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NUMERICAL ANALYSIS FOR SMOKE SPREAD IN AN AIRCRAFT HANGAR

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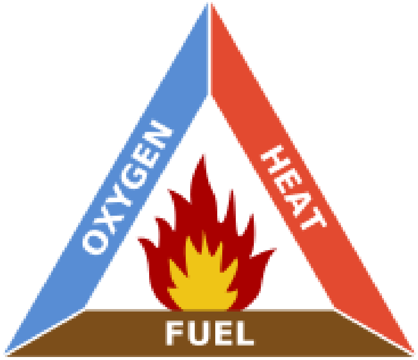
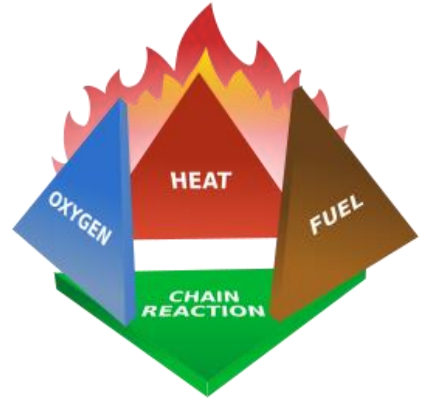
1. Introduction

Smoke is one of the most dangerous factors in aircraft hangar in case of fire. As it causes reduce in visibility and deaths due to high temperature or toxicity also prevents applying evacuation plan for workers.

Aircraft hangars, by their very nature, pose a unique challenge for fire safety engineers. Large, open floored areas with high roof decks house aircraft contents worth millions of dollars

Fire Cause





Classes of Fire

CLASSES OF FIRES	TYPES OF FIRES	PICTURE SYMBOL
A	Wood, paper, cloth, trash & other ordinary materials.	
B	Gasoline, oil, paint and other flammable liquids.	
C	May be used on fires involving live electrical equipment without danger to the operator.	
D	Combustible metals and combustible metal alloys.	
K	Cooking media (Vegetable or Animal Oils and Fats)	

2. Literature Review

1. **Q Wang** revealed the effect of smoke exhaust openings arrangement on the smoke spread performance in the tunnel fire of semi-transverse smoke extraction mode.

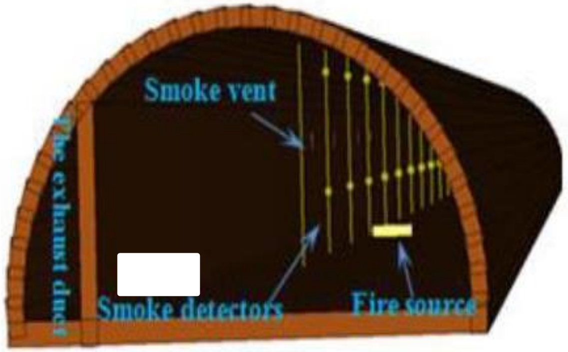
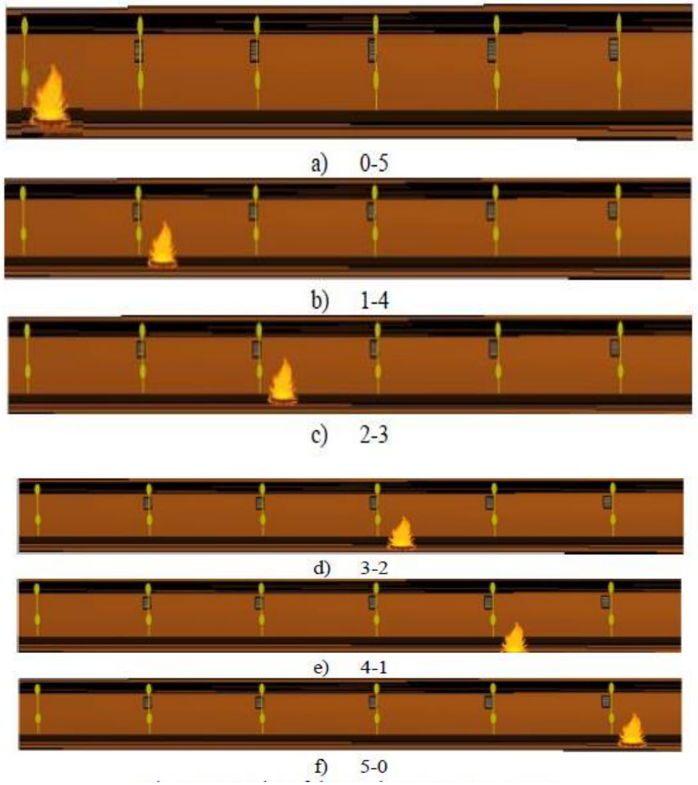


Fig. 1. Model configuration of the tunnel.

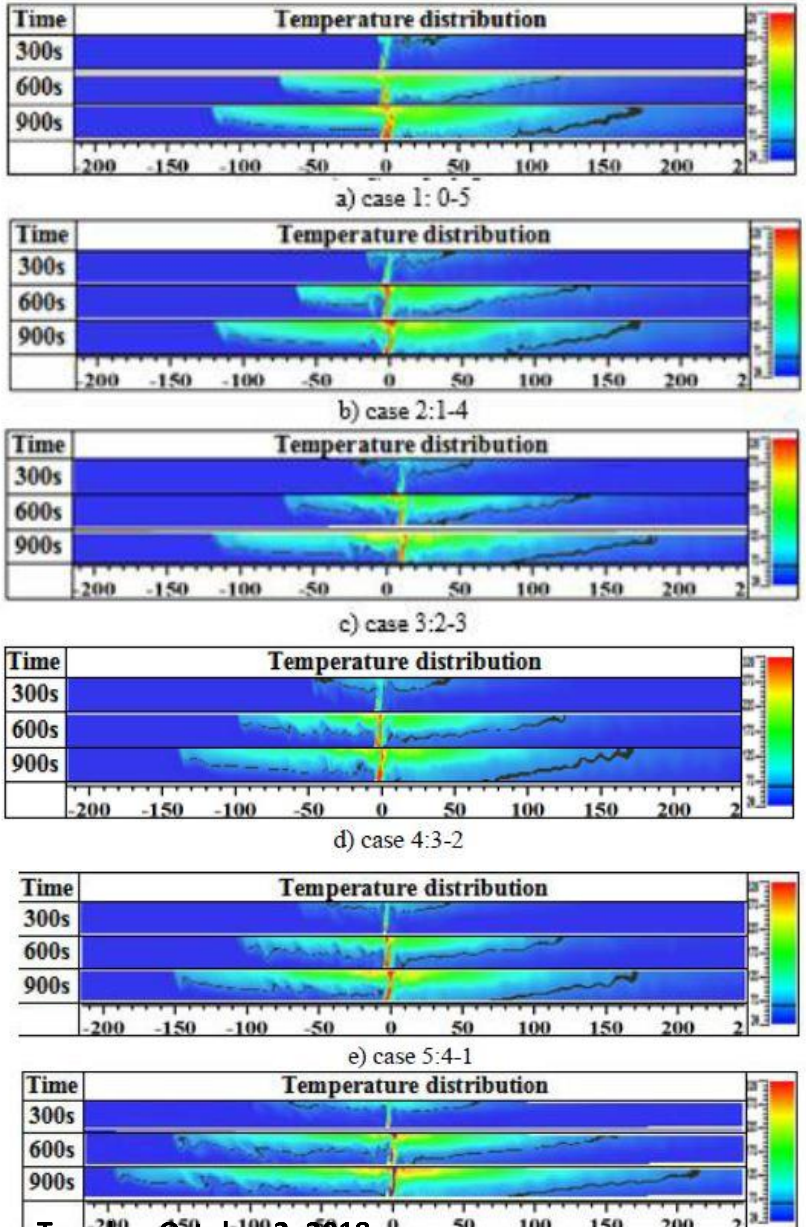
Case Study

A full scale semicircle tunnel model is built with a length of 1000m and a diameter of 14.5m, just as shown in the figure. The fire size in the model is taken to be 20MW



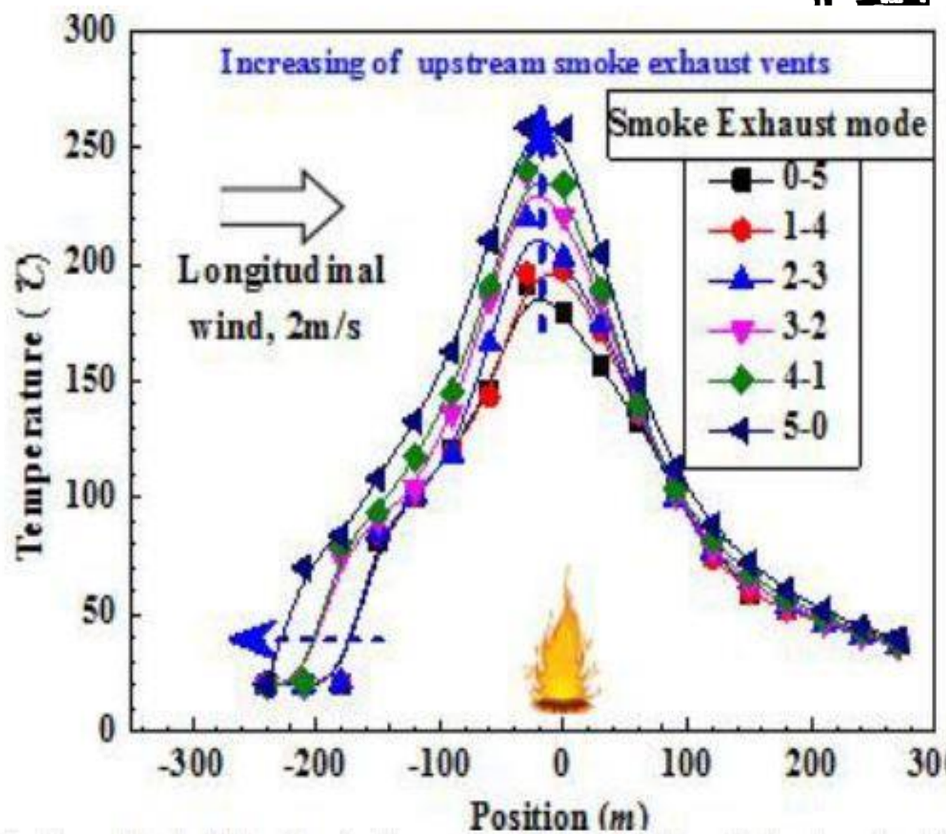
The size of the smoke exhaust vent is 2m (length)*1.5m (height). The smoke exaction volume flow rate was taken as $110m^3/s$

Temperature Distribution

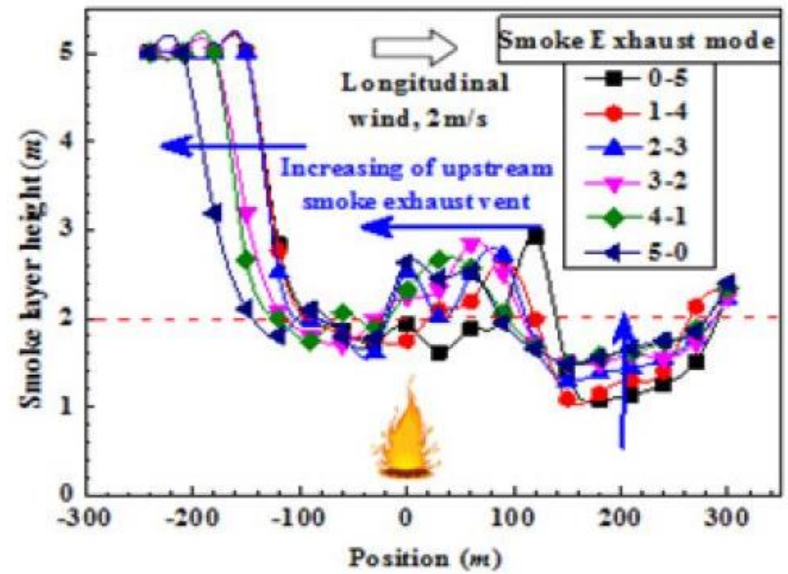


a) case 1: 0-5
b) case 2:1-4
c) case 3:2-3
d) case 4:3-2
e) case 5:4-1
f) case 6:5-0

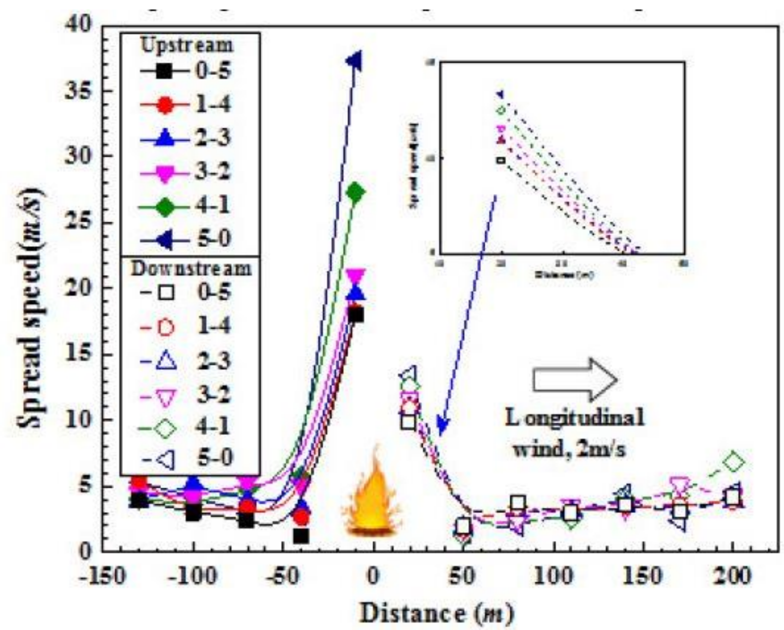
Temperature Distribution at the Height of 2m



Smoke Layer Distribution In The Center Of The Traffic Lane



Smoke Layer Spread Rate At Different Position Along The Tunnel Center In Two Directions

