Case Study: CFD Application for Building Evaluation

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***Abstract* – From Uphaar Fire Tragedy to recent Mumbai Secretariat Fire accident shows how Vulnerable are Old Constructions, while new one are well designed with Necessary Fire Protection Systems. It is well known fact many of Old Structures in India doesn't have basic Fire Protection systems such as F.E. This paper is intended to study one of such old Constructions, a college Auditorium and Evaluate risk on loss of Life due to Suffocation and Thermal Injuries using Simulation**

Keywords – Cell Size- Dimensions of cell; Grid Size:-Total number of cells within grids; KS-Thermal conductivity; Navier-Stokes Equations- Governing equations for particle flow in FDS; Smoke view-Visualization of FDS prediction; Ct- Critical Time; Rt –Reaction Time; S: Relative Visibility (m); ASET- Available Safe Egress Time; SFPE- Society of Fire Protection Engineers

INTRODUCTION

The construction of smoke hazard management systems in large buildings such as Auditoriums, shopping malls, cinemas, airports and train stations are increasingly performance based design. These systems are designed by fire protection engineers using design guides and computer modeling techniques such as Computational Fluid Dynamics (CFD) that have become more accepted among Fire Protection Engineers.

Importance of Smoke Exhaust System:

According to NCBI USA, In 169 consecutive cases of autopsied fire victims about 50% had lethal levels of carboxyhemoglobin. Soot in the respiratory tract was found in about 90% of the cases.

50-55C about few seconds is sufficient to Produce Burns.

Case Study:

Building Type: Collage Auditorium

Dimensions: 95'x75'

Area: 7030Sqft

Year of Construction: 1997

Typical Usage: Intended to use for both College and Private Meetings/Seminars/Workshops

Location: Ground Floor, Vidya Bhavan Junior& Degree College Vijayawada

Capacity:

Sitting	Stage
533	8
Total:541	

No. of Exit Doors: 3

Door Dimension: 5 Feet

Type of Ventilation System:

- 1-5 Rows, Stage: Cassette A.C
- Other Rows: Wall Mounted Side-stand Fan

Type of Exhaust System: 4 Mechanical Exhaust Fans

Separate Emergency Power for Exhaust Fans at time of Fire: Absent

Fire Protection Systems:

- Sprinklers: Absent
- F.E: Absent
- Emergency Lights: Absent
- Smoke& Fire Detectors: Absent
- Hose Reels: Absent
- Standard Smoke Exhaust System: Absent

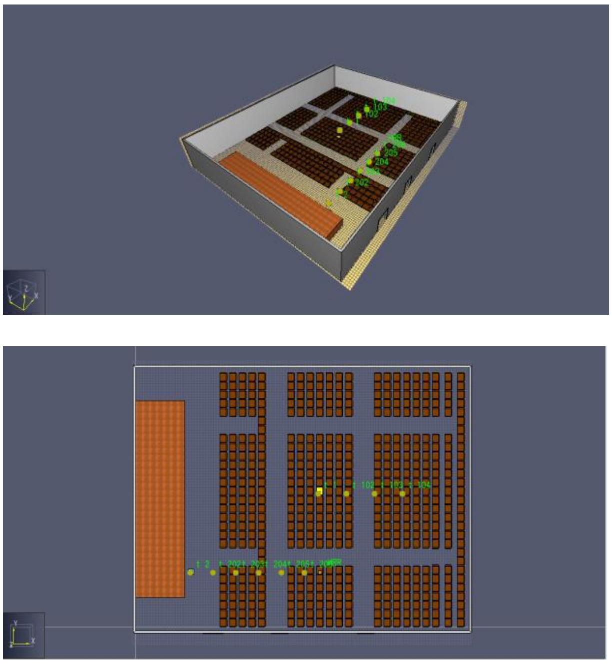


Fig. 1 (a): 3D View , Fig. 2(b) : Plan Typical Computer model of Auditorium

Tools used:

1. *FDS (Fire Scenario)*

CFD techniques have been used in engineering analysis of the ventilation system in the fire scenario for many years. Computer modeling for smoke control in buildings was proposed in 1980s, and then took centre stage in fire safety design with the fast development of computer science. FDS is a powerful CFD model of fire driven fluid flow developed by NIST, which has been applied widely in solving practical fire problems in fire protection engineering. It solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. FDS provides a more rigorous, three-dimensional treatment where the underlying conservation equations are solved in a numerical grid containing typically tens or hundreds of thousands of points. Incorporating with a simplified pyrolysis model, large eddy simulation turbulence model, mixture fraction combustion model, and finite-volume radiative heat transfer model, FDS can describe fires in complex geometries, and the incorporation of a wide variety of physical phenomena. The advanced model interface, a solution ‘picture ‘comprising temperatures, smoke concentrations, air velocities, etc. at each grid point, allows the engineer or designer to assess in detail the interaction of fire and smoke with building designs and smoke control systems of arbitrary complexity, and to study the implications for means of escape. It is a valuable tool that can be very useful in designing and analyzing smoke management systems.

FDS can be divided into the following categories:

- Comparison with full-scale tests conducted specifically for the code evaluation.
- Comparison with engineering correlations.
- Comparison with previously published full-scale test data.
- Comparison with standard test.
- Comparison with documented fire experience.

2. *Path-Finder (Evacuation):*

Modeling method: Movement model

Structure of model: This is a fine network system. The model provides a simulation of the evacuation to visually present the location of the occupants as a function of time.

Perspective of model and occupant: The model views the occupants as individuals. The model has the capability of tracking individuals’ movements and positions throughout the simulation. The model views the population through a global view only to assess the density of certain areas of the building. The occupants, on the other hand, have a global view of the building because of their route choices. They can choose the shortest route to the exit or the shortest cue route.

Occupant behavior: No behavior.

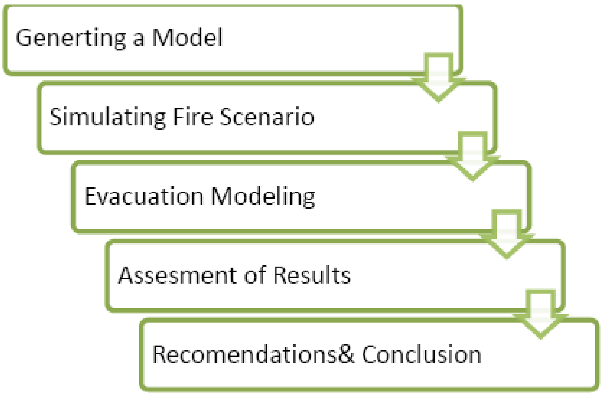
Occupant movement: The occupants move toward the exits under the constraints of the SFPE Handbook1, which incorporates speed reductions based on the density of the space and the capacity of the doors and stairways. The primary areas of analysis focus on movement in open spaces, on stairways, and through doorways. The user specifies initial occupant loading by specifying the density in certain areas (by noting the occupancy of the room) or by giving discrete number of occupants.

Parameters for Performance Assessment:

- Temperature and visibility are two critical criteria for tenability analysis for performance based assessments
- “Ct ” is time from start of Fire to the attainment of intolerable Levels
- “Rt” time used by the occupant to react to the fire and reach safely by either evacuating the area or establishing area of refugee

- Ct, Rt is used to create ASET Model such that Ct<Rt

Methodology:



Flow chart of Evaluation Process

STEP I: Generating Model

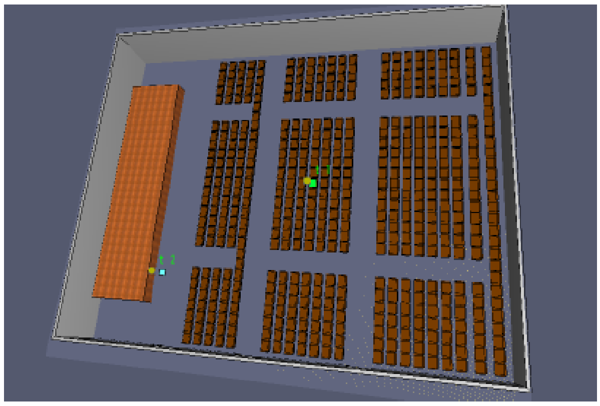
- A Geometry Model is created with Dimensions of 94'X75'X15'
- Seats are generated with 2.6' X1.75' including Dimensions
- 3Doors are created on wall with 5'X6' dimension
- Materials assigned with their respective NIST mentioned Fire Properties :

