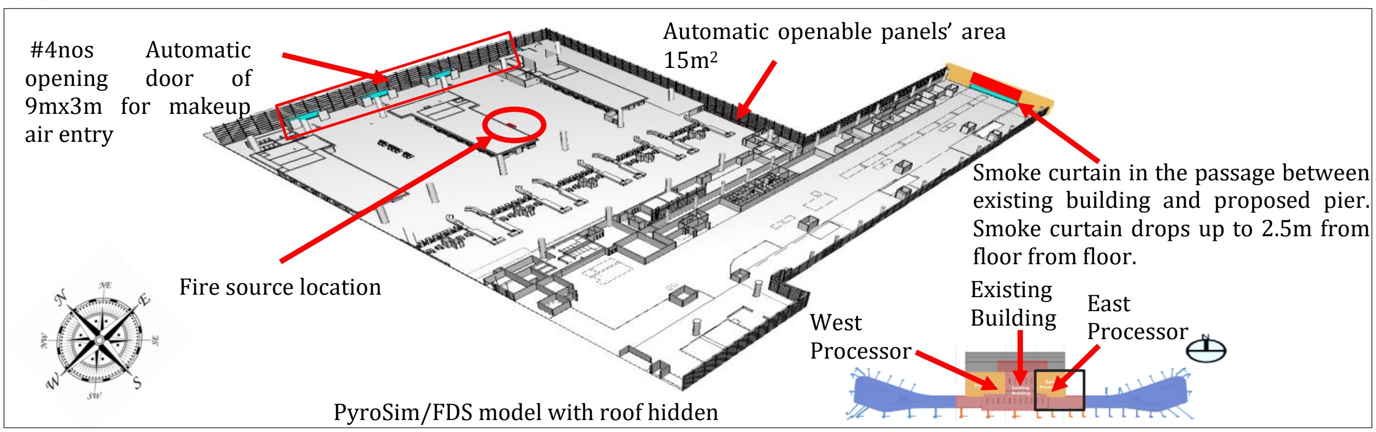


Figure 8: Level F (Processor)

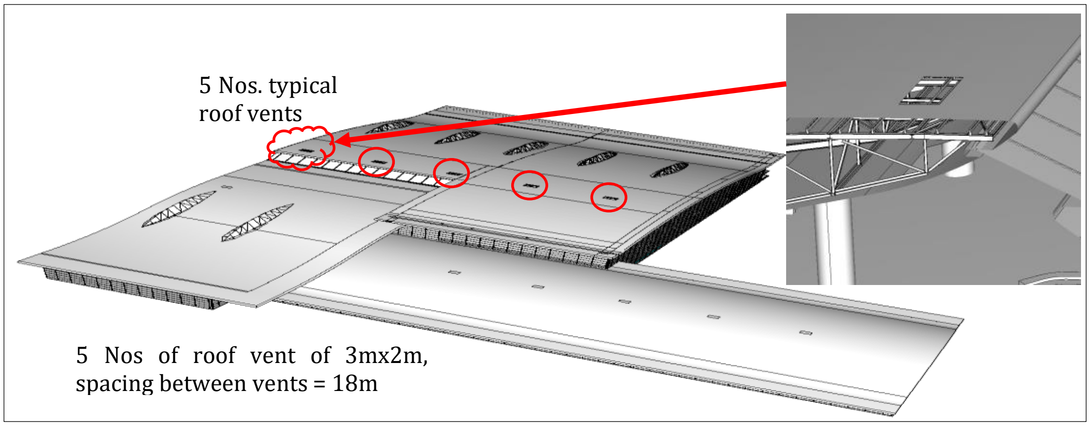


Figure 9: PyroSim/FDS model - Level F (Processor)

<u>Level D Processor (Existing & Expansion) with wind effect</u>

Level D Processor (Existing & Expansion) international and domestic baggage reclaim area and airport village. Although Level D is protected by sprinkler, an unsprinklered baggage fie is considered for smoke management design. Compared with the sprinkler-controlled fire (1.8 MW fire) and baggage fire (1MW fire), 2.5 MW design fire size is considered in this CFD analysis as a conservative assumption.

External wind flow of 5.2 m/s from the West direction is also considered to account for wind effect on the smoke spread.