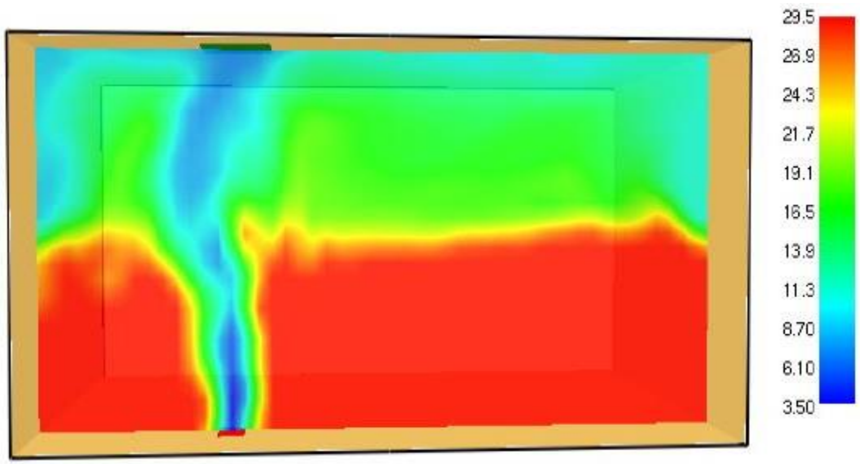


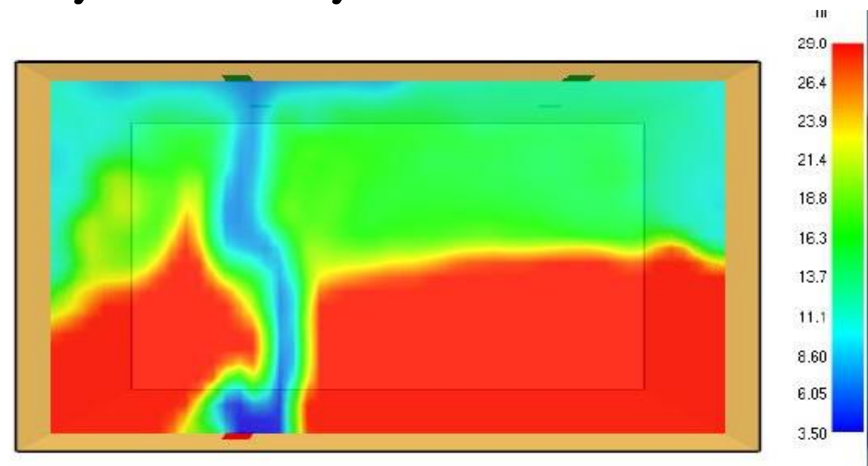
2. ***J Chen*** stated that large space buildings have their own fire characteristics, and built an ideal large space building model

The ideal model building used is 20m in length, 12m in width and 10m in height, so the volume is 2400m^3

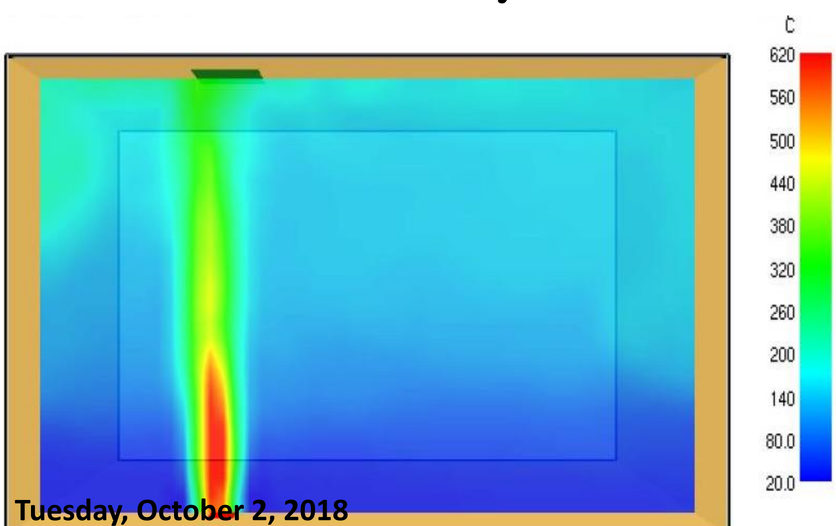
Simulation and Analysis of Different Smoke Vent Arrangements

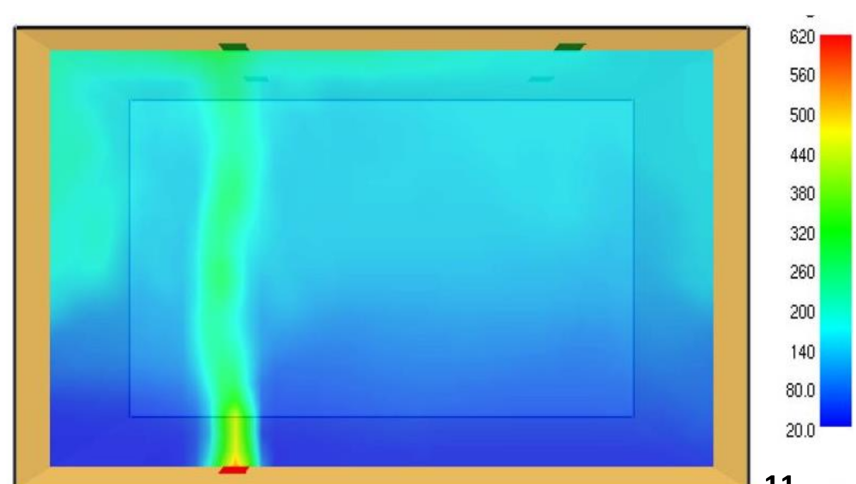
1. Simulation Analysis of Smoke Layer Visibility



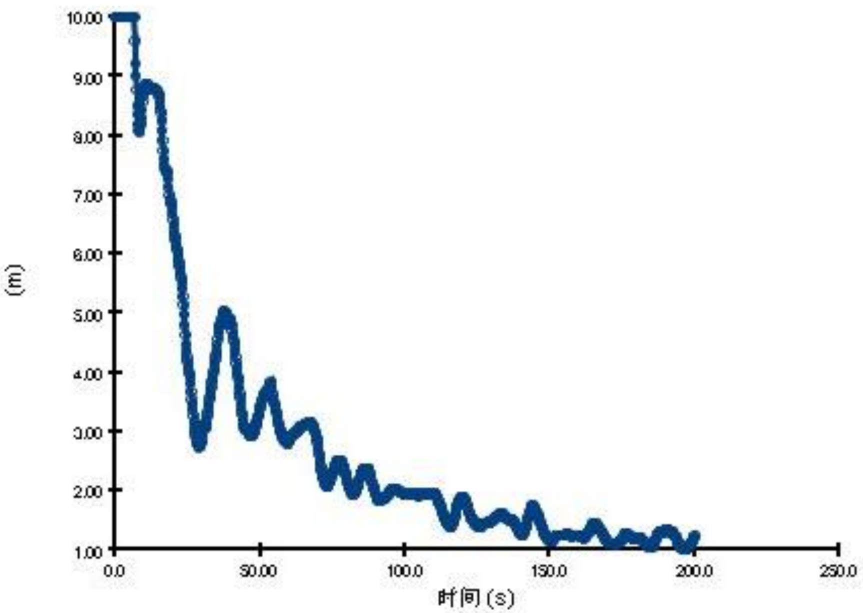


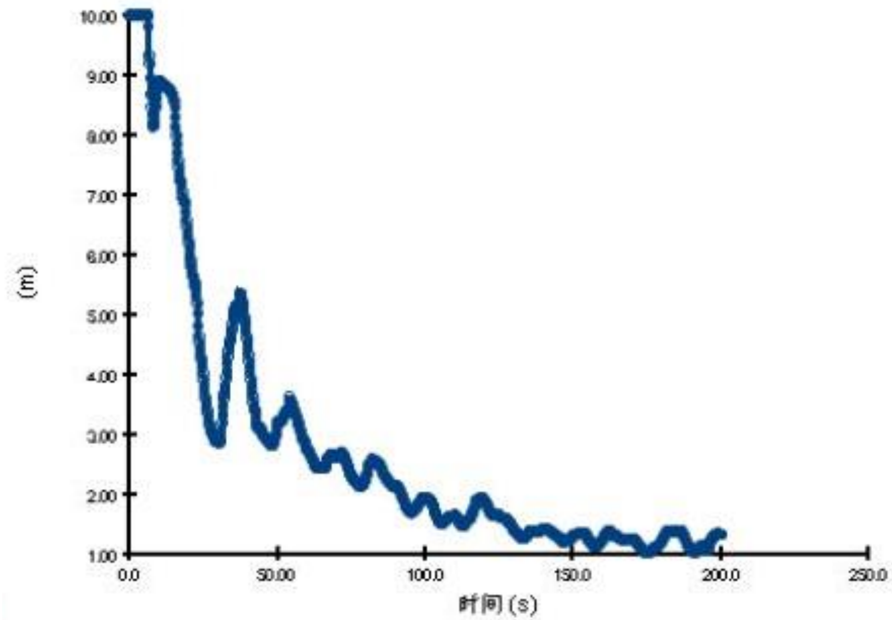
2. Simulation Analysis of Smoke Layer Temperature





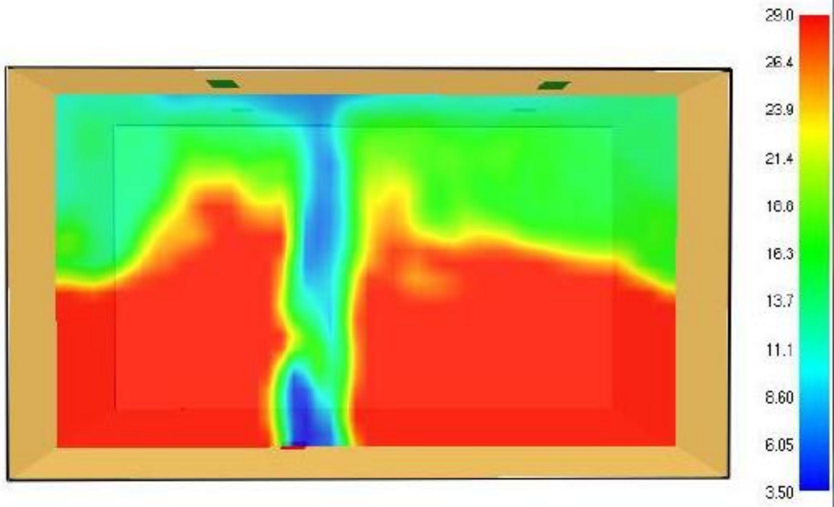
3. Simulation Analysis of Smoke Layer Height

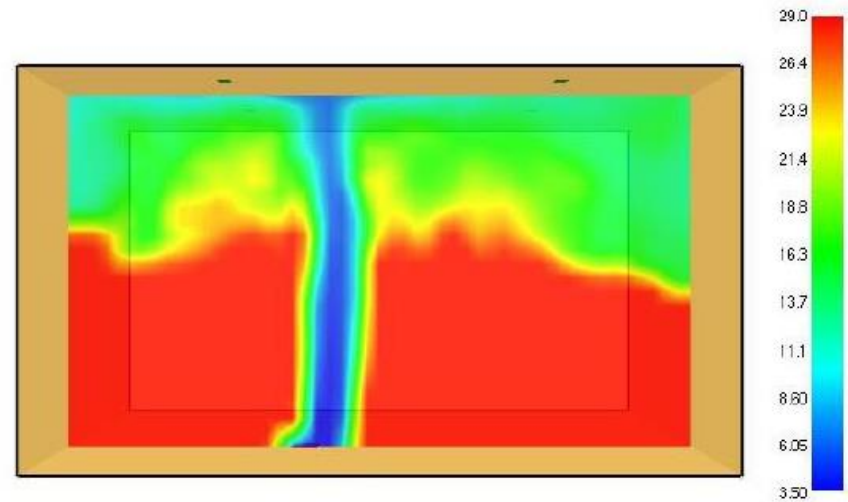




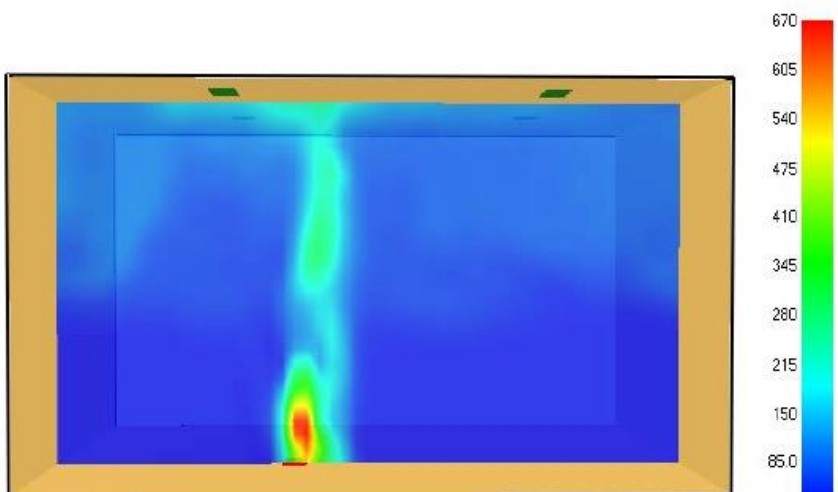
Simulation and Analysis of Different Smoke Exhaust Rates

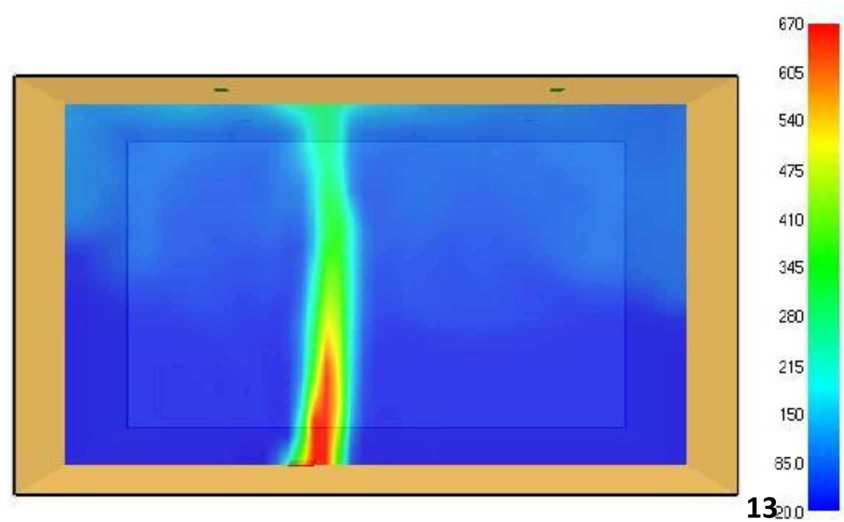
1. Simulation Analysis of Smoke Layer Visibility



