FIRE AND EVACUATION MODELLING FOR A LARGE COMMERCIAL CUM OFFICE BUILDING

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ABSTRACT

A large commercial cum office building with a built-up area of about 76000 m^2 caters to different occupancy types – retail, assembly, and business. Retail shopping area has 5 floors and office tower has 15 floors. The population of each floor is based on the occupancy type. Fire escape staircases are to be provided to allow egress of the population of the floor in case of fire. As per the building architecture, retail and office tower staircases are interlinked. As per local building code, retail and office tower shall be independent of each other. Since the staircase is common for retail and office tower, to make sure that the occupants are evacuated within safe time limit, performance-based design has been carried out to ascertain the number of staircases. Evacuation modelling has been carried out using Pathfinder to determine the egress of occupants in terms of RSET (Required Safe Egress Time). Pyrosim/FDS has been used to simulate fire scenarios on a retail floor as well as on a typical office tower floor 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. Based on the performance-based analysis of fire and egress in this case study, total staircase width is reduced by 20%, resulting in a reduced number of fire escape staircases, thus providing opportunity for optimisation while ascertaining life safety.

KEYWORDS

Fire and Evacuation; Performance based design; FDS; PyroSim; Pathfinder; Life Safety; ASET; RSET

INTRODUCTION

Evacuation calculations are increasingly becoming a part of performance-based design analysis to assess the level of life safety provided in buildings. Hand calculations usually follow the equations given in the Emergency Movement Chapter of the Society of Fire Protection Engineers (SFPE) Handbook. The calculation focuses mainly on points of constriction throughout the building (commonly the door to the outside) and calculates the time for the occupants to flow past these points and to the outside. To achieve a more realistic evacuation calculation, engineers have been looking to computational evacuation models to assess a building's life safety. The Society of Fire Protection Engineering (SFPE) was one of the first organizations to introduce a standard method for calculating egress time as a function of occupant speed and distance [1].

Pathfinder enables performance-based occupant movement, evacuation, and congestion studies through software-based simulation. Stadiums, hospitals, skyscrapers, aircraft, and other buildings can be analyzed to provide realistic visual results in a fraction of the time that manual computation takes. Pathfinder helps to analyze the Required Safe Egress Time (RSET) for the last occupant inside the building.

To maintain the tenability conditions inside the building in case of fire, performance-based design is carried out using Fire Dynamic Simulator (FDS)-PyroSim. All PyroSim (FDS) models that include combustion must define a gas phase reaction that converts fuel to combustion products. In "simple chemistry" approach in FDS, the fuel is assumed to consist of Carbon, Hydrogen, Oxygen, and Nitrogen that reacts with Oxygen to form Water, Carbon Dioxide, Soot, Carbon Monoxide, and Nitrogen. The reaction of fuel and oxygen is assumed to be infinitely fast and controlled only by mixing. When we specify a Heat Release Rate, we are really specifying the rate at which fuel is released into the fire simulation. The fuel mass flow rate is calculated so that combustion will release heat at the desired rate [2]. Simulation of smoke spread is carried out by using PyroSim for the duration of 20 minutes. For the 20 minutes duration, smoke should not come down below 1.8 m height from the floor level and visibility should be more than 10 m within 1.8m height from floor level. Also, the smoke temperature should be less than 60^0 C. By doing this engineering analysis, we would be able to calculate the Available Safe Egress Time (ASET). Combined analysis using pathfinder for RSET and Pyrosim for ASET provides assessment of adequacy of egress and smoke exhaust design for life safety during an event of fire. In this work, performance-based design of building is carried out using Pathfinder and Pyrosim for evaluation of life safety of occupants in the event of fire.

THE BUILDING

The building consists of 2 basements, B-1 and B-2. Above the basements, there is 1 office tower area and 1 retail shopping mall area. Built up area is about 76,000 m^2. Office tower has 15 floors and 15th floor is terrace floor and shopping mall consists of 5 floors (ground to 4th floor). In the shopping mall area, the ground floor consists of parking area and retail shop area. Shopping mall from 1st to 4th floor consists of largely retail shop area. In the shopping mall, there are 4 stairs in which 2 will connect ground floor to terrace floor level in office tower, 1 will connect to 4th floor and 1 will connect to 3rd floor. There are 4 refuge floors available which are located at the office tower level 1st, 5th, 9th and 13th. The final exit points to come out of the building are on the ground floor and 1st floor. Apart from this, external stairs are also provided from the 1st floor which connects the 2nd and 3rd floor. In the event of fire in the building, occupants will use only these 4 stairs for evacuation from the building. The ground floor and above floors are considered for egress time analysis.

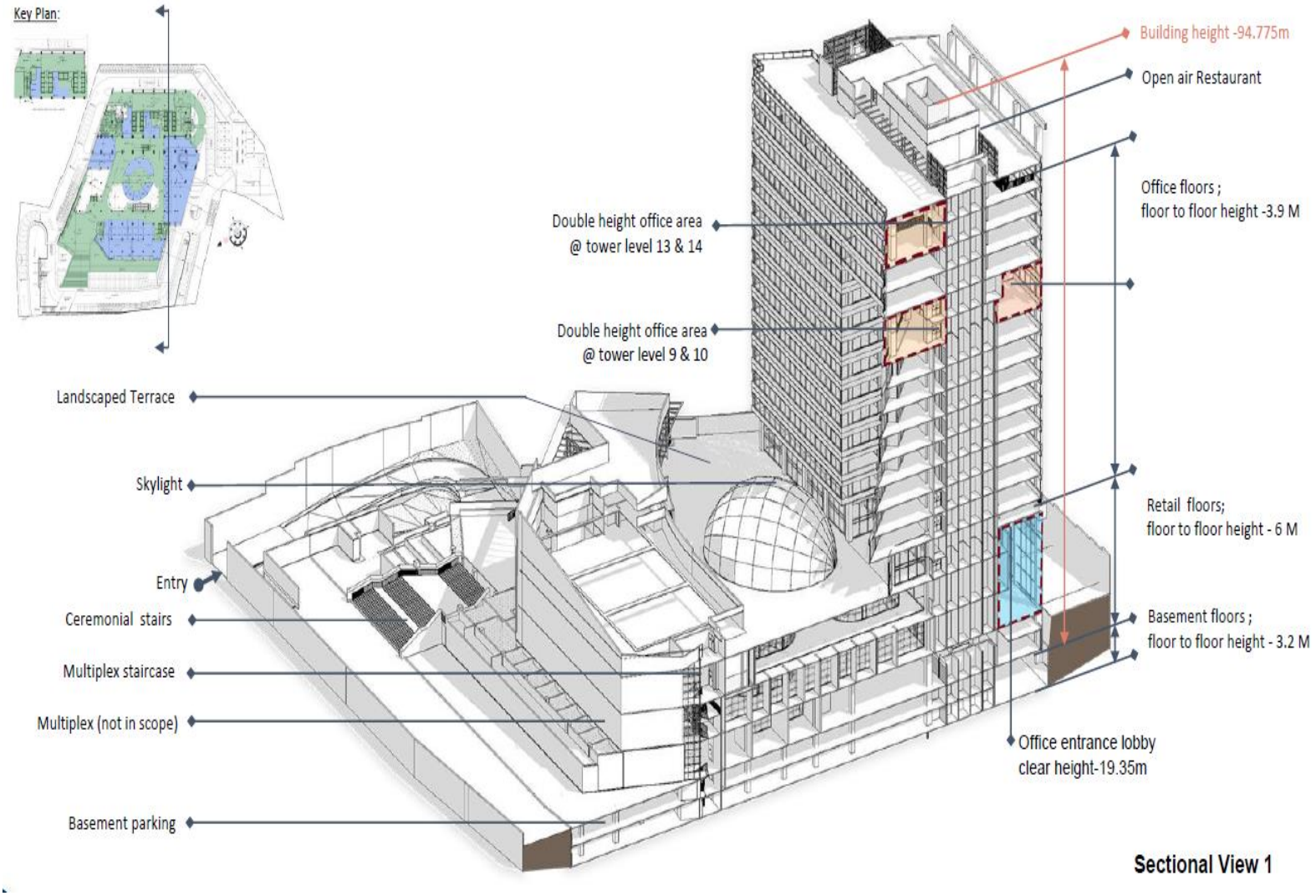


Figure 1: Layout of the building

THE METHODOLOGY

Initially egress analysis is carried out for whole building except the basement to determine the RSET value using Pathfinder tool then smoke exhaust analysis is carried out for 2nd floor in retail area and 14th floor office level to evaluate the ASET value using FDS/PyroSim.