Smoke vents are provided on both East and West facades. Make up air is provided through entrance doors.

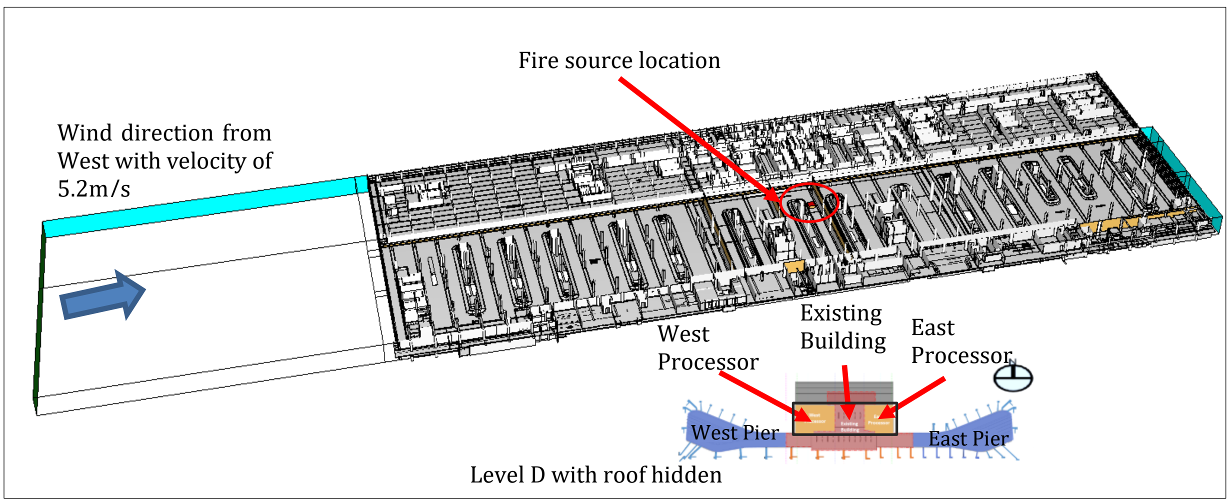


Figure 10: PyroSim/FDS model - Level D (Processor)