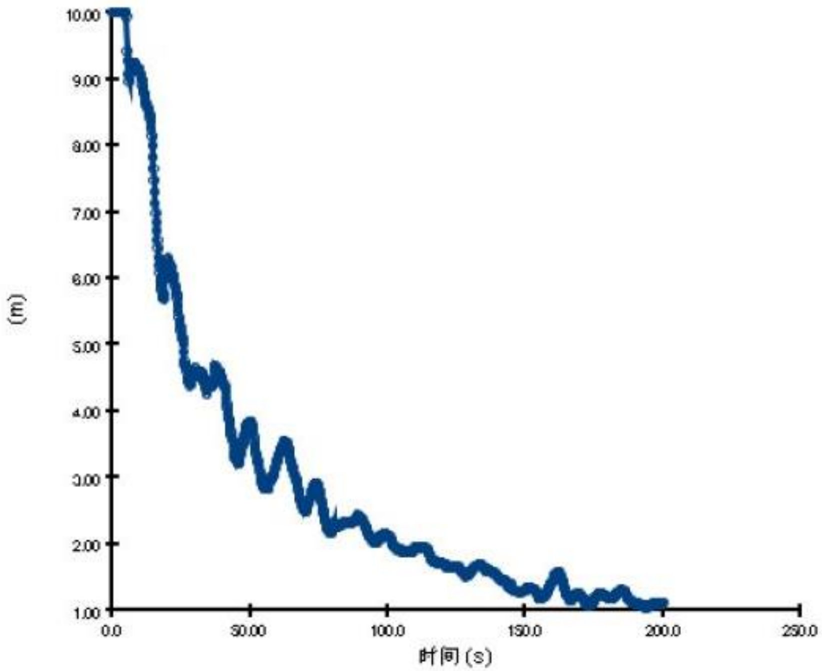


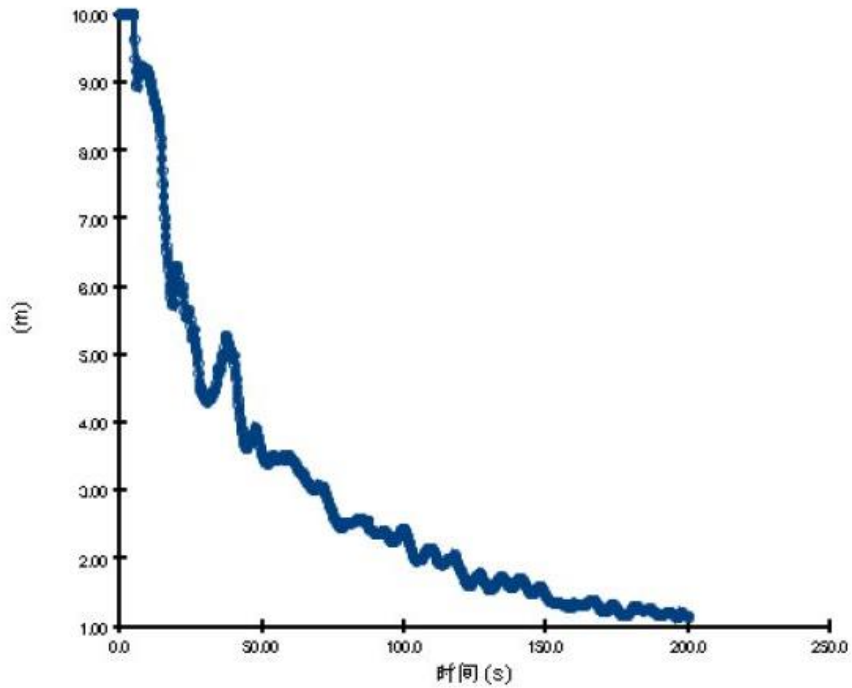
2. Simulation Analysis of Smoke Layer Temperature





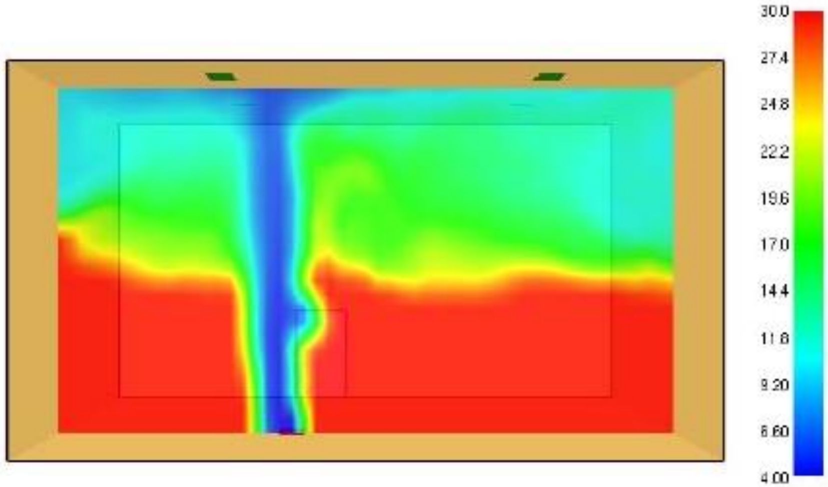
3. Simulation Analysis of Smoke Layer Height

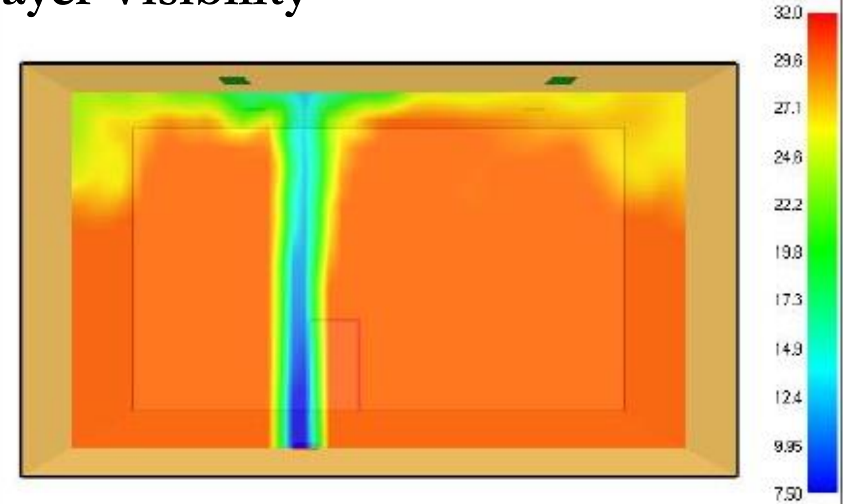




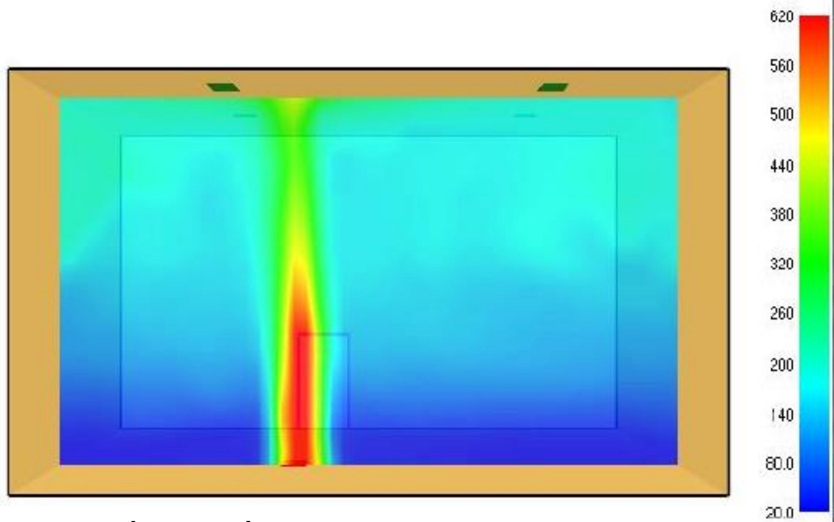
Simulation and Analysis of Different Heat Release Rates

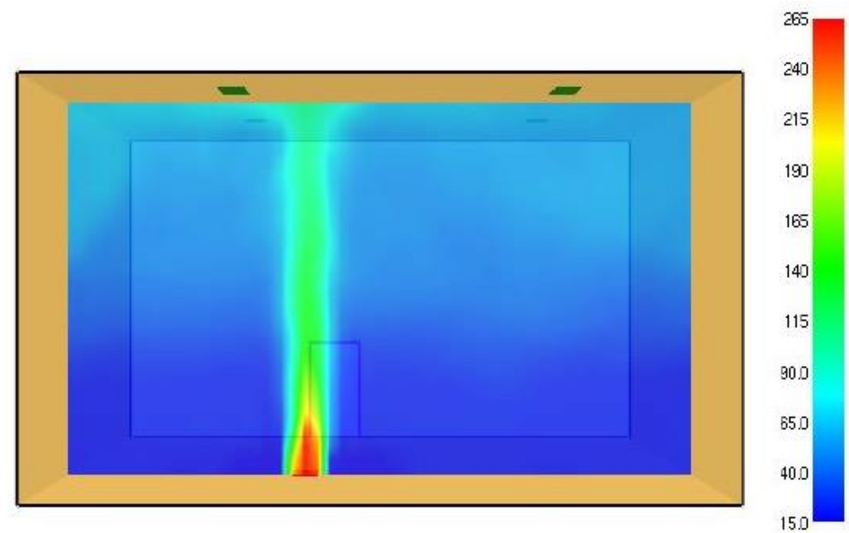
1. Simulation Analysis of Smoke Layer Visibility



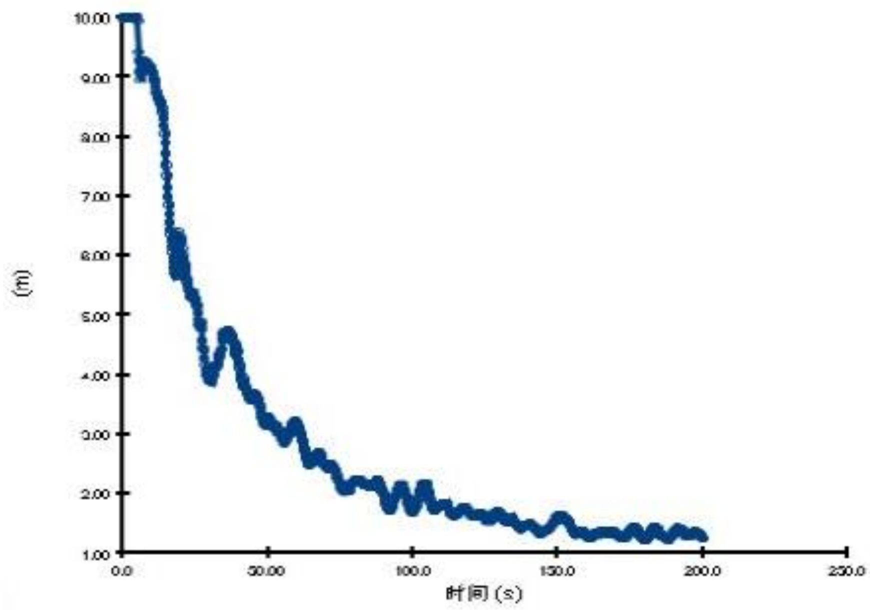


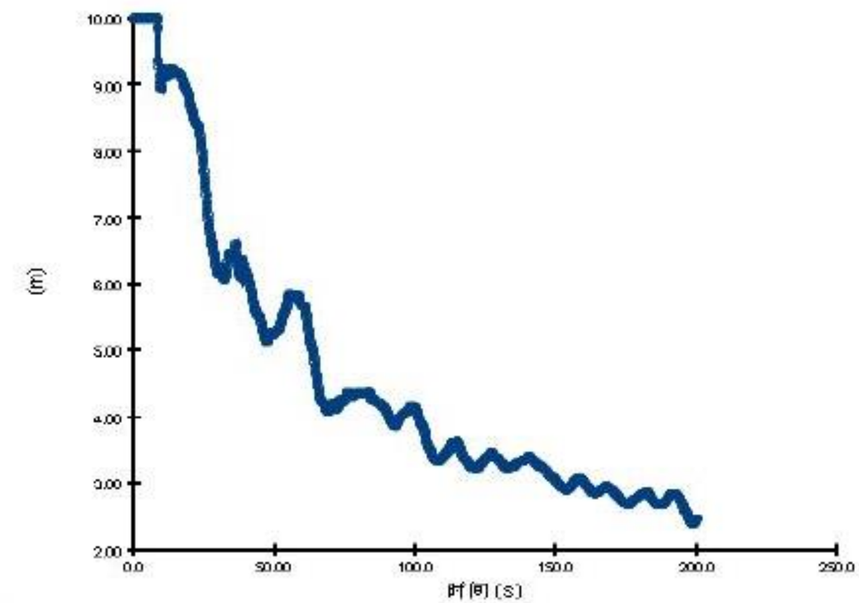
2. Simulation Analysis of Smoke Layer Temperature





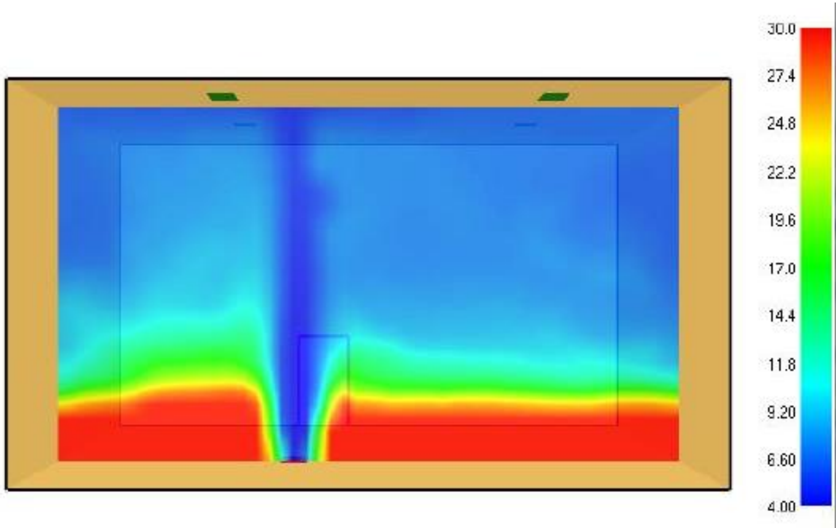
3. Simulation Analysis of Smoke Layer Height