Scope for Egress Time Analysis (RSET)

- Creation of 3D model that comprises the exit details of the building.
- Carry out egress analysis using Pathfinder to determine egress time during event of fire.
- Analyze the output results for RSET

Egress parameters

Behavior and characteristics of occupants during egress:

- Occupants will take the nearest stairs or nearest exit from their respective positions, and they can use any of the exit door and stairs for evacuation which is nearer to them.
- Maximum velocity of occupants during egress is 1.19 m/s.
- Human shape is considered cylinder with diameter of 0.45m and height of 1.7m.

Table 1: Occupant distribution on each floor

Floor	Function	Occupancy Considered	Total Occupants
Ground	Retail/Car Park/Common Area	Parking/Business/Assembly D-6	1327
1st	Retail	Assembly D-6	1056
2nd	Retail/Multiplex/Food court	Assembly D-6	1587
3rd	Retail	Assembly D-6	1082
4th	Retail/Restaurant	Assembly D-6	278
Tower Level 1	Office/Refuge Area/Services	Business	270
Tower Level 2	Office/Refuge Area/Services	Business	273
Tower Level 3	Office/Refuge Area/Services	Business	273
Tower Level 4	Office/Refuge Area/Services	Business	259
Tower Level 5	Office/Refuge Area/Services	Business	258
Tower Level 6	Office/Refuge Area/Services	Business	259
Tower Level 7	Office/Refuge Area/Services	Business	259
Tower Level 8	Office/Refuge Area/Services	Business	259
Tower Level 9	Office/Cafeteria/Services	Business	187
Tower Level 10	Office/Cafeteria/Services	Business	231
Tower Level 11	Office/Refuge Area/Services	Business	267
Tower Level 12	Office/Refuge Area/Services	Business	267
Tower Level 13	Office/Refuge Area/Services	Business	173
Tower Level 14	Office/Refuge Area/Services	Business	182

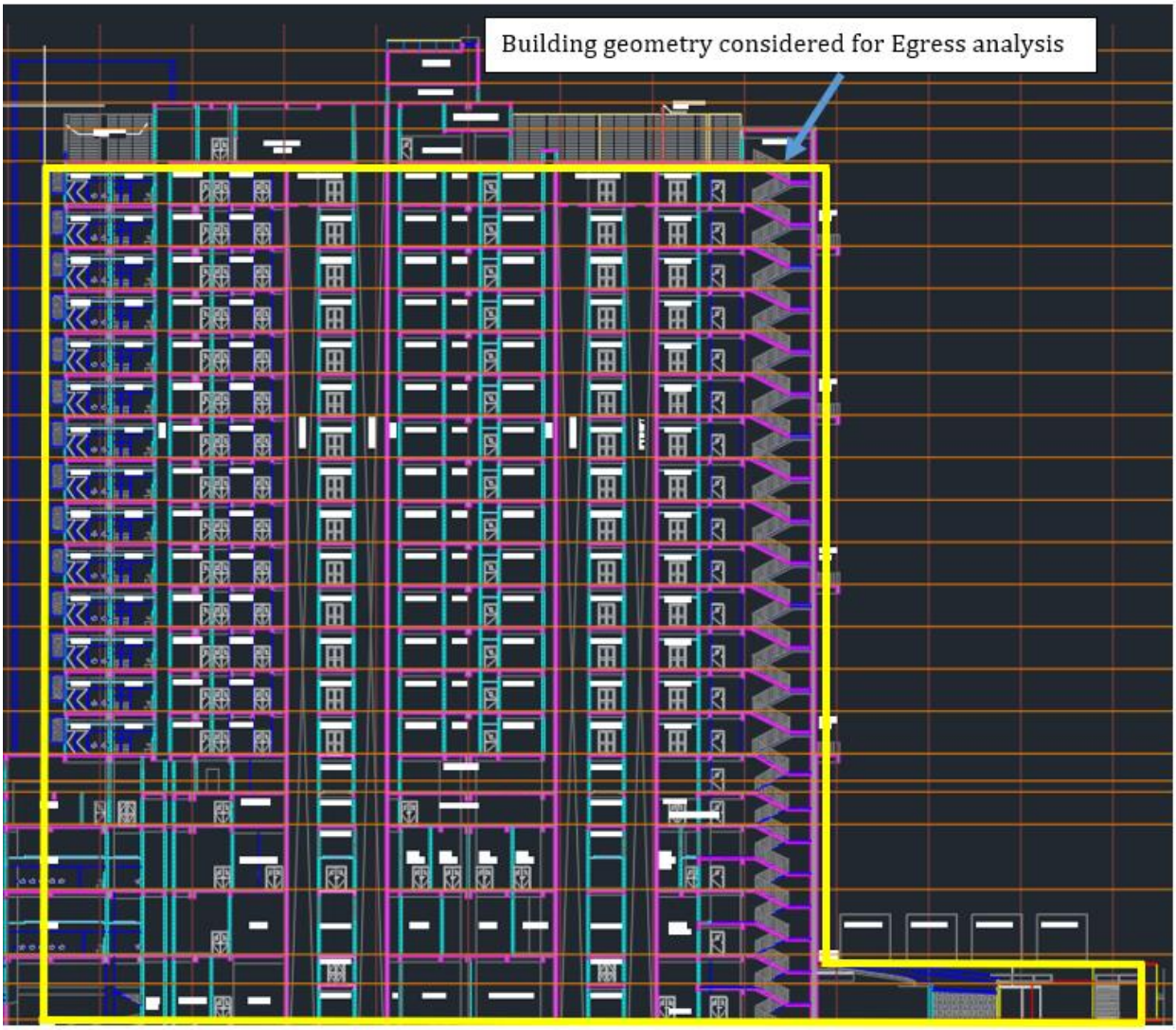


Figure 2: Section view of the building

Scope for smoke extraction study (ASET)

- Creation of 3D model of the building suitable for PyroSim.
- Performing CFD simulation for calculating smoke visibility levels and temperature limits for fire scenarios with ambient air temperature of 37.2^0 C.

Retail area fire scenario (2nd floor)

Fire Source:

Retail fire HRR = 3.125 MW located at 2nd floor [3]
Fire source dimensions = 2.236m x 2.236m x 2.0m (Length x Breath x Height)
Retail fire source size = 2.236m x2.236m= 5.0 m^2
Heat release rate per unit area (HRRPUA) = 625 kW /m^2
Soot yield = 0.1 kg/kg (considered as conservative design for burning of plastics)

Smoke exhaust system:

Smoke exhaust fan capacity (each) = 20000 cfm
No of smoke exhaust fans = 2 nos.