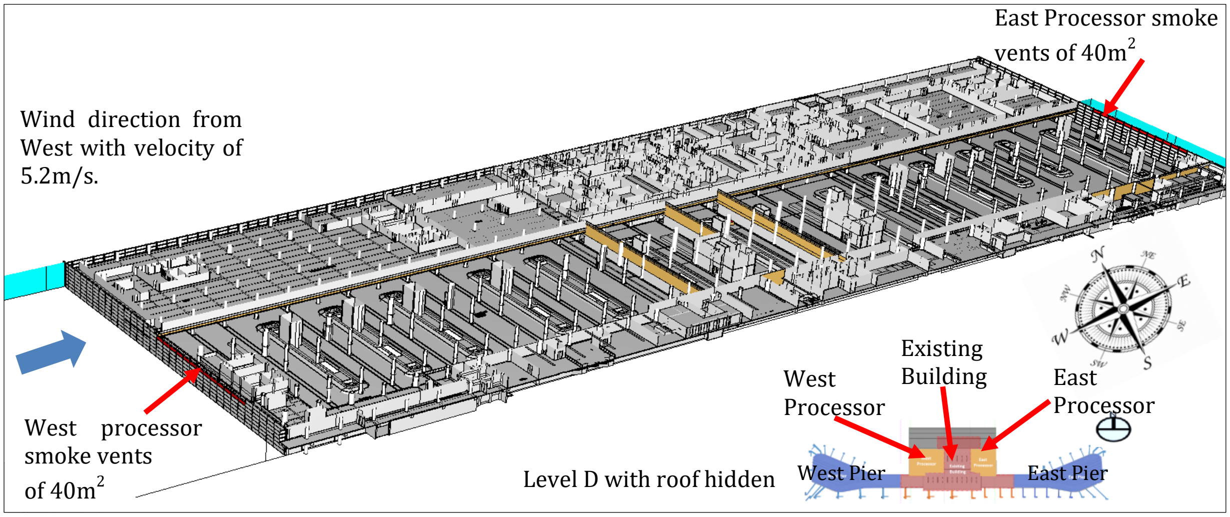


Figure 11: PyroSim/*FDS model - Level D (Processor)*

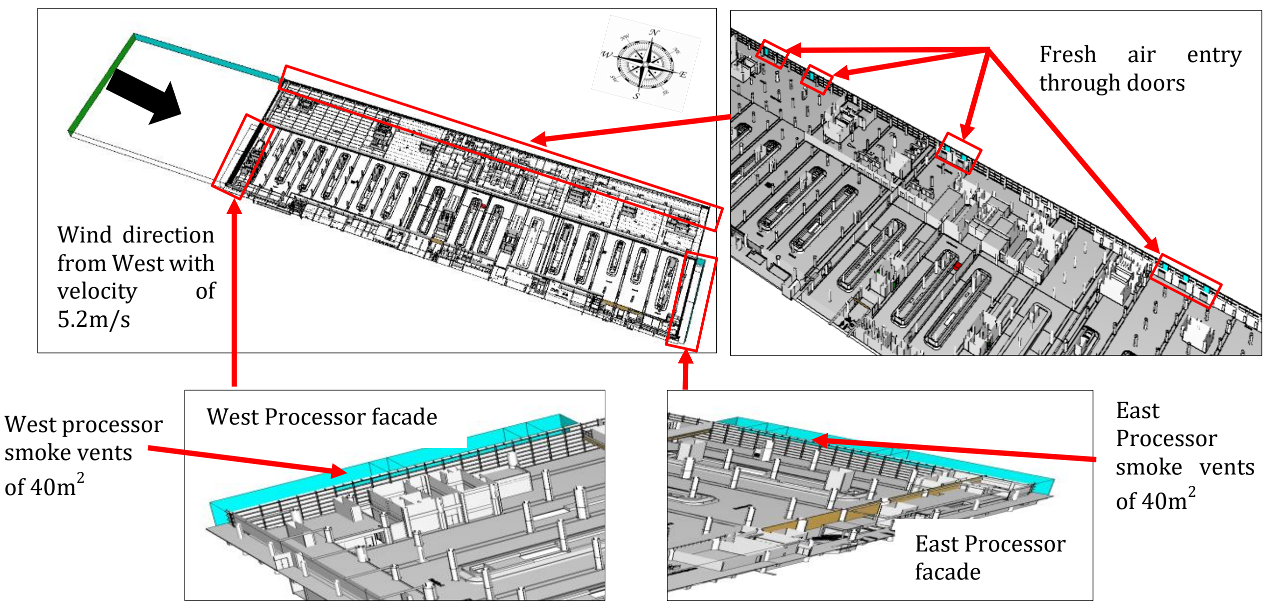


Figure 12: PyroSim/FDS model - Level D (Processor)

RESULTS

Level F East Processor – Visibility and temperature plots across Check-in counter hall fire.