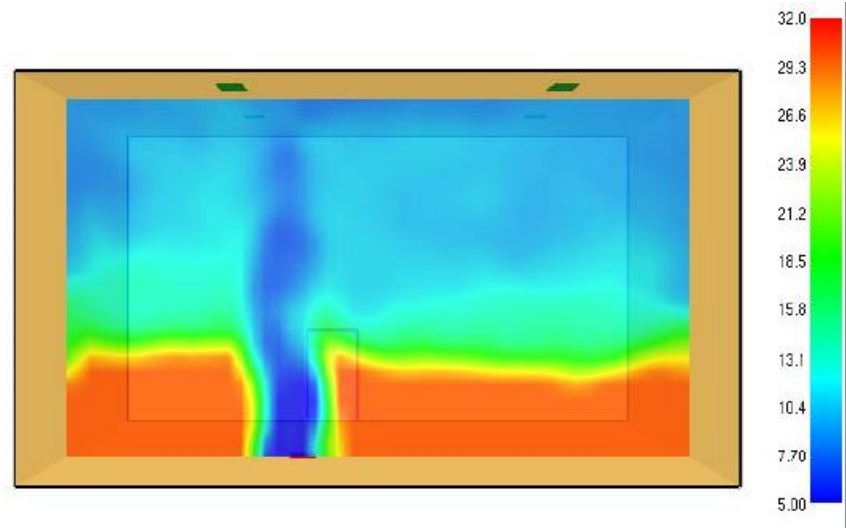




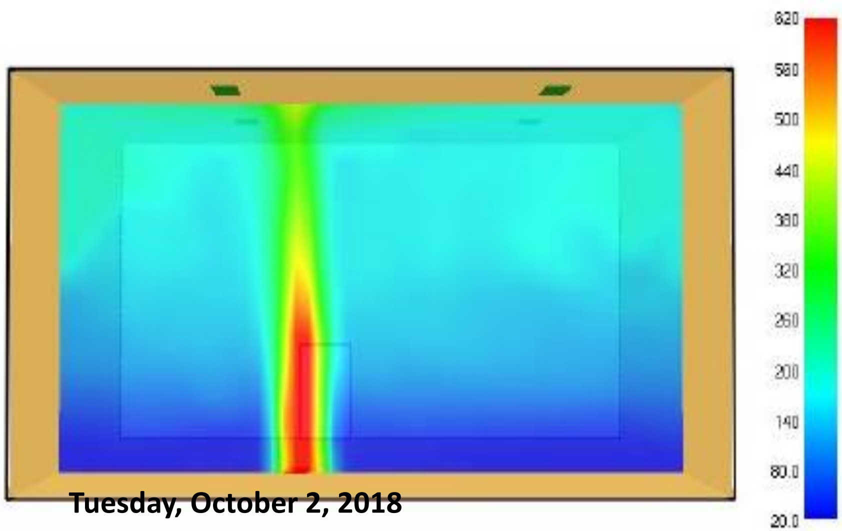
Simulation and Analysis of Different Smoke Exhaust Volumes

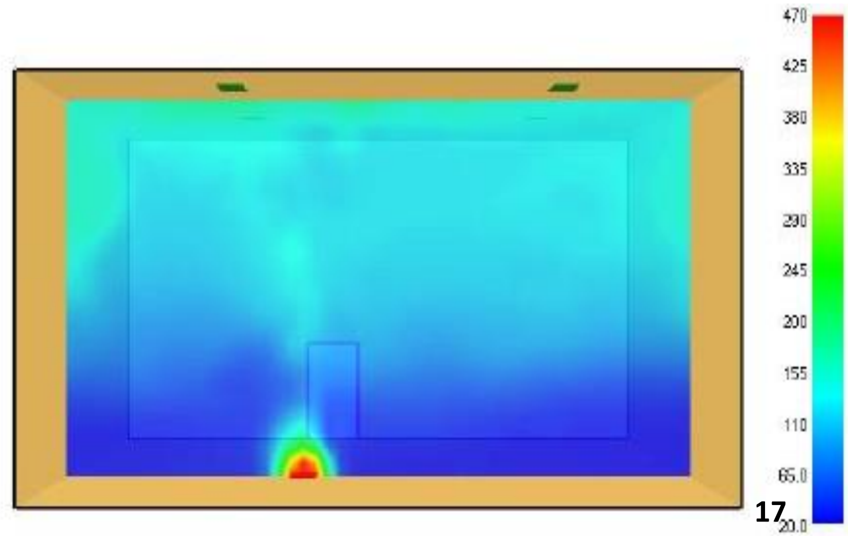
1. Simulation Analysis of Smoke Layer Visibility



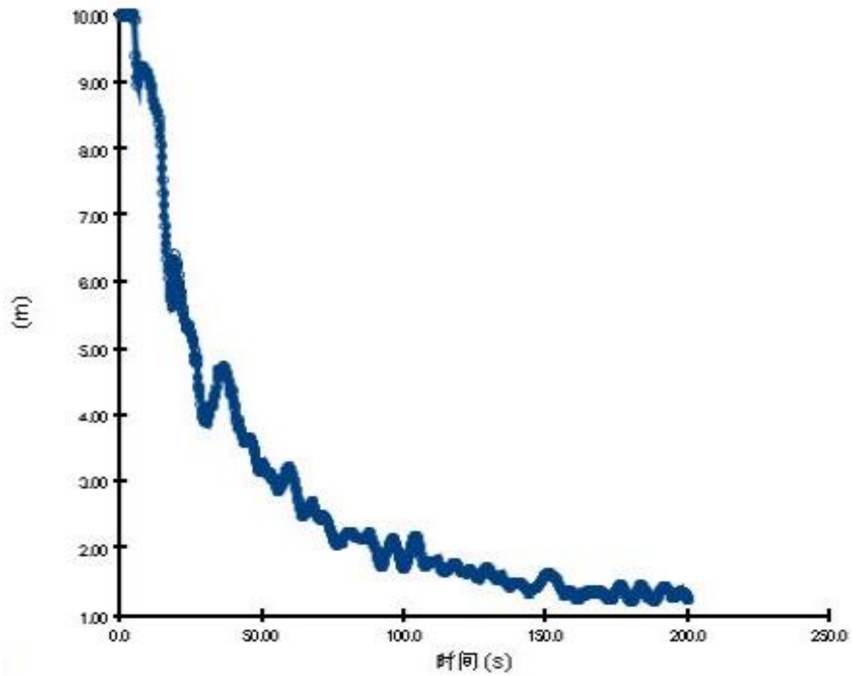


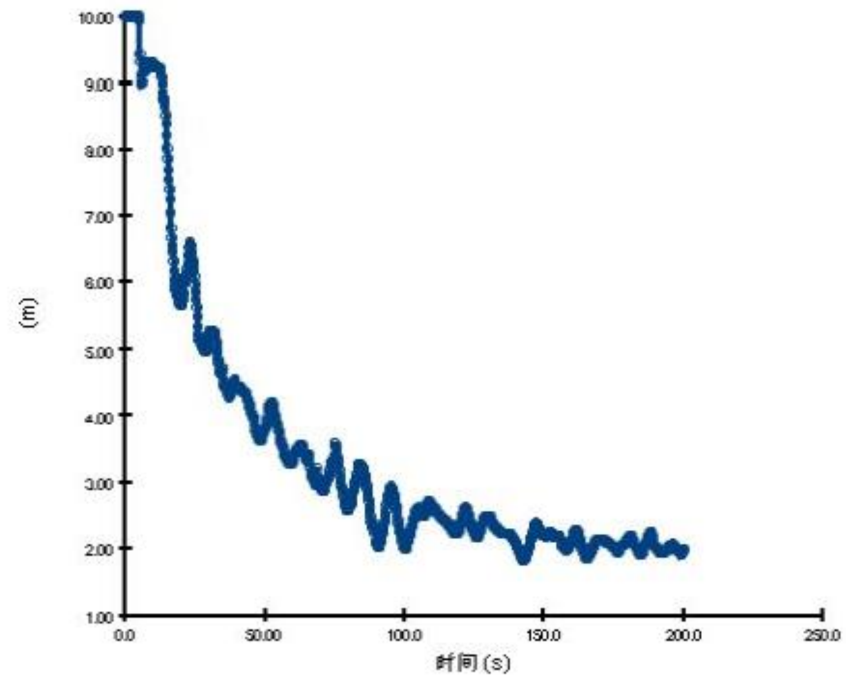
2. Simulation Analysis of Smoke Layer Temperature





3. Simulation Analysis of Smoke Layer Height





3. Governing Equations

- Conservation Of Mass
- Conservation Of Momentum (Newton's 2^{nd} Law)
- Conservation Of Energy (1^{st} Law Of Thermodynamics)
- Equation Of State For A Perfect Gas
- Conduction Heat Transfer For A Solid
- Radiation Heat Transfer To Solids
- Convective Heat Transfer To Solids

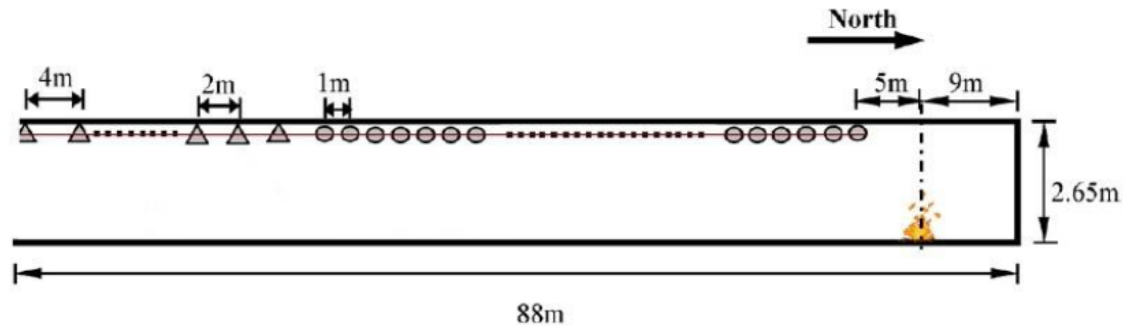
4. Numerical Analysis Principles

1. Validation of PYROSIM (6.1.0)

The validation for FDS and grid sensitivity analysis is done by using experiment of Hu and its correction on long channel.

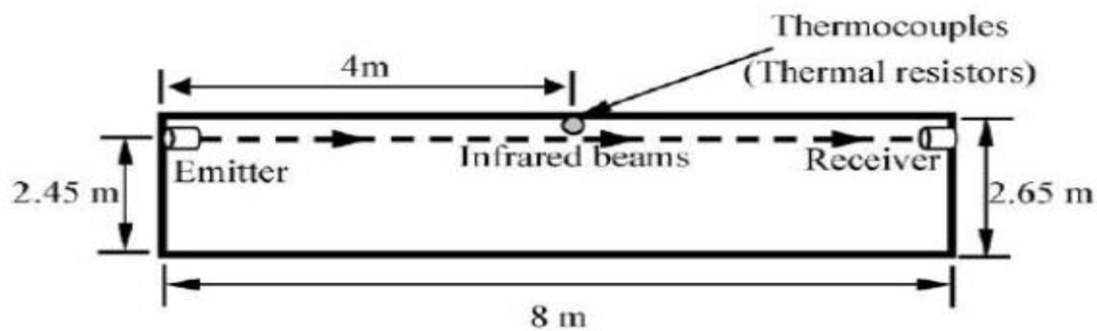
- The long channel dimensions are 88m long, 8m wide and 2.65m high.
- The north end was closed while the south end half-opened.
- The sidewalls were made of concrete and the ceiling made of gypsum.
- The ambient temperature was about 27.5 and 28°C for the two tests, respectively.

Diesel pool fires were set up at floor level at about 9m away from the north end and in the middle of the two sidewalls

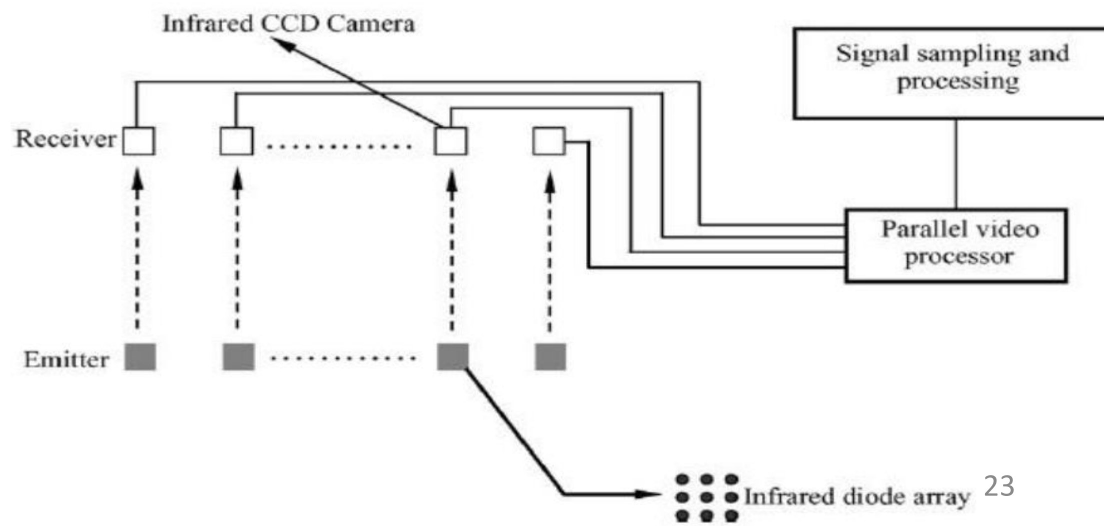


Longitudinal view

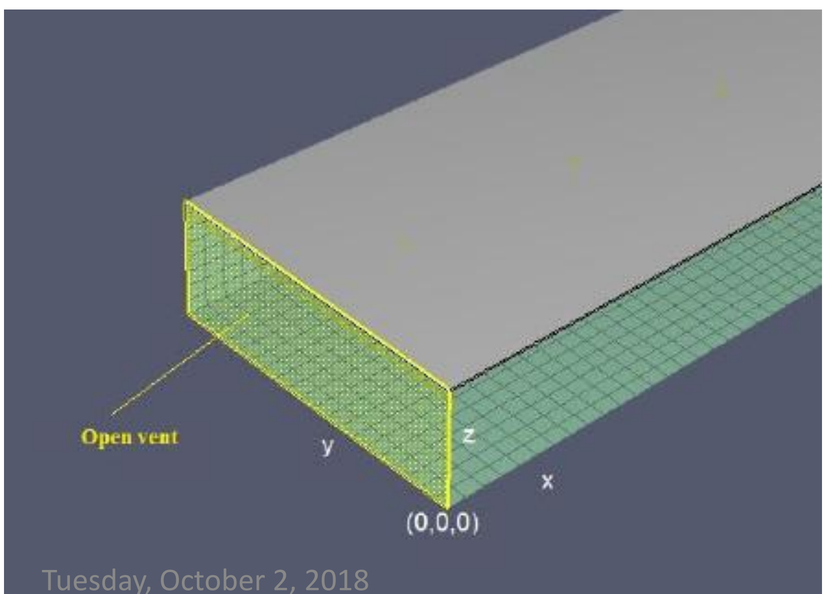
49 thermocouples,
8 thermal resistors and
10 pairs of infrared beams, each composed of one emitter and one receiver were used to measure the smoke temperature distribution along the channel.