Office area fire scenario (14th floor)

Fire Source:

Workstation fire = 1.8 MW [4]

Fire source dimensions = 4.0m x 2.0m x 0.8m (Length x Breath x Height)

Retail fire source size = 4.0m x2.0m= 8.0 m^2

Heat release rate per unit area is 225 kW /m^2

Soot yield = 0.1 kg/kg (considered as conservative design for burning of plastics)

Smoke exhaust system:

Smoke removal fan capacity for office 1 area = 10333 cfm

Smoke removal fan capacity for office 2 area = 6666 cfm

Smoke removal fan capacity for office 3 area = 13166 cfm

Smoke removal fan capacity for office 4 area = 9333 cfm

No. of smoke exhaust fans = 4

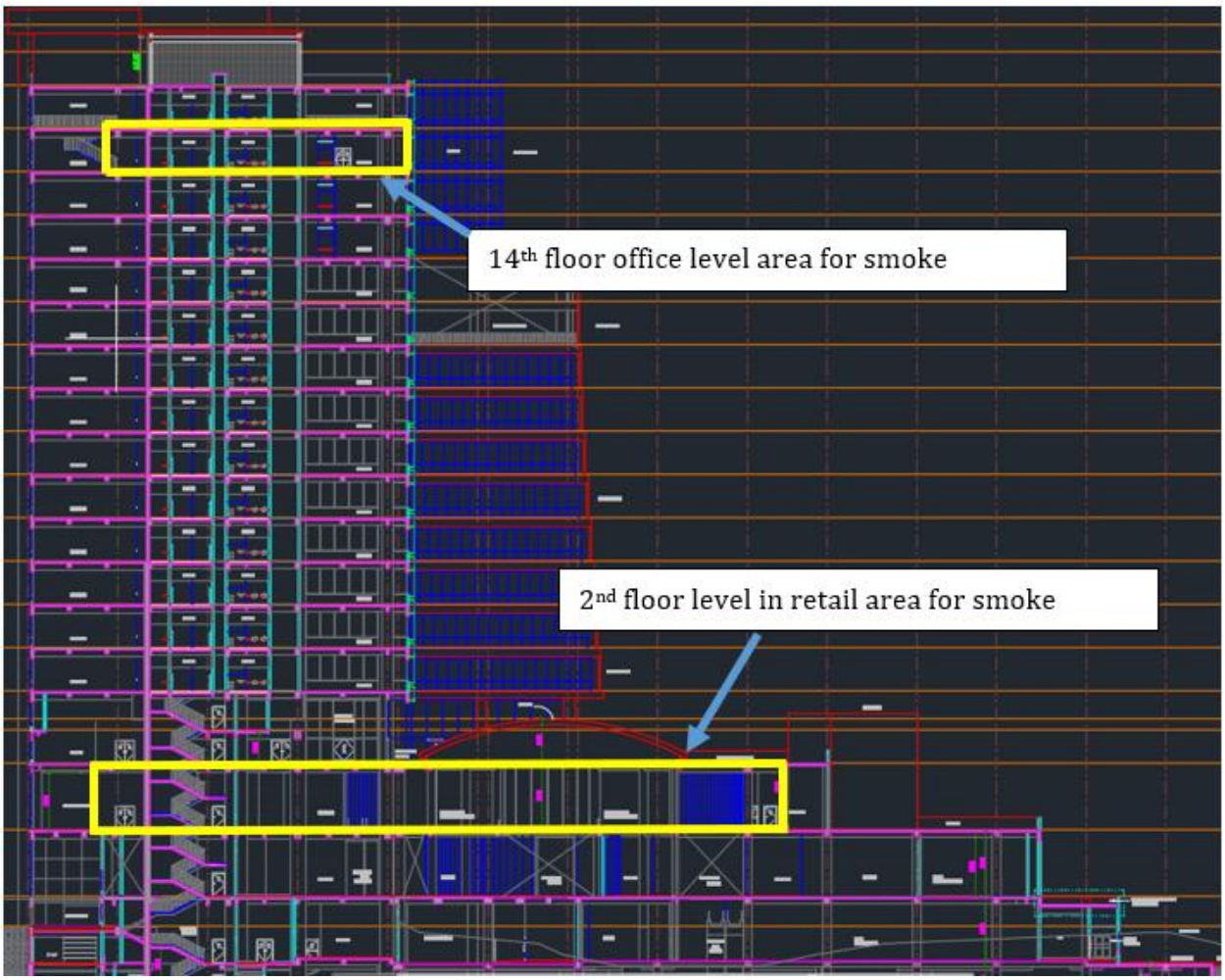
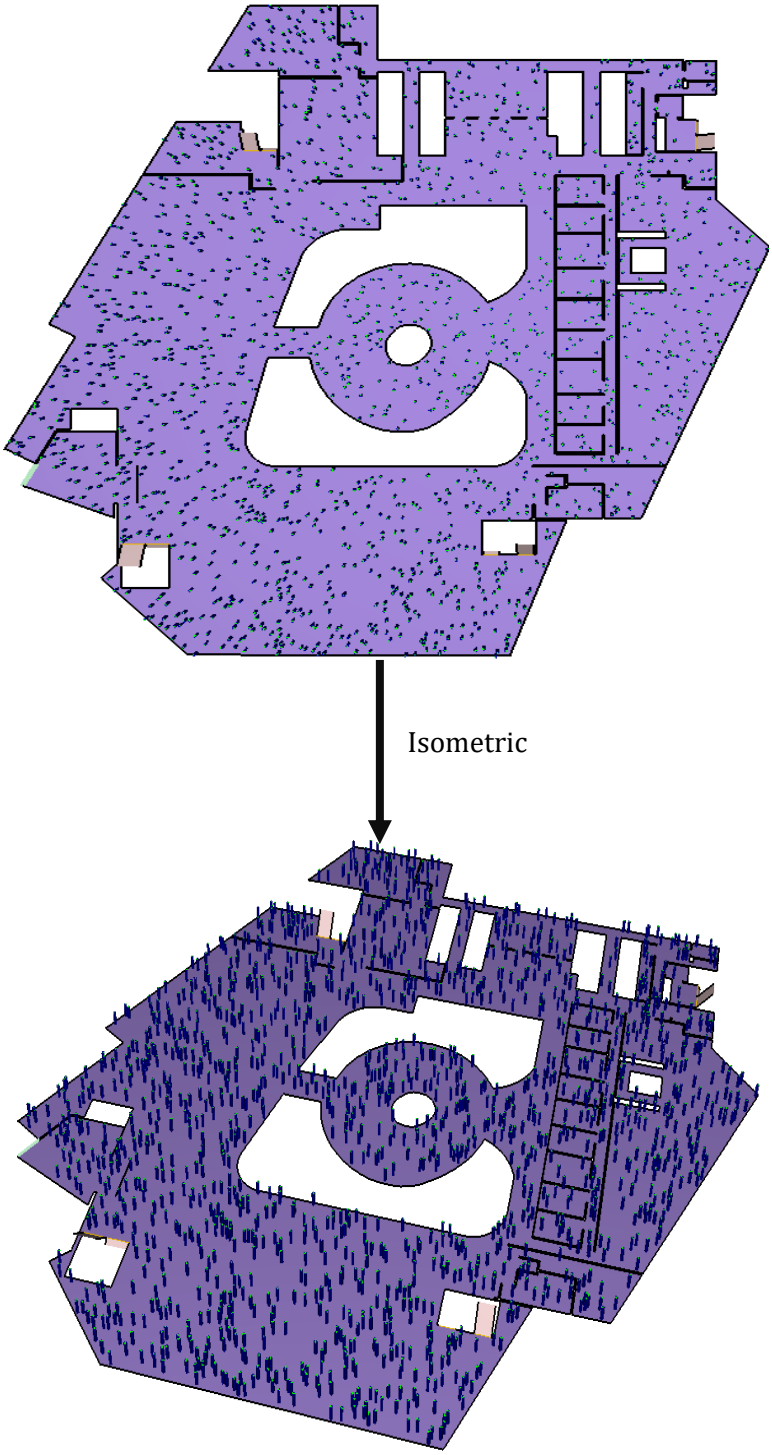
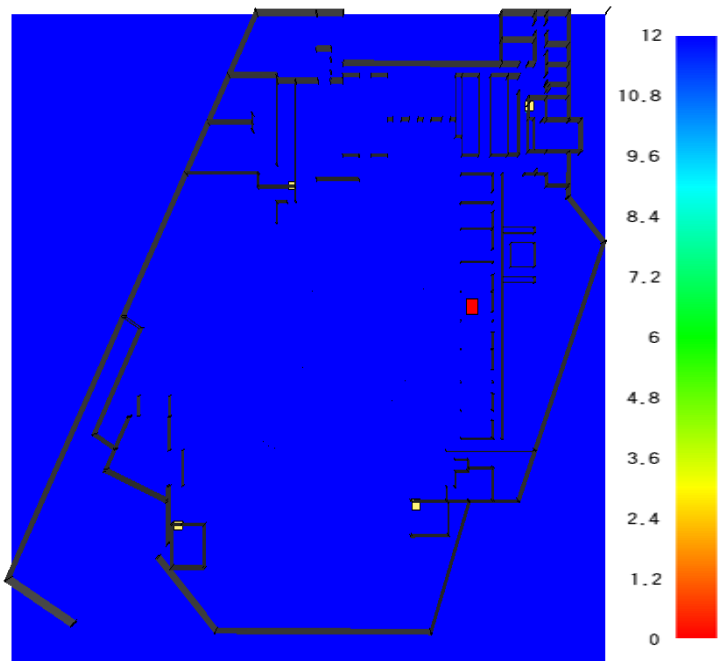