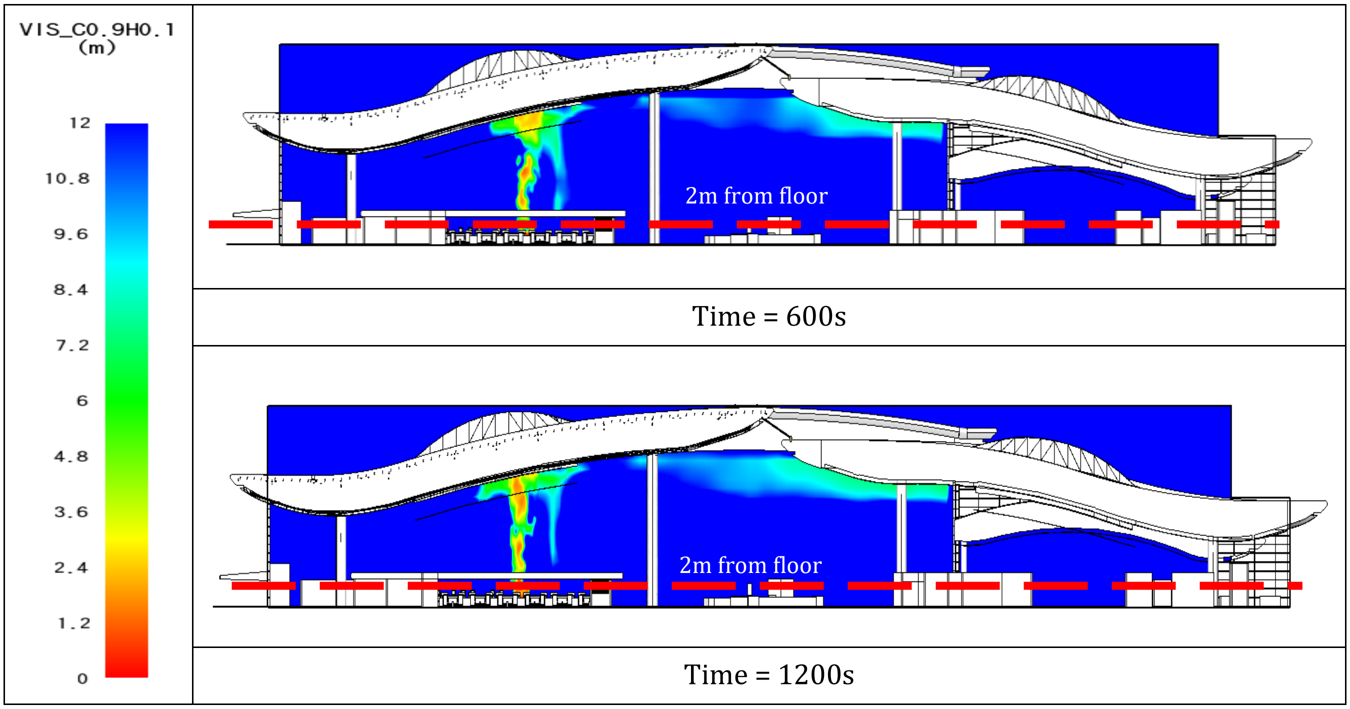


Figure 13: Smoke visibility plots across fire

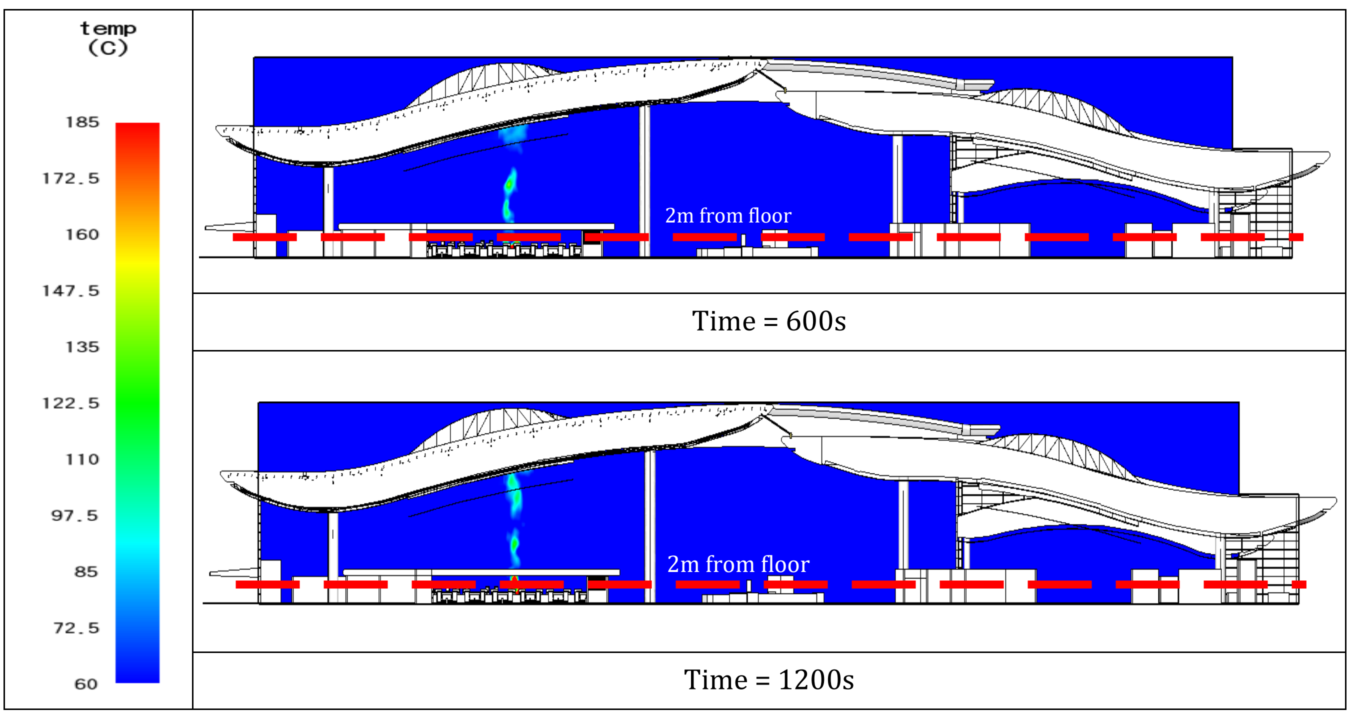


Figure 14: Temperature plots across fire

Level D Processor (Existing and Expansion) with wind effect – Visibility and temperature plots across baggage fire.