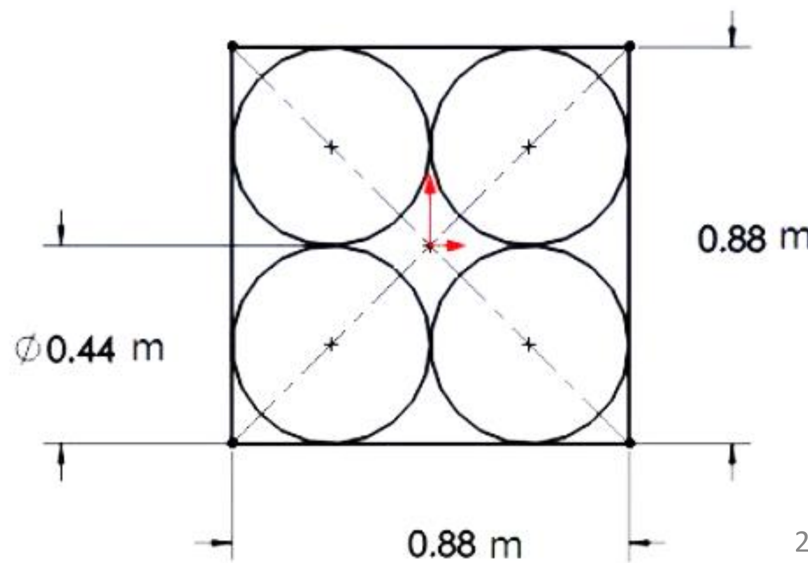


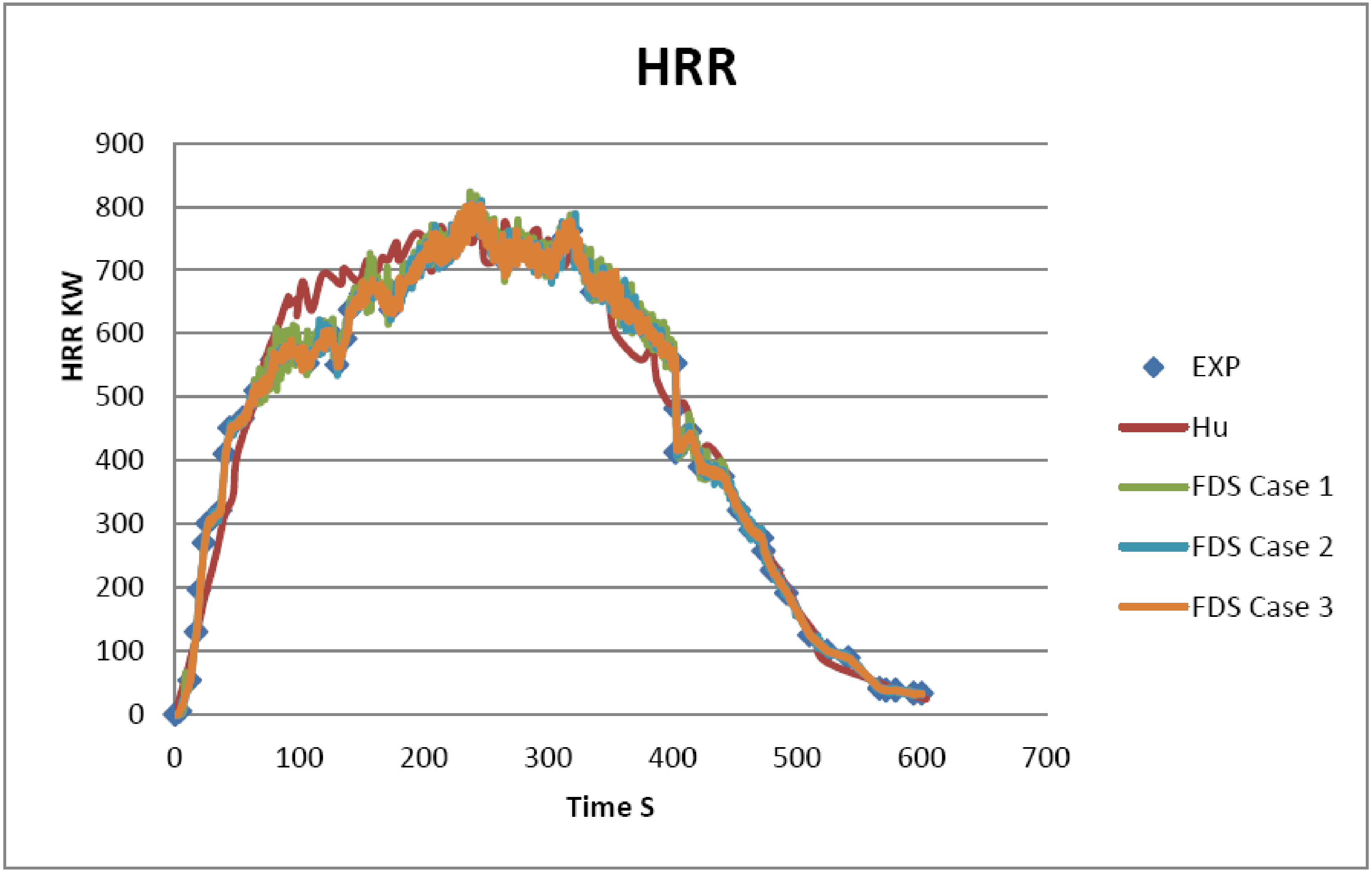
Cross-sectional view

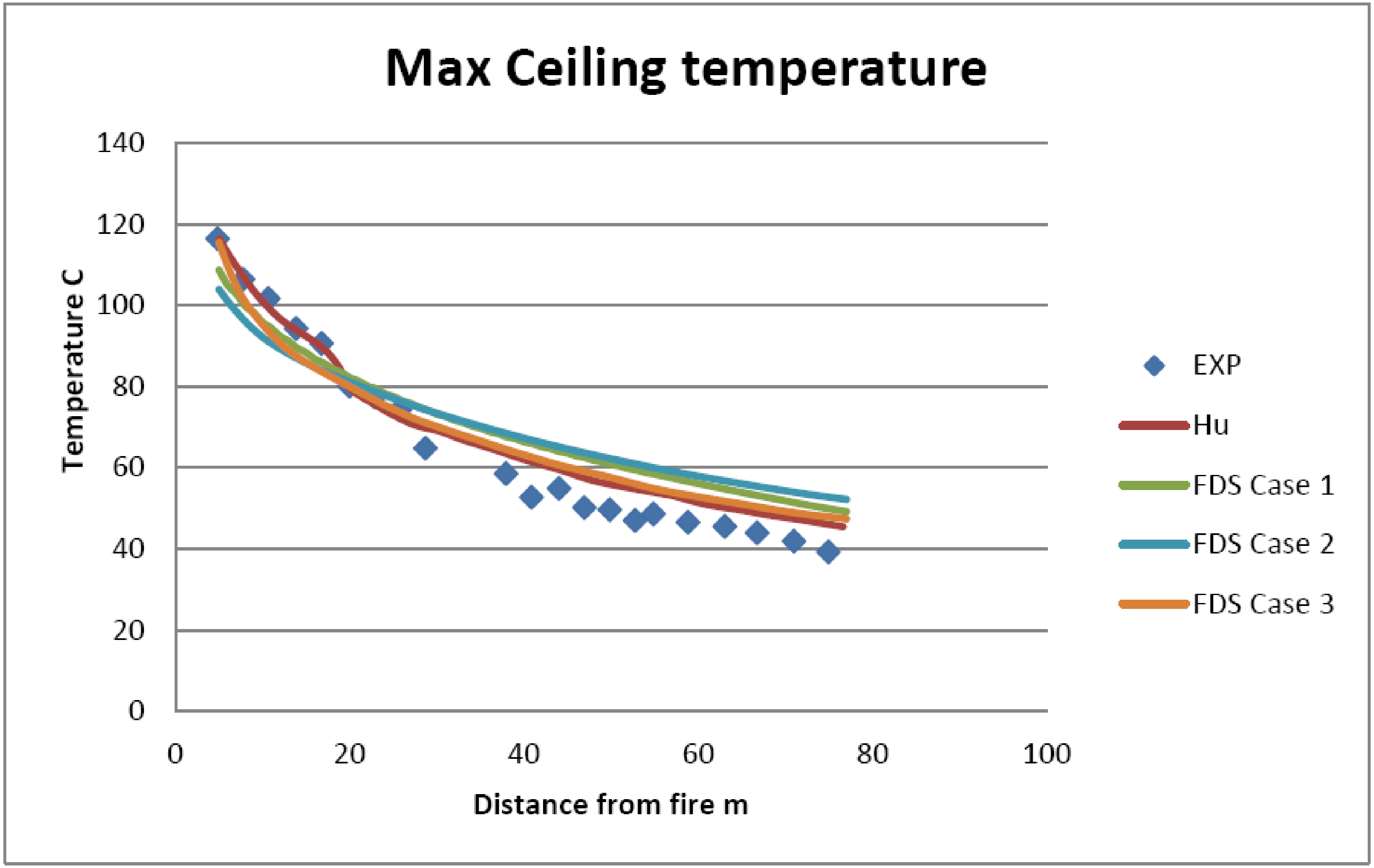


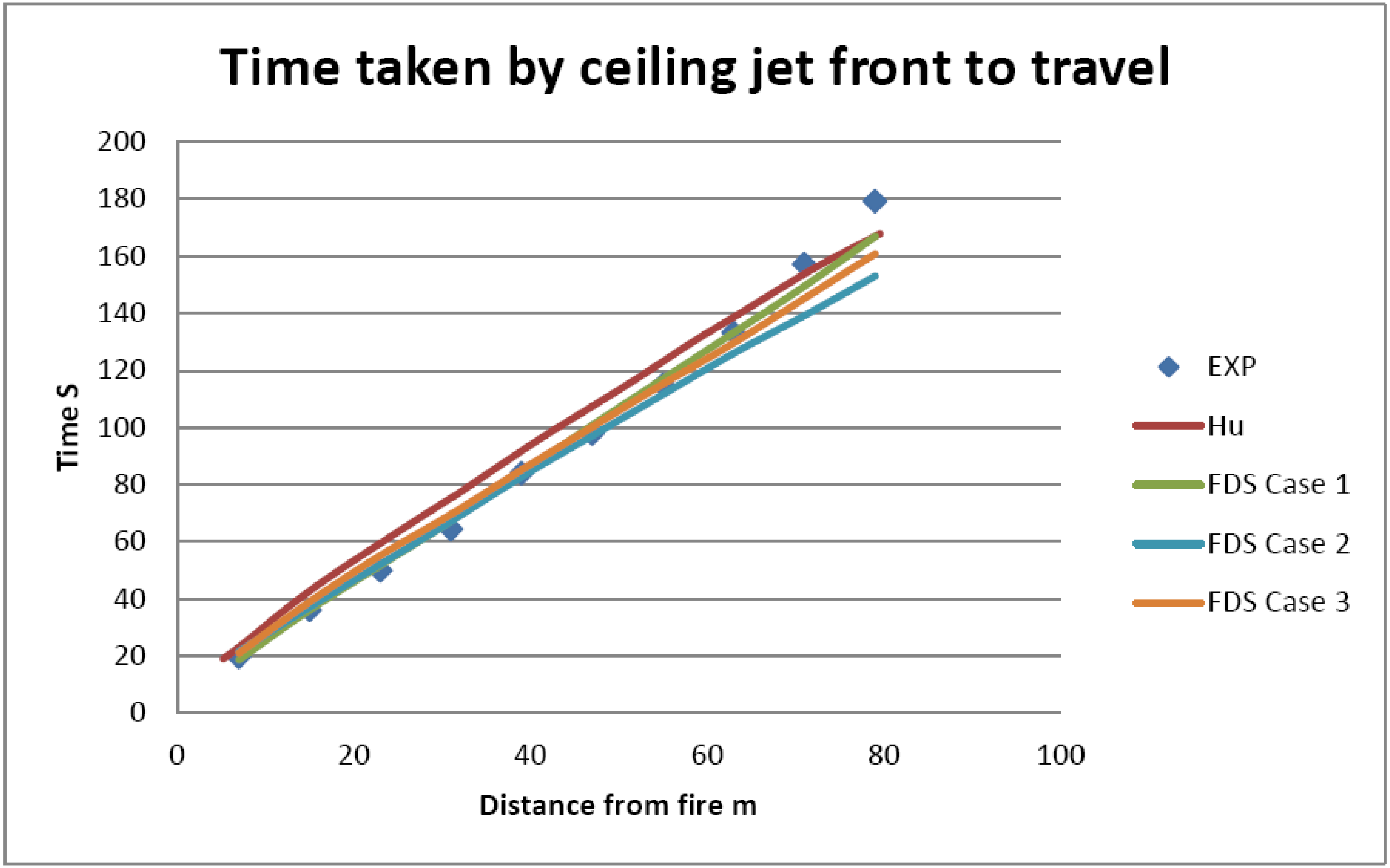
Case Number	Number of Grid Cells (n_x X n_y X n_z)	Dimensions of Mesh (meter)	Number of Meshes
1	220X20X8	0.4X0.4X0.34	35,200
2	440X16X40	0.2X0.17X0.2	281,600
3	660X60X24	0.13X0.13X0.11	950,400