Figure 3: Section view of area considered for smoke analysis

RESULTS

This section shows comparison of results between the RSET value evaluated by egress analysis using pathfinder and ASET values evaluated by the smoke analysis using FDS/PyroSim for 2nd floor level in retail area and 14th floor office level

Table 2: Retail area (2nd floor)

<table>
<tr><td colspan="2">Comparison between Pathfinder and FDS/PyroSim – Assessment RSET/ASET</td></tr>
<tr><td>PATHFINDER – RSET/Egress</td><td>PyroSim – ASET/Visibility</td></tr>
<tr><td rowspan="2"> 
</td><td> 
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 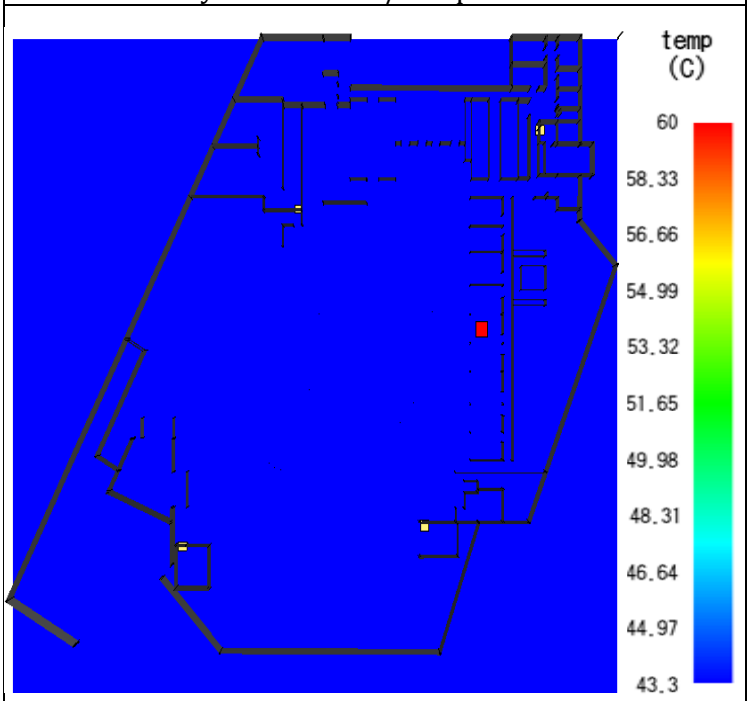