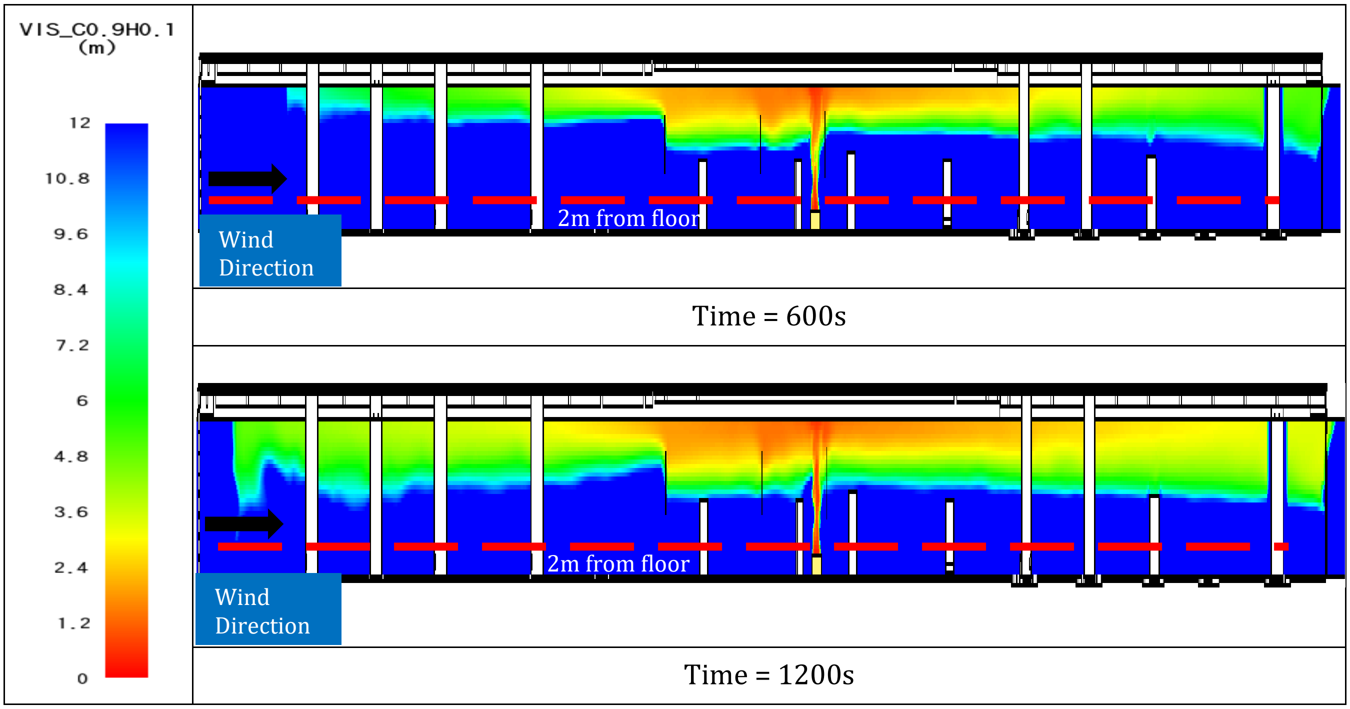


Figure 15: Smoke visibility plots across fire

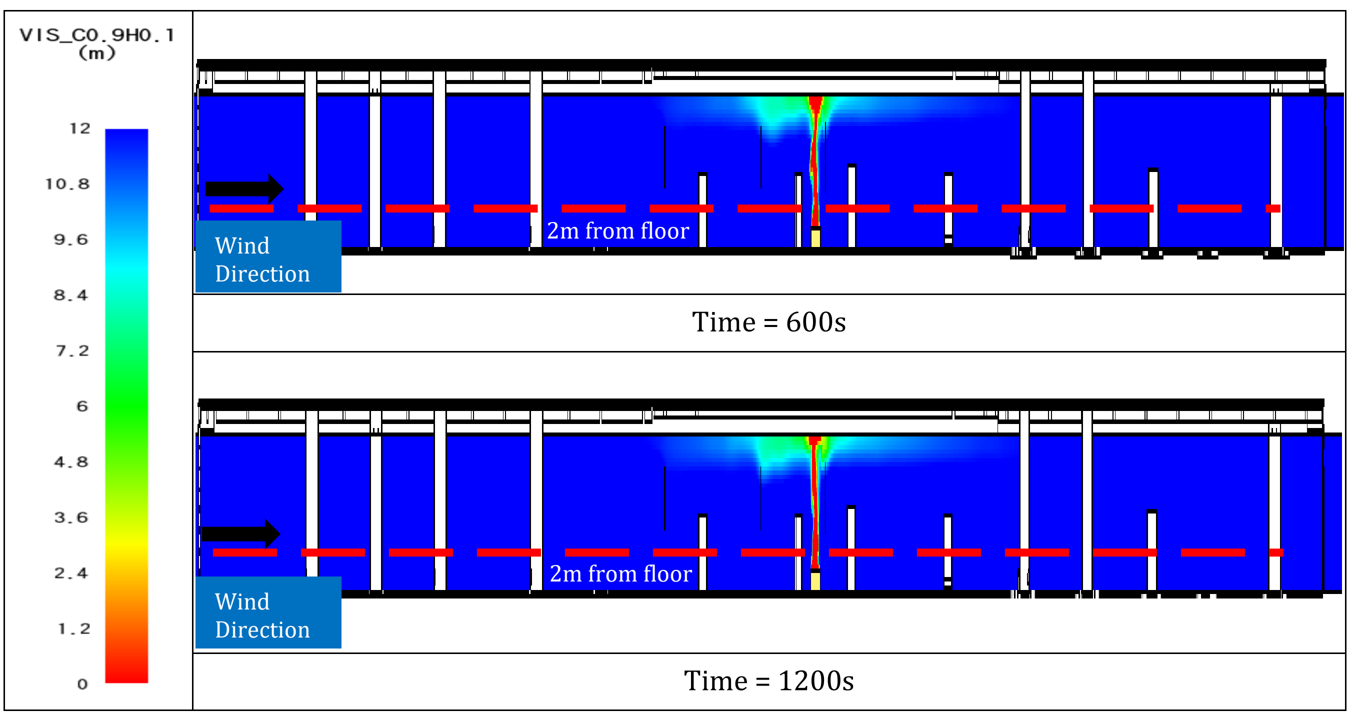


Figure 16: Temperature plots across fire

CONCLUSIONS

The CFD results from PyroSim/FDS show that tenable conditions are maintained for a duration of 20 minutes. Smoke with 10m visibility or less and temperatures of 60°C or more is confined within the smoke zone of fire origin and kept at a level above human head height (2m).

RSET (Required Safe Egress Time) has been calculated to be 3.5 minutes (maximum) for PTB Levels D & F. CFD results demonstrate that ASET (Available Safe Egress Time) is 20 minutes, which is more than RSET.

Smoke spread in the windward direction is affected by wind flow

Based on the CFD results for smoke movement and achieving tenable conditions for life safety, the proposed smoke management system is considered adequate to meet the design performance requirement stipulated under the fire safety strategy without additional compartmentation for the international airport expansion project under consideration.

REFERENCES

CIBSE Guide E, Fire Engineering, CIBSE, UK, 2003.

The SFPE Handbook of Fire Protection Engineering, Society of Fire Protection and National Fire Protection Association, USA, 2002.