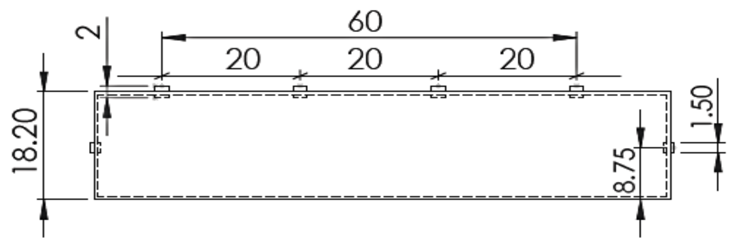

HRR
HRR KW
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
Time S
EXP
Hu
FDS Case 1
FDS Case 2
FDS Case 3

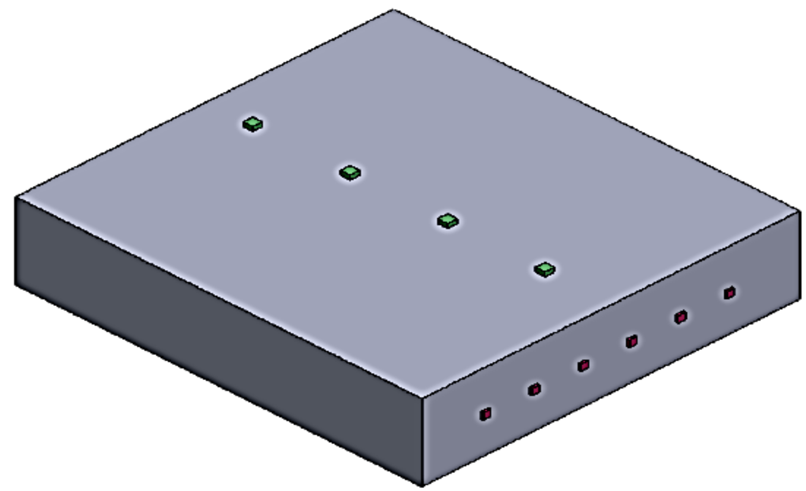

Max Ceiling temperature
140
120
100
80
60
40
20
0
Temperature C
0
20
40
60
80
100
Distance from fire m
EXP
Hu
FDS Case 1
FDS Case 2
FDS Case 3

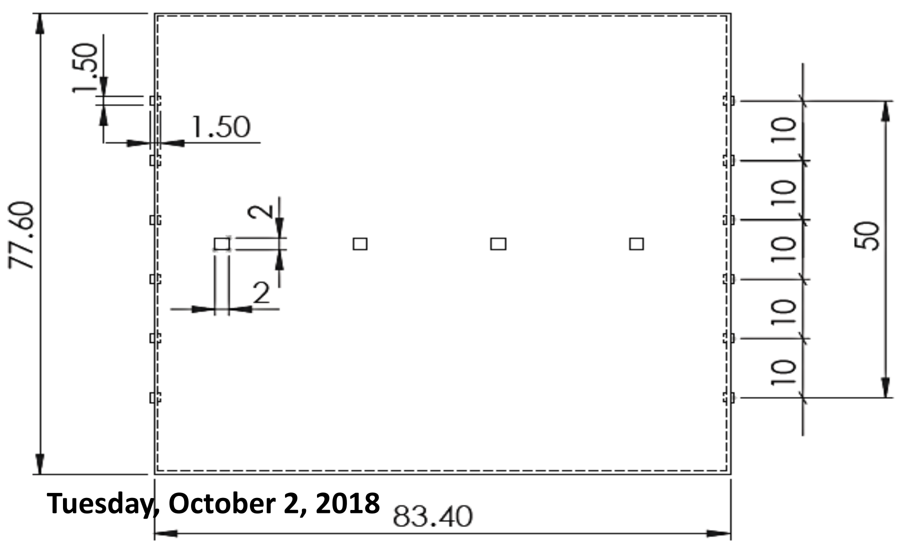

Time taken by ceiling jet front to travel
200
180
160
140
120
100
80
60
40
20
0
Time S
0
20
40
60
80
100
Distance from fire m
EXP
Hu
FDS Case 1
FDS Case 2
FDS Case 3

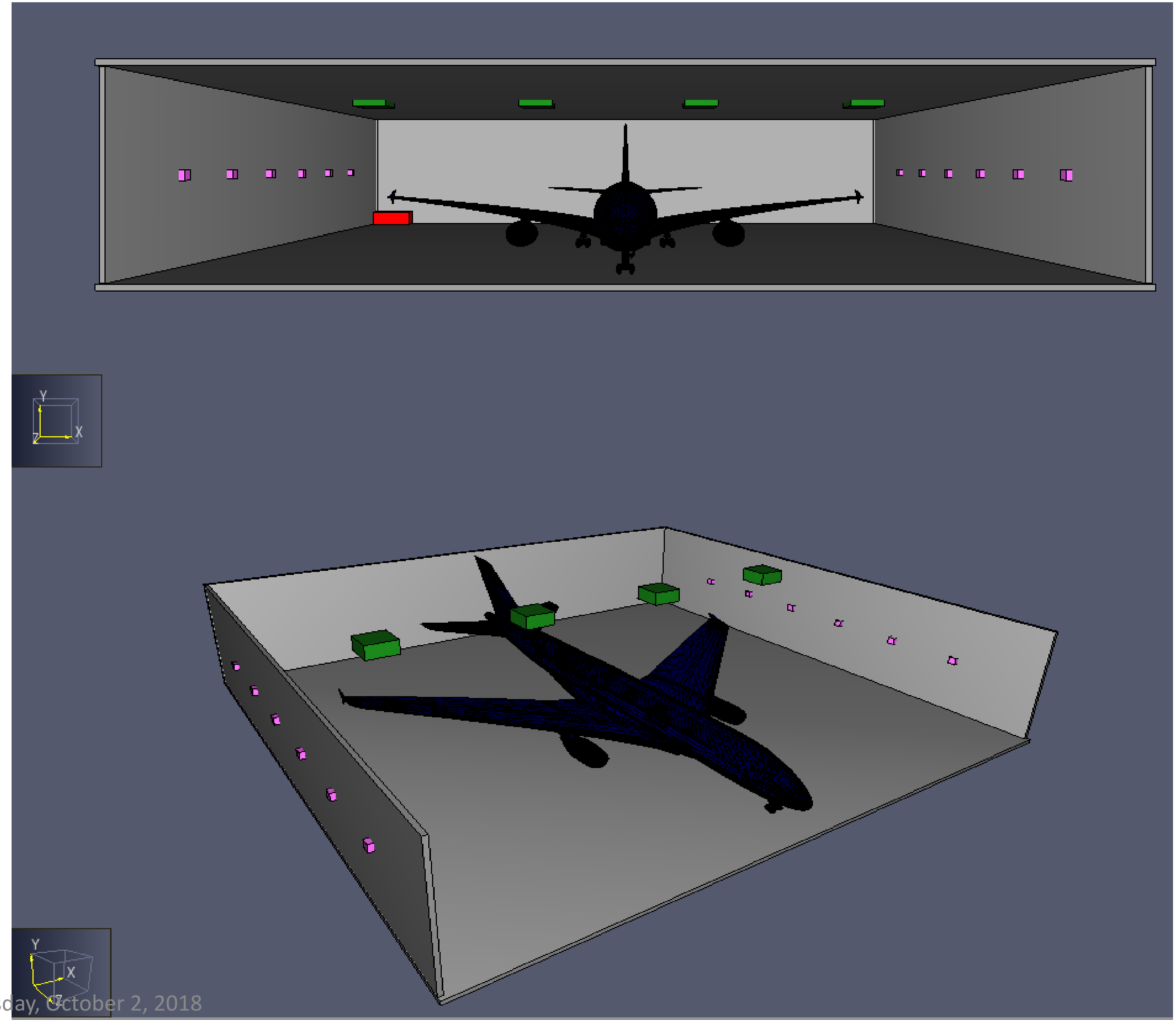
2. Computational Domain

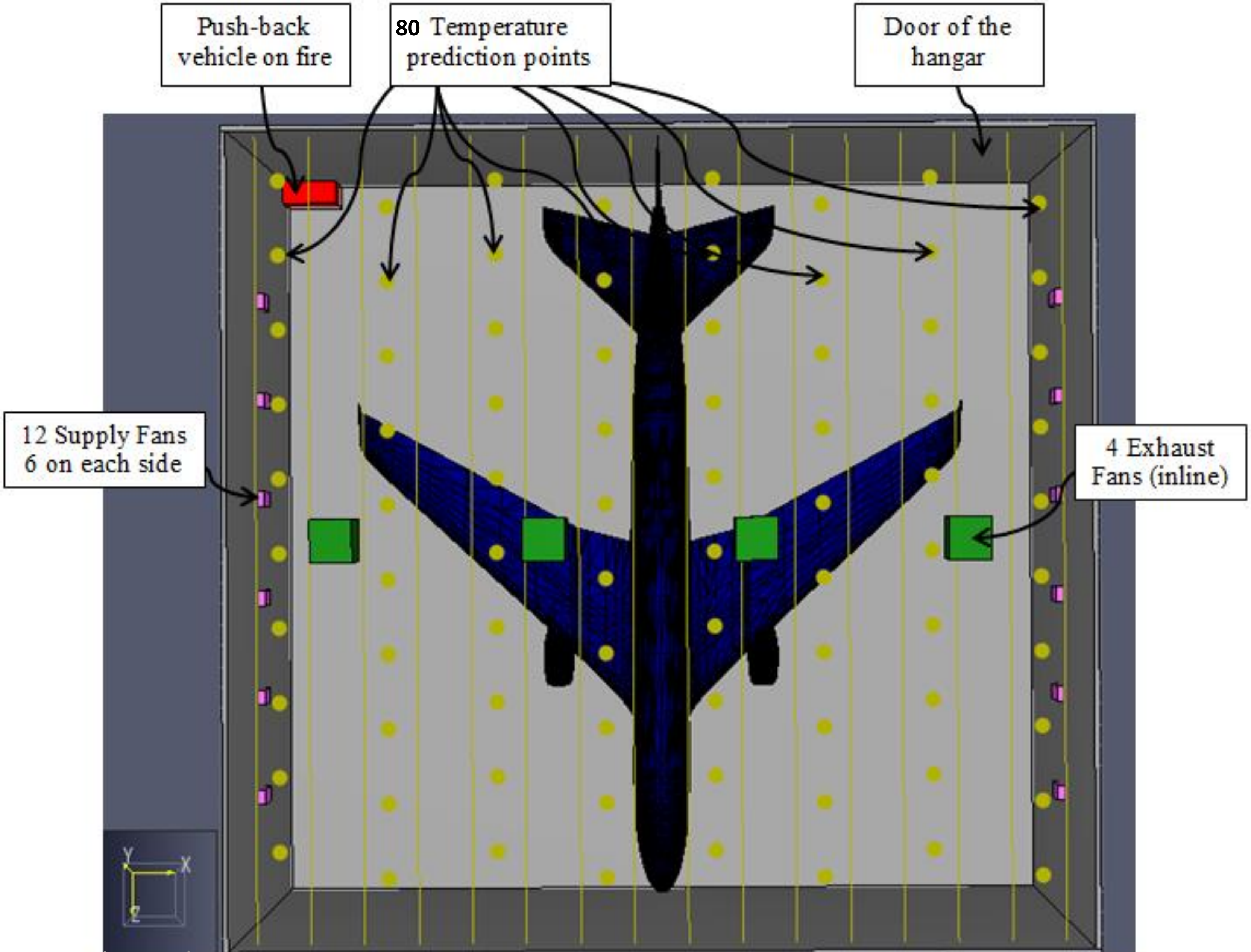
The air-craft hangar under analysis is a real hangar located in Brandenburg-Germany





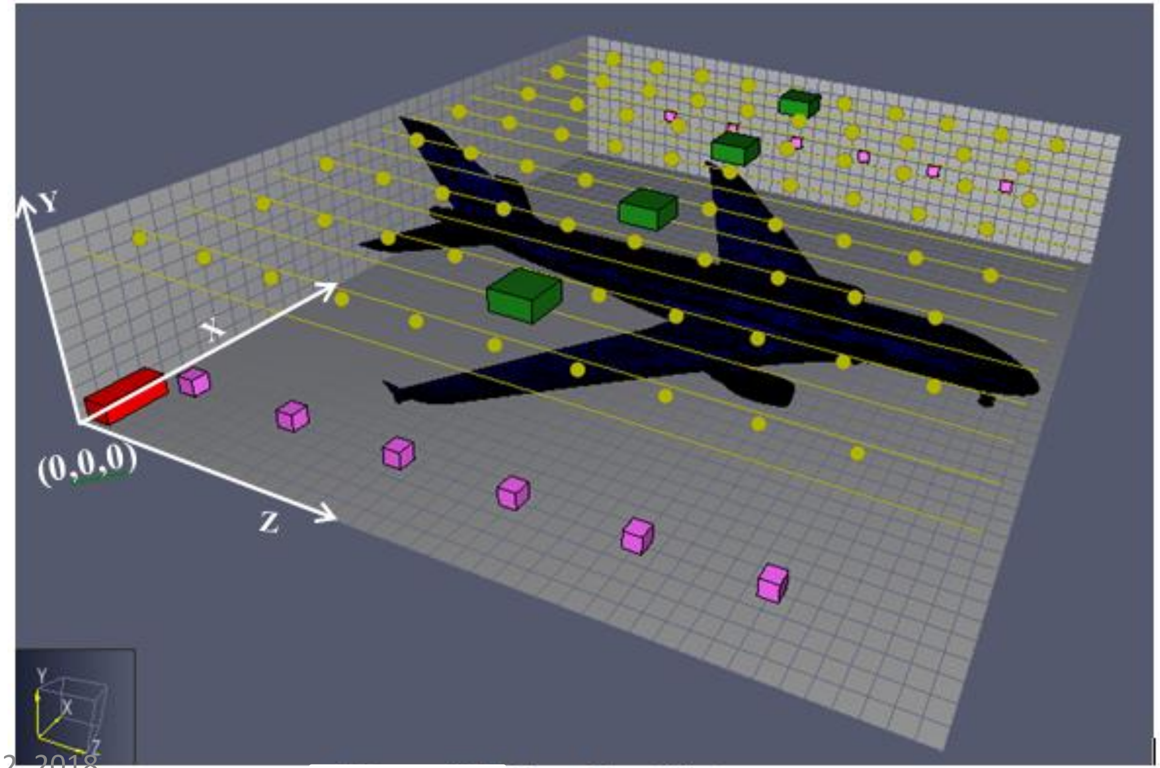



Y
X
Z
Y
X
Z


Push-back vehicle on fire
80 Temperature prediction points
Door of the hangar
12 Supply Fans 6 on each side
4 Exhaust Fans (inline)