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<tr><td>Time= 0 seconds</td><td>Time= 0 seconds</td></tr>
<tr><td colspan="2">Comparison between Pathfinder and FDS/PyroSim – Assessment RSET/ASET</td></tr>
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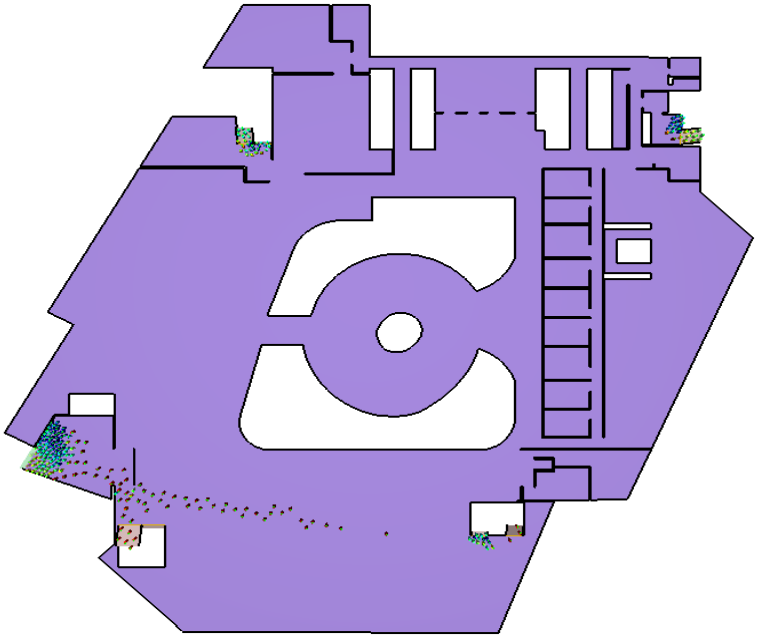
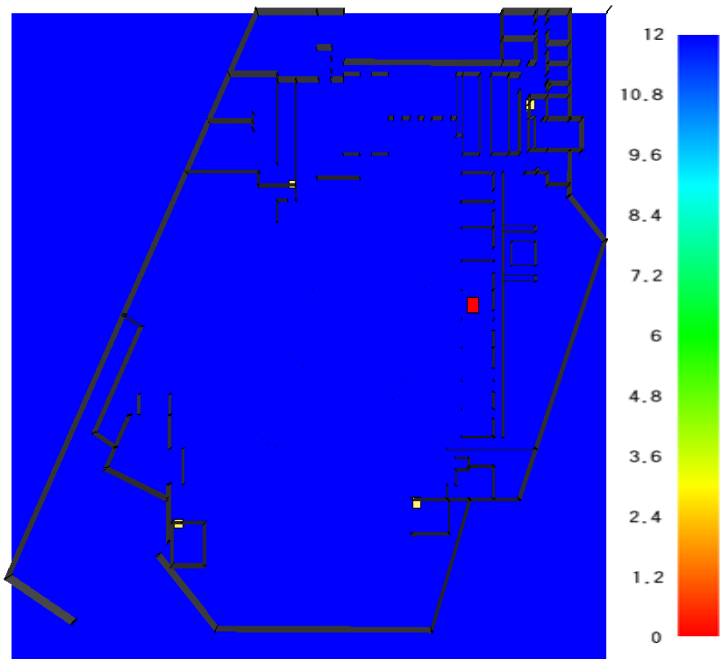
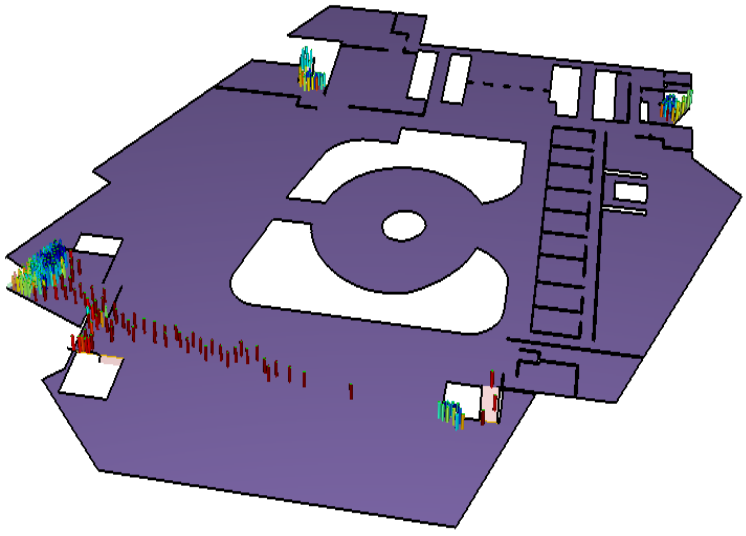
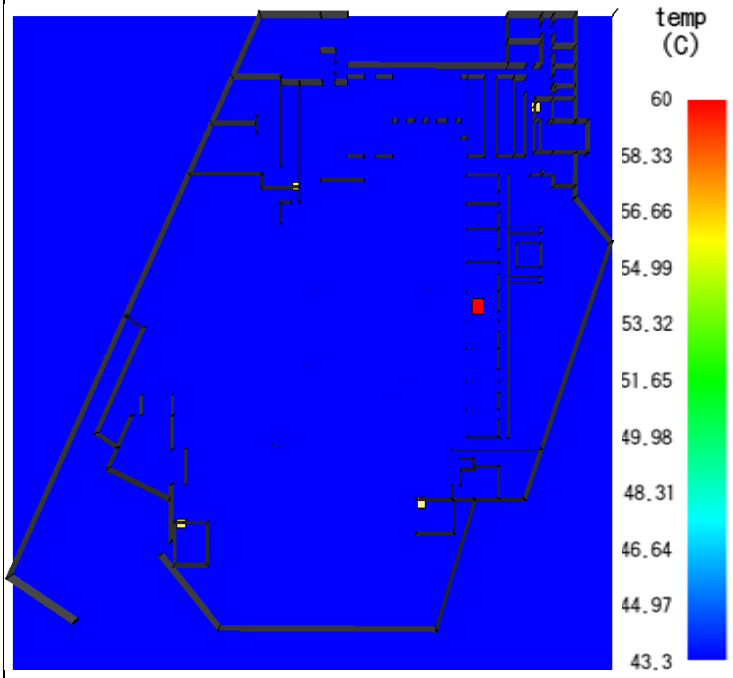
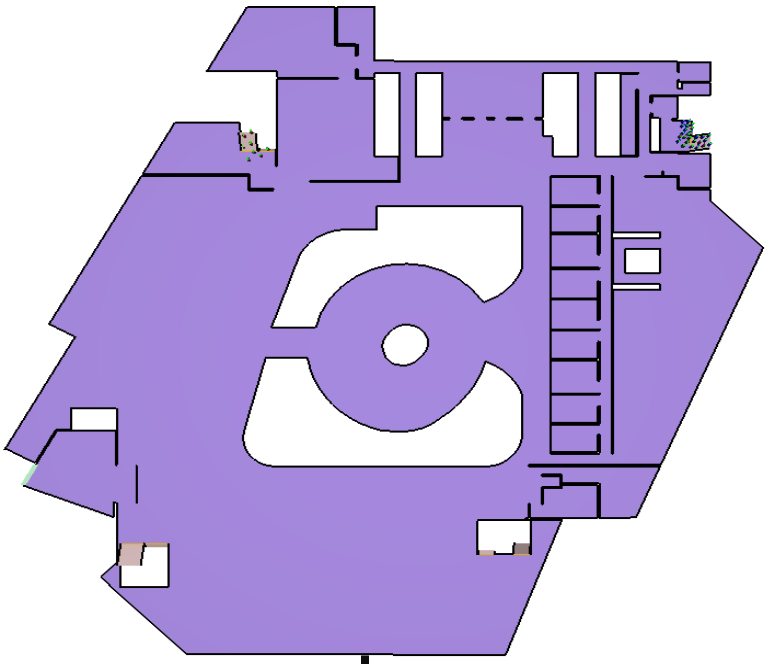
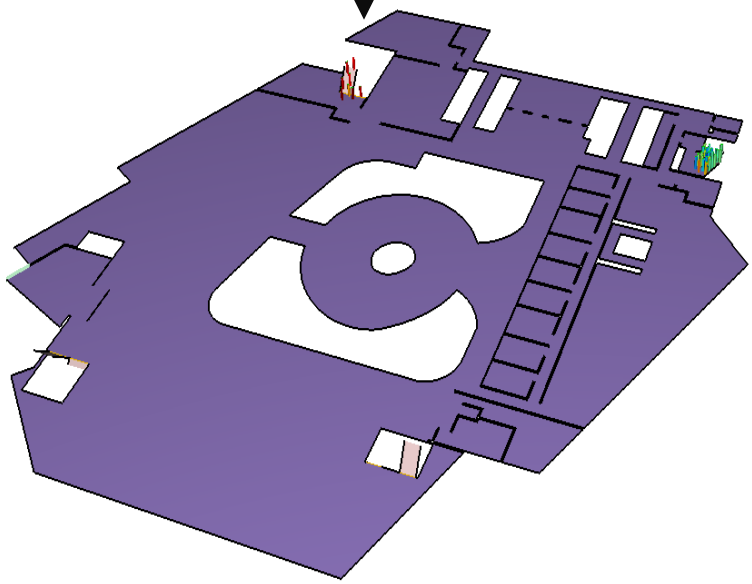
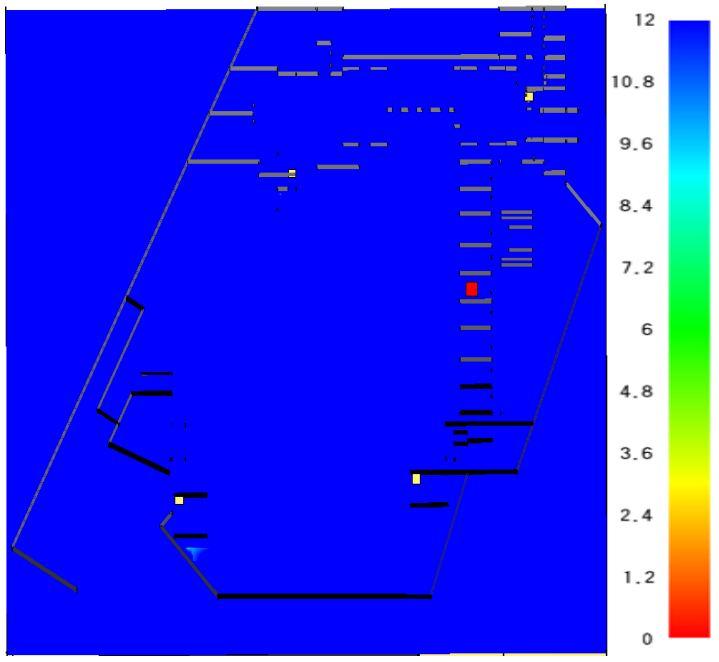
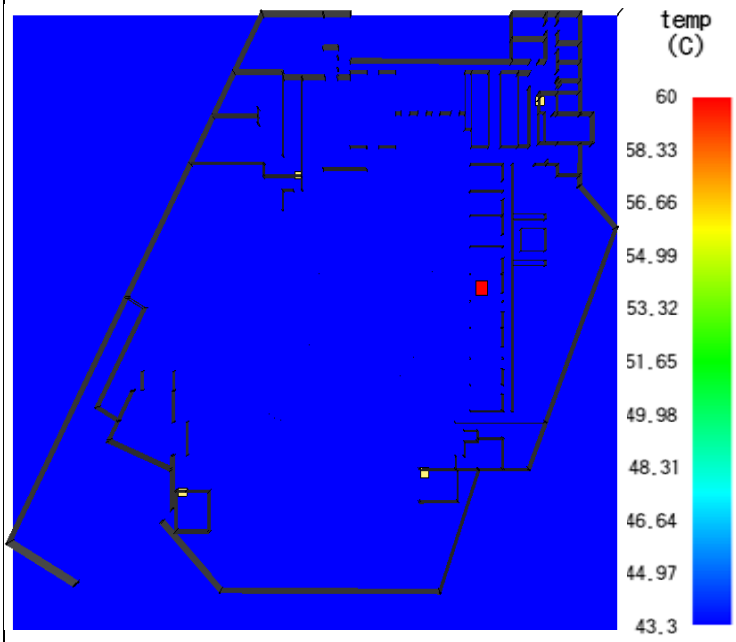
PATHFINDER – RSET/Egress	PyroSim – ASET/Visibility
	