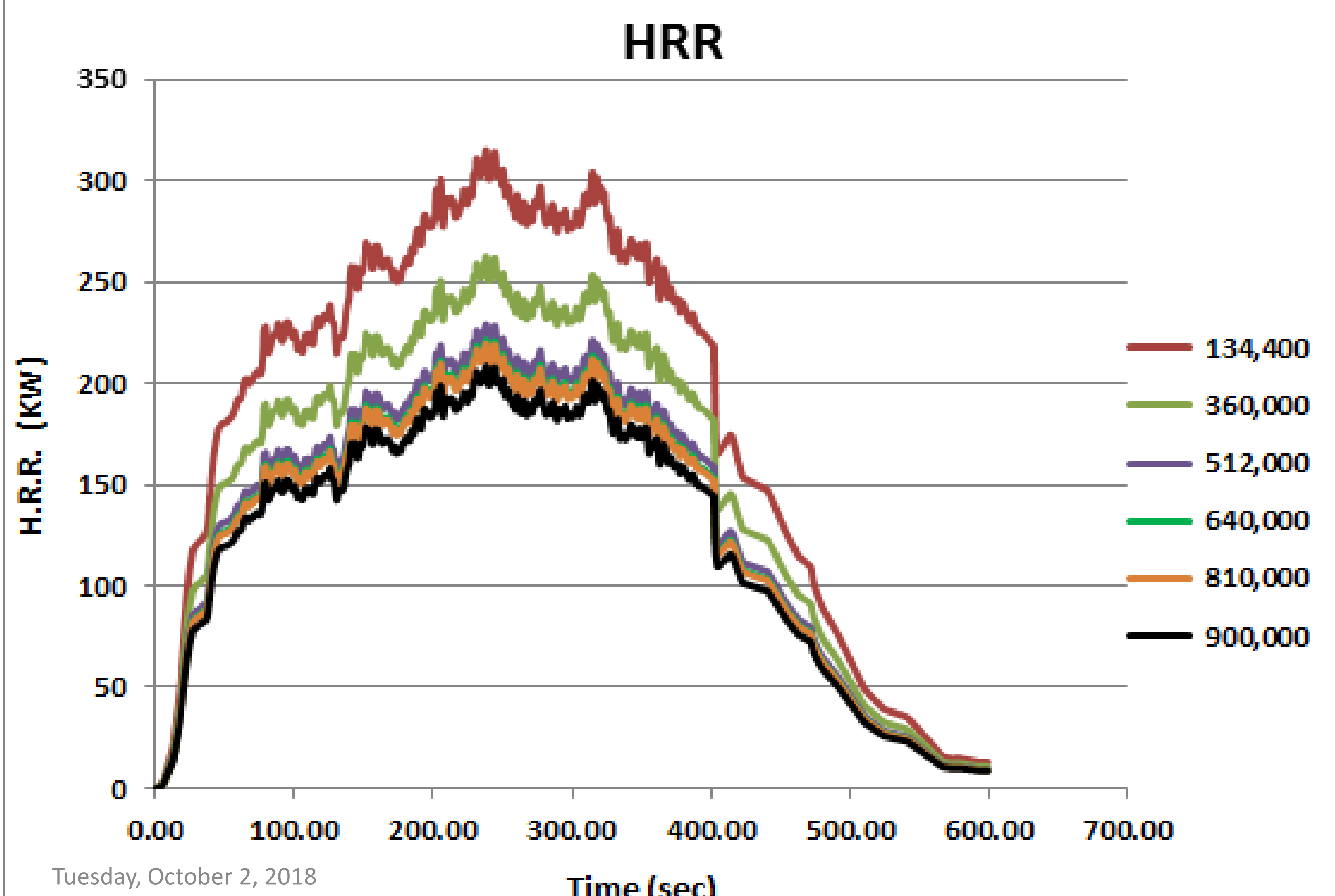
Cases Carried Out For Grid Sensitivity Analysis

Case Number	Number of Grid Cells (n_x X n_y X n_z)	Dimensions of Mesh (meter)	Number of Meshes
1	84X20X80	0.9929X0.91X0.97	134,400
2	120X25X120	0.695X0.728X0.6467	360,000
3	80X80X80	1.0425X0.2275X0.97	512,000
4	100X80X80	0.834X0.2275X0.97	640,000
5	100X90X90	0.834X0.2022X0.8622	810,000
6	150X40X150	0.556X0.455X0.5173	900,000

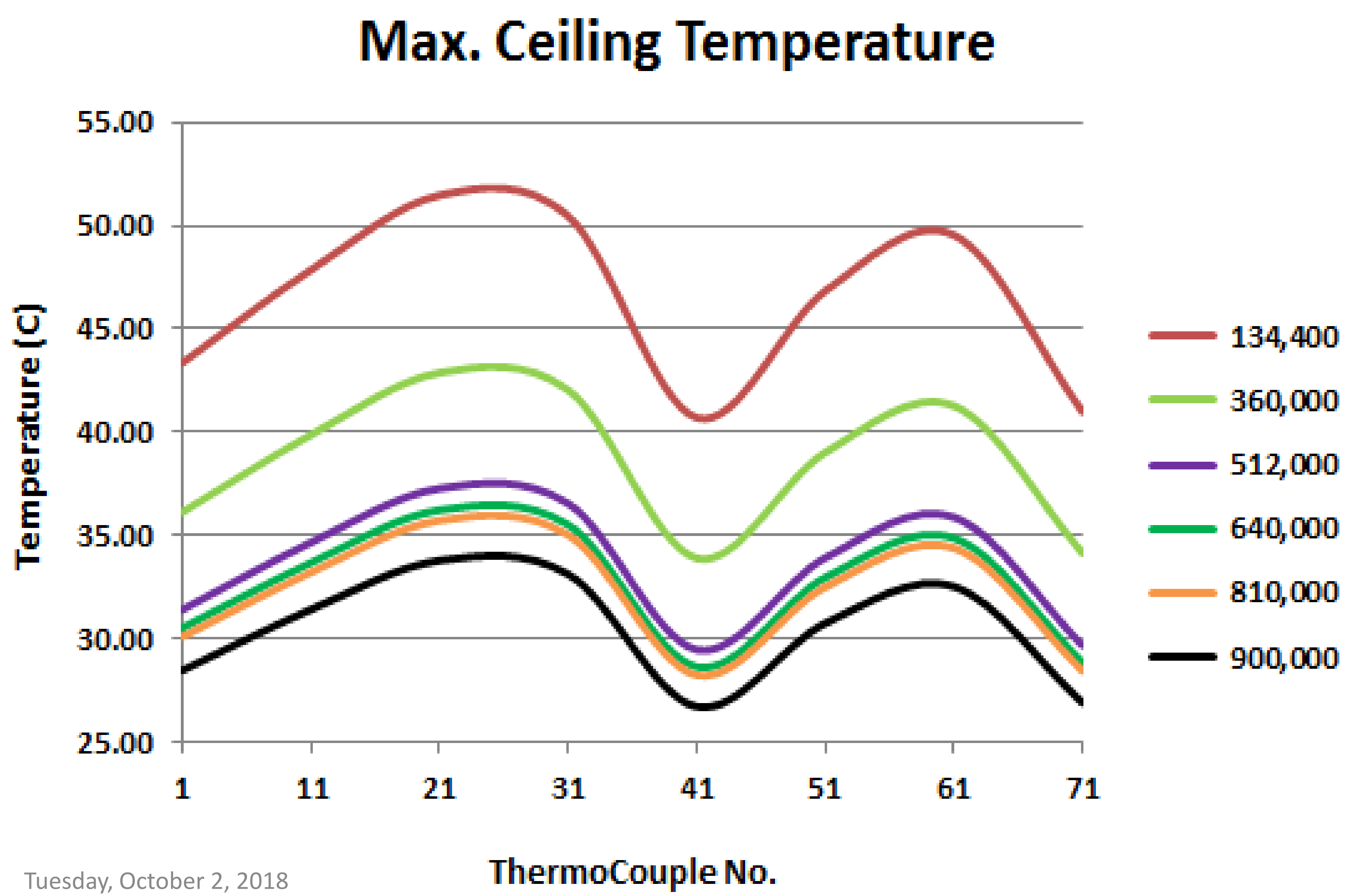


Coordinate System

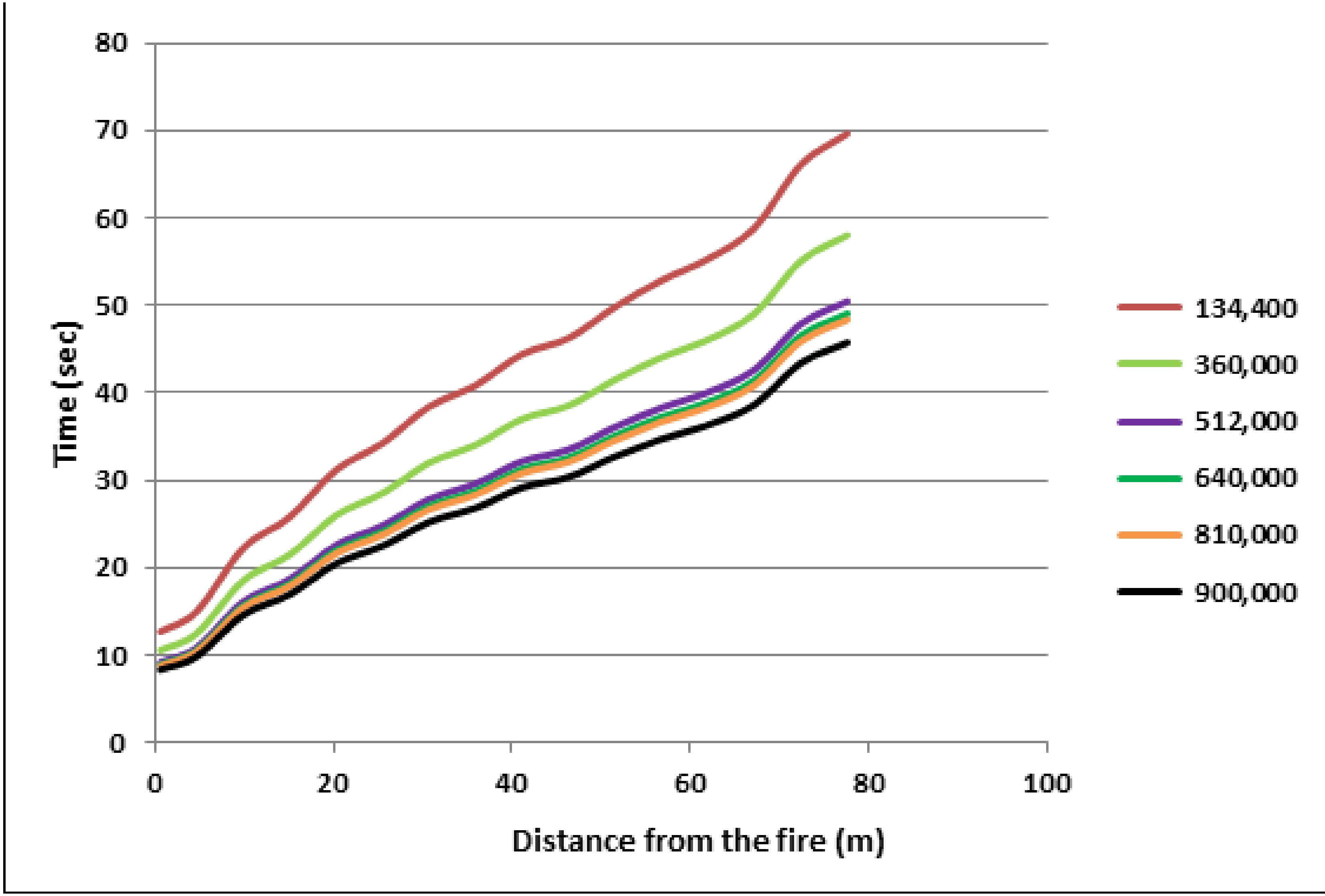
HRR variation with time



Maximum Ceiling Jet Temperature



Time Taken By Ceiling Jet Front to Travel



3. Boundary Conditions

- The ceiling, the side wall and the floor were set to be concrete.
- Randomly distributed the airplane (Airbus A330-300) in the middle of the hangar with actual dimensions are imported and set to be steel.
- The properties of these two materials were just set according to the database of FDS.
- Ambient temperature is considered 35°C.
- The Push-back vehicle on fire is located at the top left corner -beside door- of the computational domain; the Push-back vehicle on fire is modeled by a block of a 5.83 m long, 2.4 m wide and 2 m high.
- Block representing push-back vehicle on fire was set to be steel.
- The fire development is confined to a steady phase fire and a peak value of 4MW.
- Soot yield is given as 0.05, as a medium value .