Isometric	PyroSim – ASET/Temperature
	
Time= 170 seconds	Time= 170 seconds

Comparison between Pathfinder and FDS/PyroSim – Assessment RSET/ASET	
PATHFINDER – RSET/Egress	PyroSim – ASET/Visibility
 Isometric 	
	PyroSim – ASET/Temperature
	
Time= 445 seconds	Time= 445 seconds

Comments

- Time taken by last occupant of 2nd floor to reach the fire escape stairs at 2nd floor is 170 seconds.
- Time taken by last occupant of 2nd floor to reach the final exit point at 1st floor is 445 seconds.

Table 3: Office floor (14th floor)

<table>
<tr><th colspan="2">Comparison between Pathfinder and FDS/PyroSim – Assessment RSET/ASET</th></tr>
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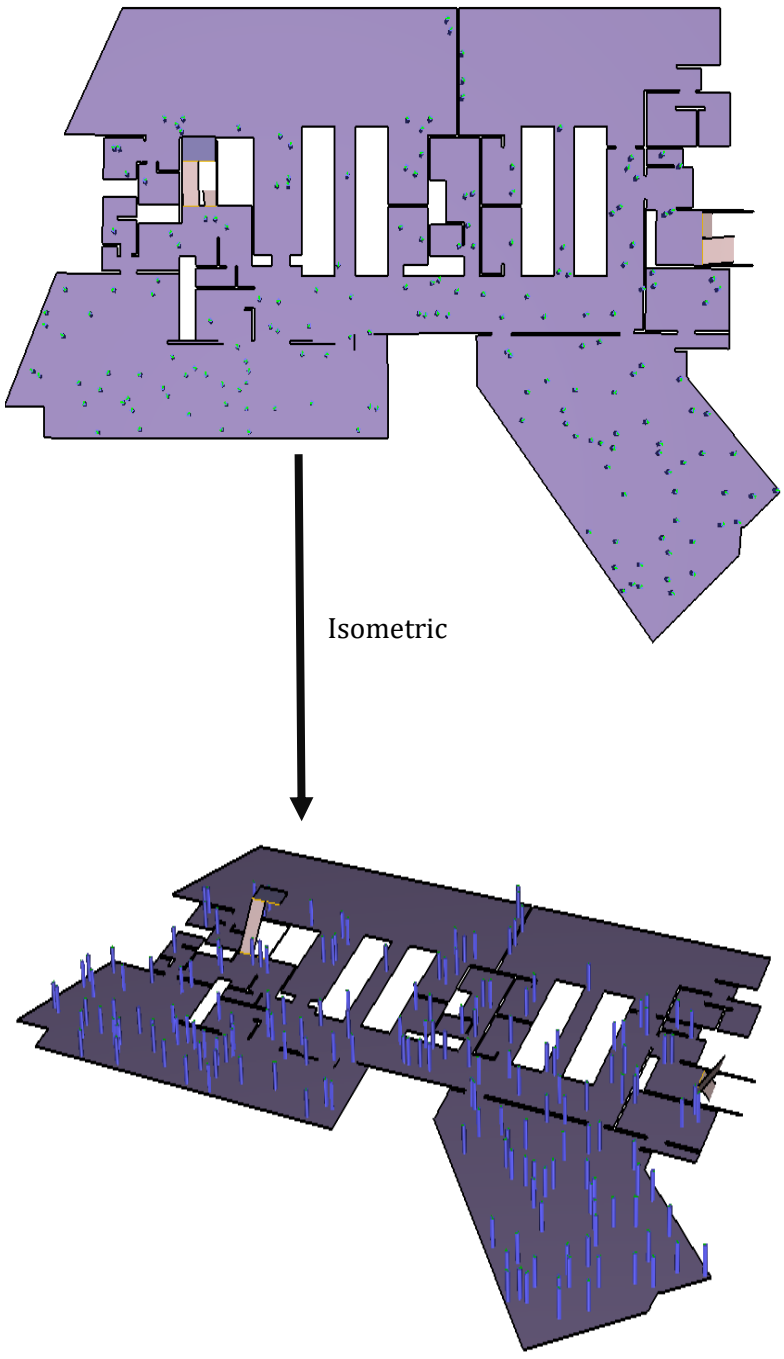