Visibility, temperature and velocity contours are calculated at human level (1.8 m) as the suitable condition for applying the evacuation plan is that the *visibility should not be less than 10 m* with *temperature not higher than 60°C* and *air speed less than 11 m/s* according to NFPA 130

5. Results and Discussion

Case Studies and Fire Scenarios

Case Number	Fire Location (X,Y,Z)	Supply			Extraction		
		Rate (ACH)	No. of fans	Position	Rate (ACH)	No. of fans	Position
1	(3.415, 1.5, 1.7)	10	12	Side-wall (center Y-axis) 8m - 9.5m	10	4	Ceiling (center Z-axis)
2	(3.415, 1.5, 1.7)	10	12		20	4	
3	(3.415, 1.5, 1.7)	10	12		10	12	
4	(3.415, 1.5, 1.7)	10	12		20	12	
5	(3.415, 1.5, 1.7)	10	12		10	8	
6	(3.415, 1.5, 1.7)	10	12		20	8	
7	(3.415, 1.5, 1.7)	10	12		10	6	
8	(3.415, 1.5, 1.7)	10	12		20	6	
9	(3.415, 1.5, 1.7)	20	12		20	6	
10	(3.415, 1.5, 1.7)	10	16		20	6	
11	(3.415, 1.5, 1.7)	20	16		20	6	
12	(3.415, 1.5, 1.7)	20	10		20	6	
13	(3.415, 1.5, 1.7)	10	10		20	6	
14	(3.415, 1.5, 1.7)	10	10	Side-wall (center Y-axis) 1.5 m – 3 m	20	6	
15	(3.415, 1.5, 1.7)	10	10	Side-wall (center Y-axis) 8m - 9.5m	20	6	Ceiling
16	(3.415, 1.5, 1.7)	10	10		20	6	
Fire Scenario 1	(3.415, 1.5, 1.7)	10	10	Side-wall (center Y-axis) 8m - 9.5m	20	6	Ceiling
Fire Scenario 2	(79.985, 1.5, 1.7)	10	10		20	6	
Fire Scenario 3	(3.415, 1.5,75.9)	10	10		20	6	
Fire Scenario 4	(79.985, 1.5,75.9)	10	10		20	6	

Parameters:

1. Effect of changing the extraction rate with changing number of extraction fans

2. Effect of changing the supply rate with changing number of supply fans

3. Effect of changing the position of supply fans

4. Effect of changing the arrangement of extraction fans

These parameters were studied to show their effect on the ***VISIBILITY, VELOCITY*** and ***TEMPERATURE***.

Effect of Different Variables on Visibility

VIDEOS

From the previous videos, it is clear that **duplicating the extraction rate** for the **same number of extraction fans**, **same way of arrangement**, **position and ACH of supply fans** ***makes the visibility better*** in addition to **increasing the number of extraction fans** also improves the visibility.

Therefore; from Visibility's point of view all cases satisfy the visibility condition which stated by NFPA 130

Effect of Different Variables on Velocity

VIDEOS

From the previous graphs we can observe that all cases show no great change in velocity all over the hangar. For all cases, the maximum velocity at any point does not exceed 7.5 m/s.

Therefore; from Velocity's point of view all cases satisfy the velocity condition which stated by NFPA 130

Effect of Different Variables on Temperature

VIDEOS

From case 1 to case 16 show a great change in temperature all over the hangar.

For case 1, case 12 and case 11; the system fails in extracting smoke at which temperature increases till reaches 625^{o}C, 625^{o}C and 875^{o}C respectively.

Case 2; there is an improvement in the temperature distribution, but it exceeds the limit stated by NFPA130 .

Case 3, case 4, case 6 and case 8; records a great improvement in the temperature at human level.

Case 5, case 7, case 9, case 10, case 14 and case 15; is not too bad but they fail during the last minutes.

Case 13 and case 16; show a perfect temperature distribution during the 600 seconds duration.

After studying visibility, temperature, and air velocity contours for different cases, ***case 13*** and ***case 16*** are the most suitable designs for the hangar.

The fresh air supply is 10 ACH with 10 supply fans distributed along the right and left walls (center Y-axis from 8 – 9.5 m) and smoke extraction is 20 ACH, six extraction fans are installed in the ceiling in a square array (case 13).

6. Conclusions and Suggested Future Work

Conclusions

1. FDS (Version 6.1.0) is a powerful tool for designing VS in hangars and service areas as it can import airplanes with actual dimensions and materials then predict smoke spread, temperature and velocity.

2. Traditional ventilation system with some modifications can increase its effective in smoke extraction.

3. Using extraction fans with rate (ACH) double the supply rate for the traditional ventilation system gives very good results in controlling the smoke.

4. Decreasing the number of supply fans will make the smoke spread rate inside the hangar lower.

5. For the four fire scenarios the system shows that it can extract the smoke within the first 30 seconds of fire occurrence.

Suggested Future Work

1. FDS (Version 6.1.0) supports the ability to run an FDS simulation on a network cluster in that mood each grid is run in a separate computer, so finer grid size can be used which is recommended especially nearby fire location.

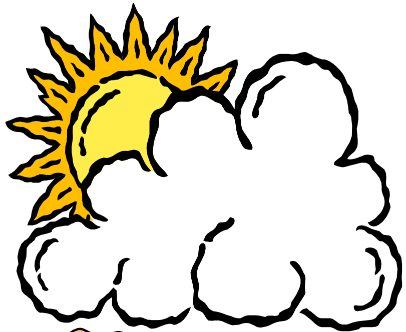
2. Class B and class C fires are not applied in simulation cases of this study so, the performance of ventilation system in case of Class B and class C fires is recommended to be studied.

3. The case of fire in the airplane itself is not studied, it is only taken as an obstacle, so; it is recommended to be studied.

4. The case is done as the hangar contains only one large wide aircraft (Airbus A330-300) which treated as an obstacle, other cases like more than one aircraft inside the hangar is recommended to be studied.

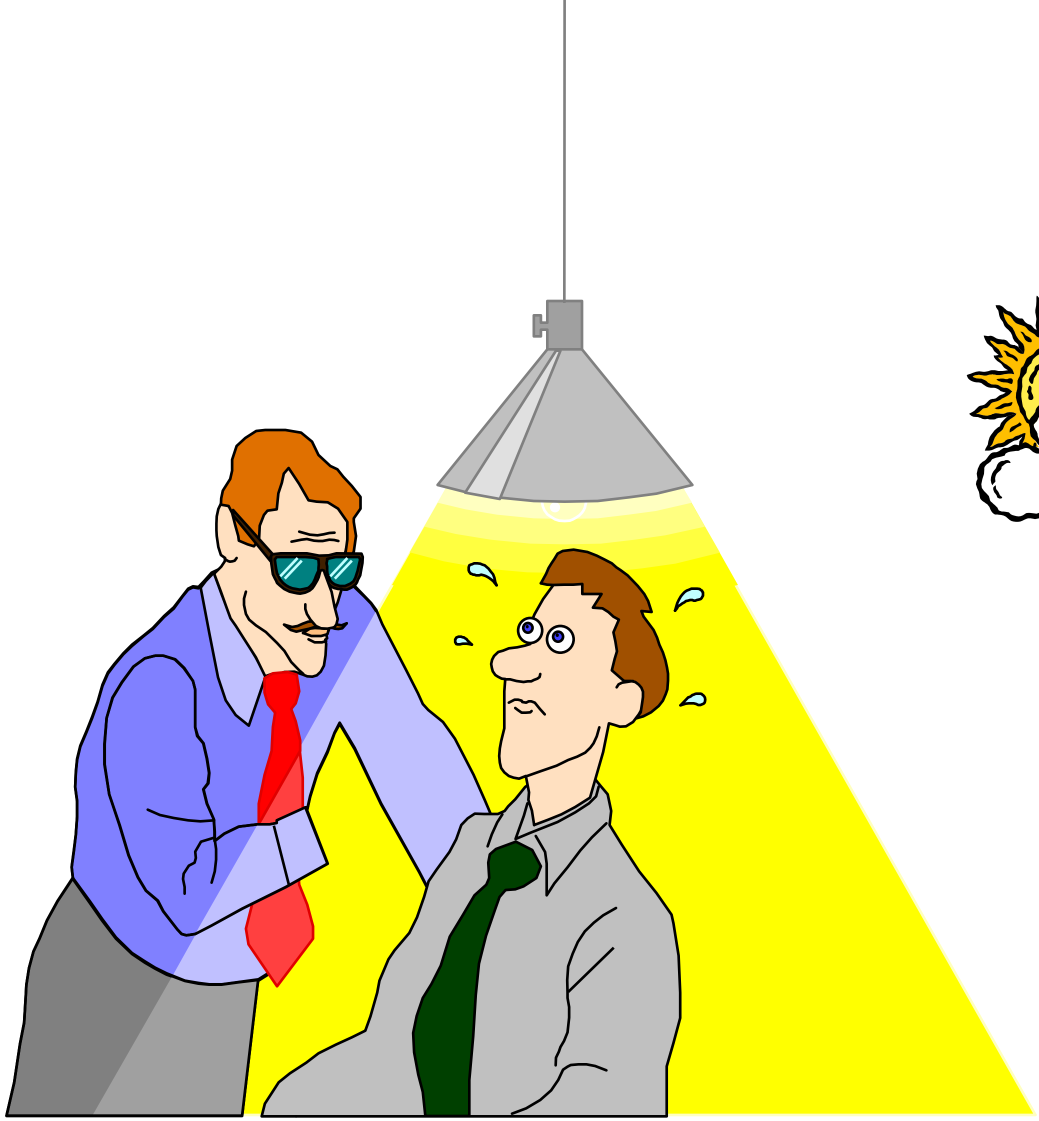
It is very gratifying to find some one that
silently appreciates your efforts

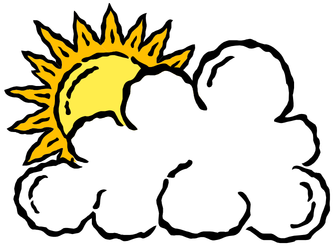
I REST MY CASE YOUR HONOURS



Thank You

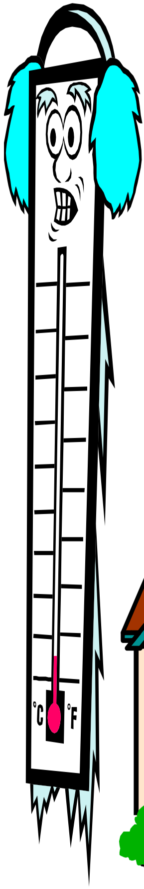
The End

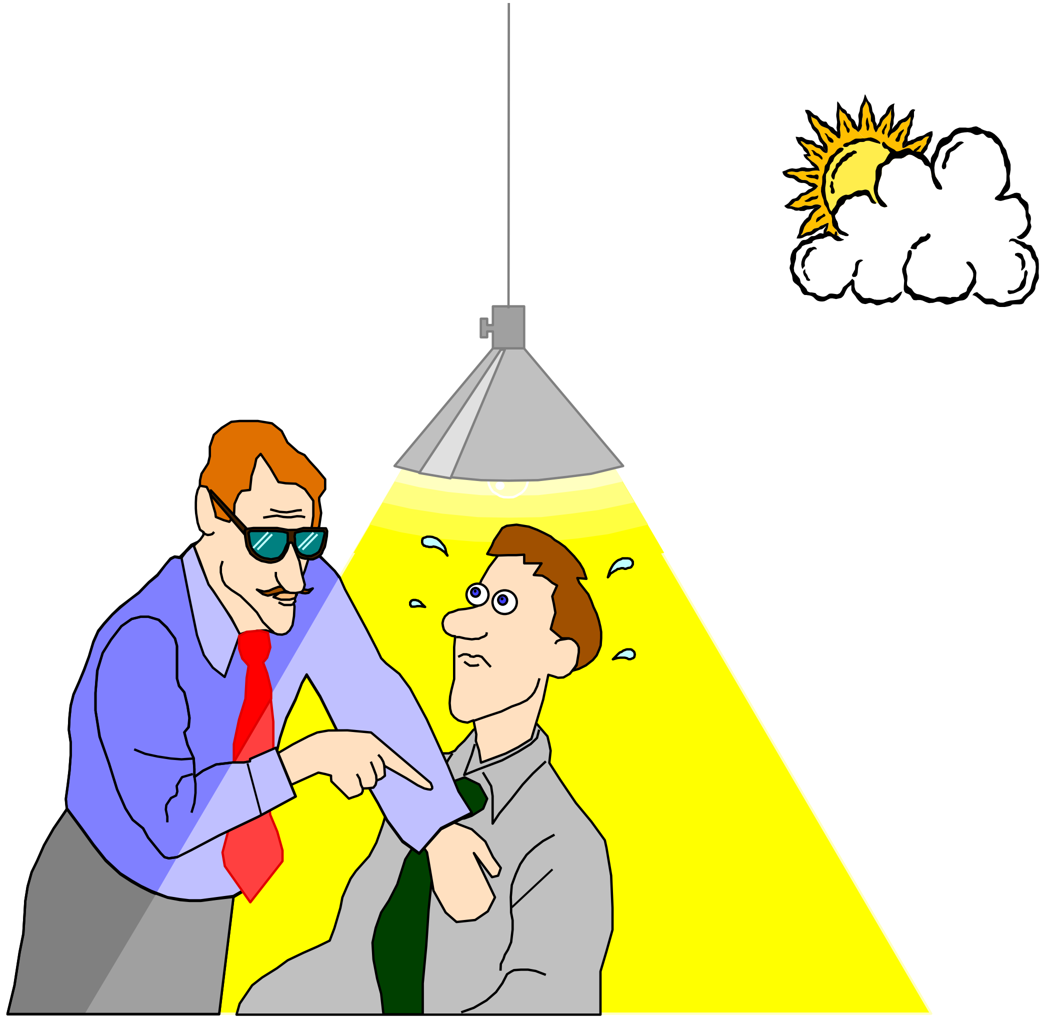




QUESTIONS !!

Yes ……. I have two hands





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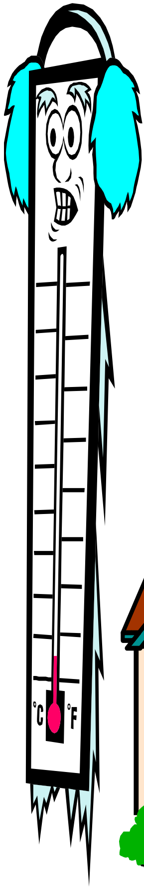

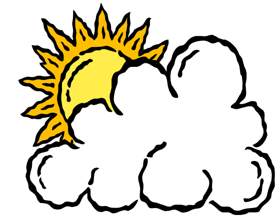

Thank you for your attention