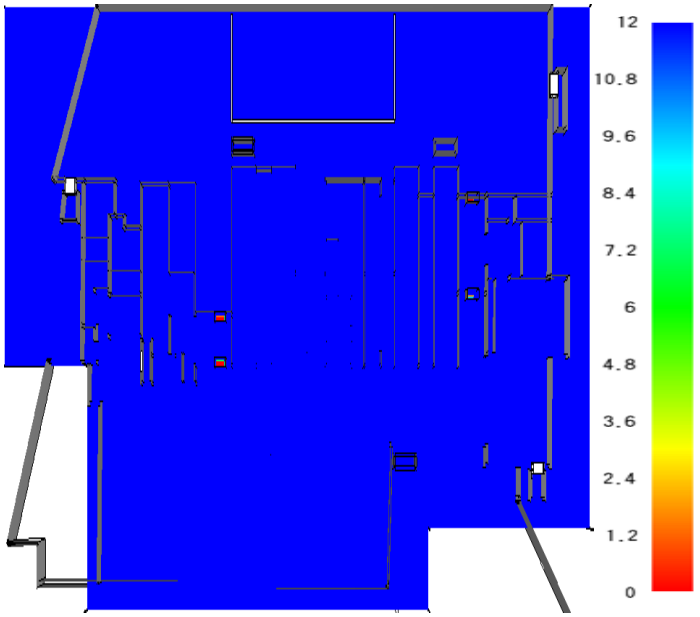
<tr><td rowspan="2"> 
</td><td> 
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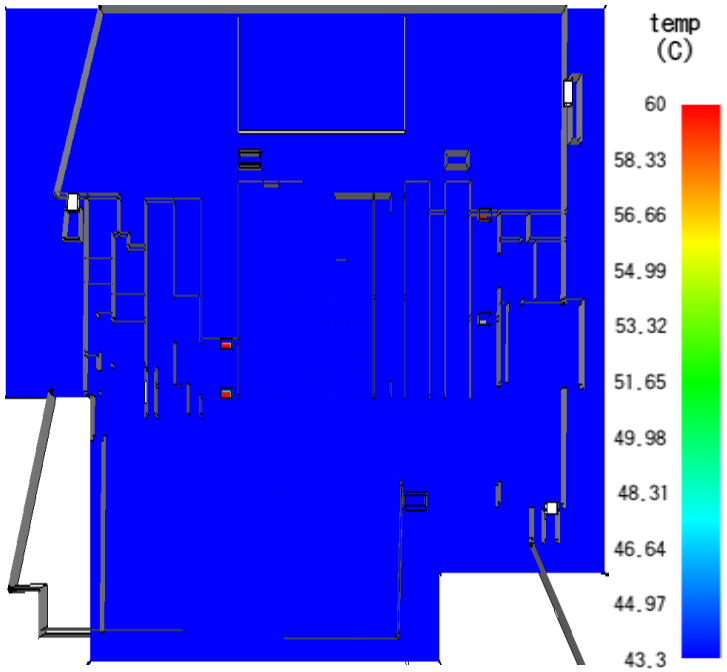
<tr><td>PyroSim – ASET/Temperature</td></tr>
<tr><td>Time= 0 seconds</td><td> 
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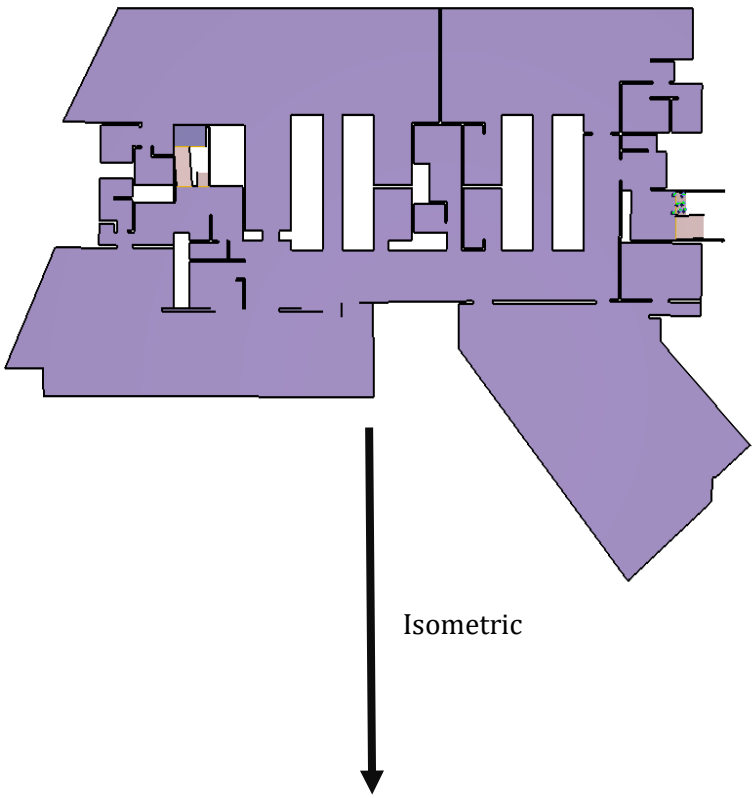
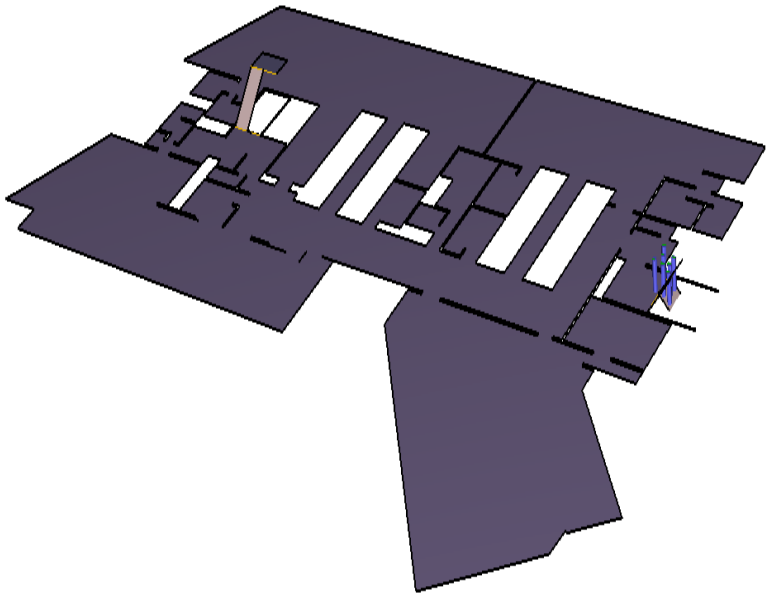
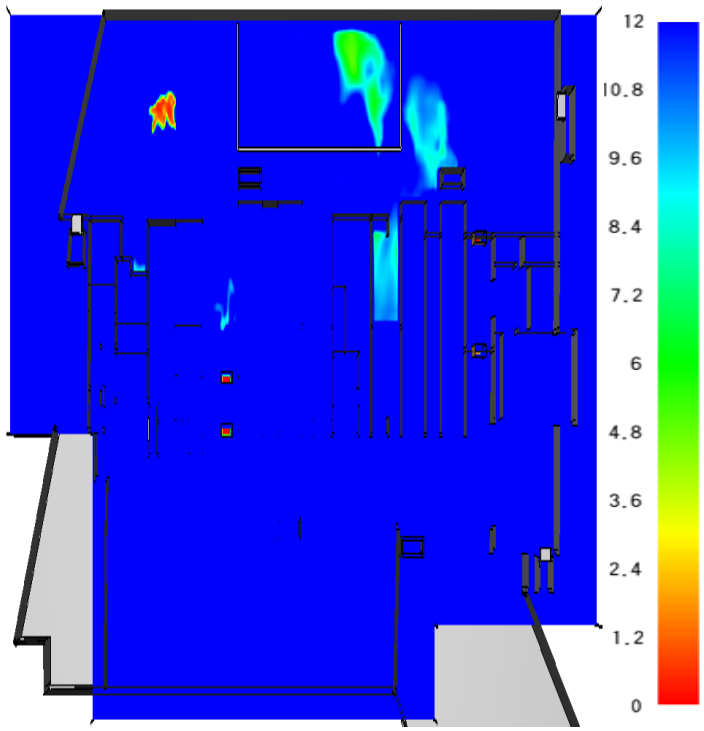
Comparison between Pathfinder and FDS/PyroSim – Assessment RSET/ASET	
PATHFINDER – RSET/Egress	PyroSim – ASET/Visibility
 Isometric 	
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	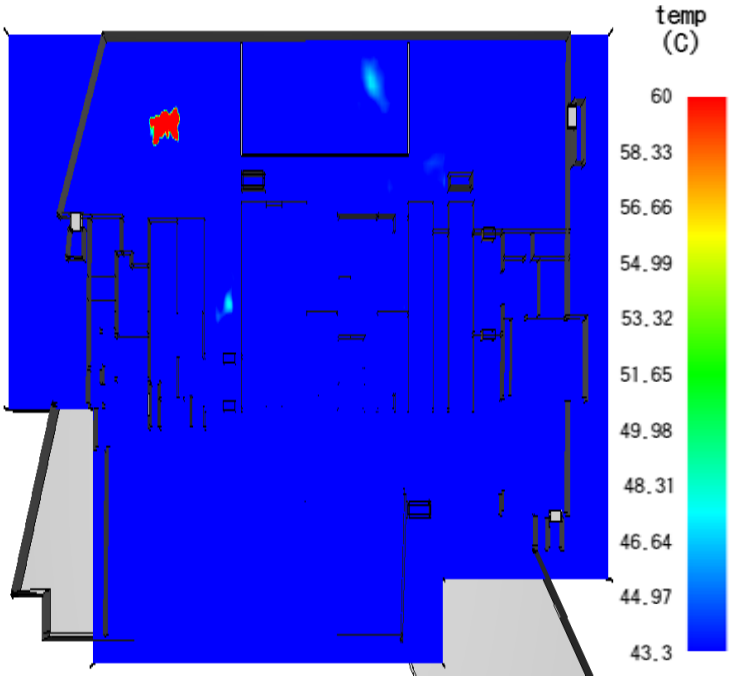
Time= 117 seconds	Time= 117 seconds

Comparison between Pathfinder and FDS/PyroSim – Assessment RSET/ASET	
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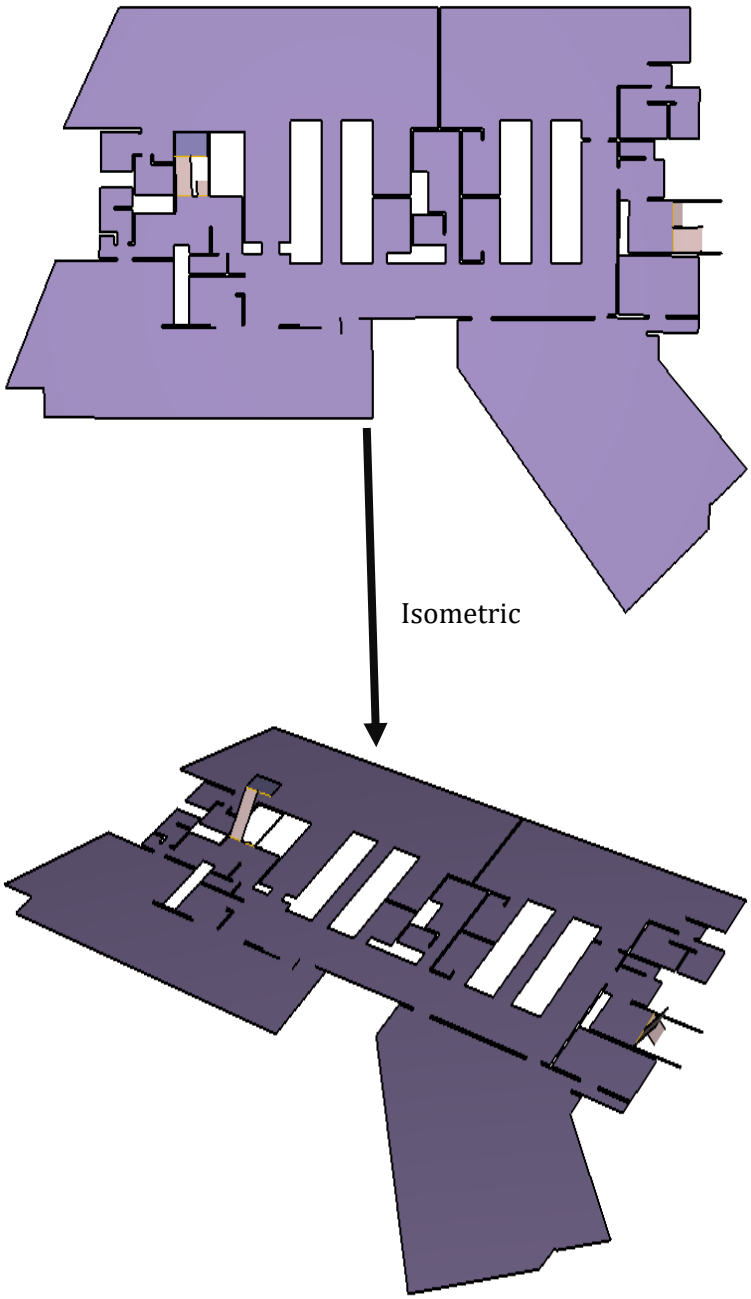
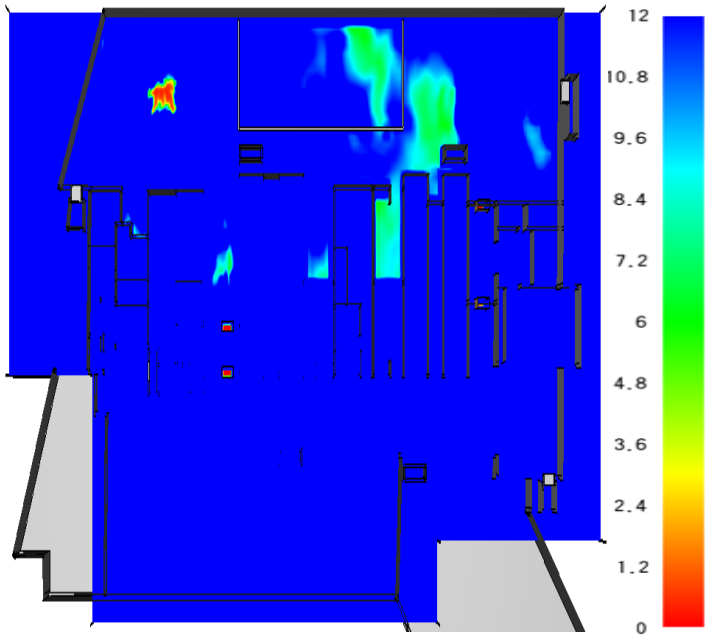
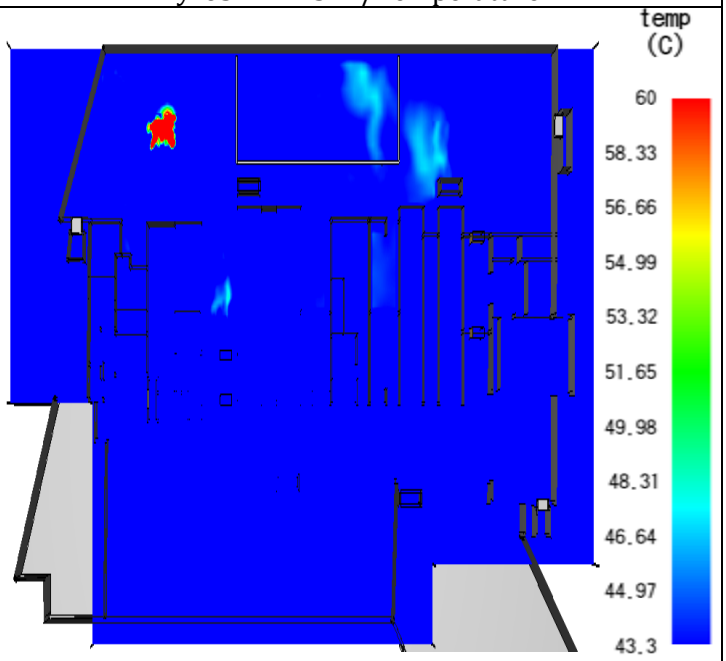
	
	PyroSim – ASET/Temperature
	
Time= 175 seconds	Time= 175 seconds

Comments

- Time taken by last occupant of office tower level 14 to reach the fire escape stairs at office tower level 14 is 117 seconds.
- Time taken by last occupant of office tower level 14 reach the final exit point at 1st floor is 1648 seconds.

CONCLUSIONS

Based on results provided above, following conclusions are made:

Retail floor (2nd floor)

- CFD results show that smoke visibility is more than 10 m within the height of 1.8 m from the floor level for a duration of 10 minutes.
- CFD results show that the tenable conditions can be maintained for duration of 10 minutes, resulting in ASET (Available Safe Egress Time) value of 600 seconds (10 minutes). RSET (Required Safe Egress Time) value is 170 seconds as per egress time simulation. Ratio of ASET value to RSET value is greater than 1.5. Therefore, provisions of staircases and smoke exhaust system is adequate for life safety for 2nd floor of retail area.
- Total number of occupants is 1587 in second floor. Actual requirement of staircase width based on local code (NBC 2016) is 15.87m, but only 5 staircases with total width of 12.5 m are sufficient as per egress analysis. So, based on the performance-based analysis of fire and egress in this project, total staircase width is reduced by 20%, resulting in a reduced number of fire escape staircases, thus providing opportunity for optimisation while ascertaining life safety.

Office floor (14th floor)

- CFD results show that smoke visibility is more than 10 m within the height of 1.8 m from the floor level for the duration of 180 seconds.
- CFD results show that the tenable condition can be maintained for duration of 175 seconds, resulting in ASET (Available Safe Egress Time) value of 175 seconds. RSET (Required Safe Egress Time) value is 117 seconds as per egress time simulation. Ratio of ASET value to RSET value is equal to 1.5. Therefore, provisions of staircases and smoke exhaust system is adequate for life safety provided for 14th office floor level area.
- So, based on performance-based design analysis, 2 staircases with total width of 3 m are sufficient for egress of 182 occupants.

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