TABLE 1

Walls	Concrete
Chair Base	Gypsum
Cushion	California Foam
Floor	Yellow Pine
Stage	Wood

Materials used for various components

- Burner is created is 1000W to Ignite Chair
- Another small Burner is placed near stage to make Fire Complex
- Uniform Cube Meshing is done to Geometrical Model
- Each cell dimension in mesh 0.16'X0.16'X0.16'
- No. of Cells in Mesh 28,067,400
- According to NIST this Mesh is enough for Mid Level accuracy , taking much less Cell dimension can make complex and 8-10 hours to simulate , thus time factor is considered
- Type of Reaction Polyurethane
- Temperature and Visibility is created in Z-axis at 5'-10'' level a mean Height of Indian to note down recordings
- Thermocouples are arranged at various location in Auditorium
- Enthalpy (H) Slice is created in Y-Axis across Burner to note down Energy release Rate



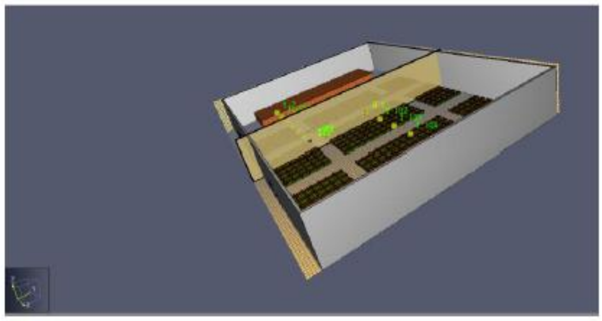


Fig. 3 (a) : A Green Color denotes Burner, where as yellow dot denotes Thermocouple, Fig. 4 (b) : Geometrical Model with Enthalpy (H) slice across Burner

STEP II: Simulating a Fire Scenario

- The pre-processing of Model is done in step I and ready for the Simulation

Fire is Generated in 8th ROW, Middle Column , 9th Seat

Parameters of Solver

- The simulation type applied Large Eddy Simulation (LES) Model.
- Smoke Quantity: Soot Mass Fraction
- Radiation Transport solver Enabled

Initial Environment of Auditorium

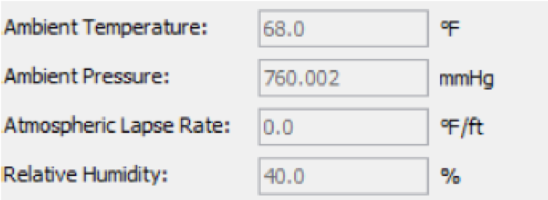


Fig. 5 : Initial Environmental Conditions

Assumptions:

- No External Wind Effect as the Auditorium is inside a Building
- The Mechanical Exhaust Fans will be switched off as soon Fire is detected as the Main & Emergency is same connection for Exhaust Fan and other Electrical Devices

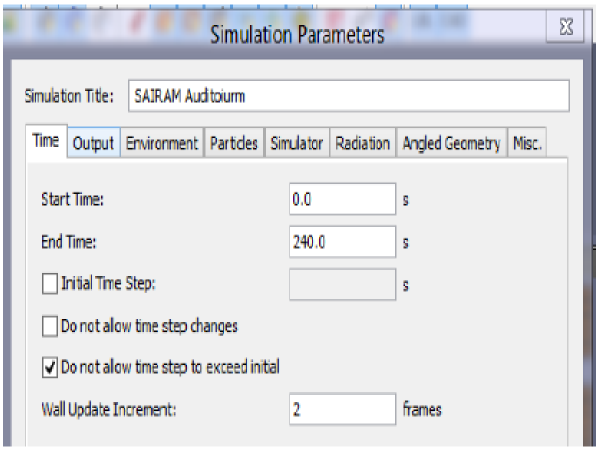


Fig. 6 : Simulation parameter Tool Box, Time of Simulation 0-240Seconds

Results:

a) Temperature

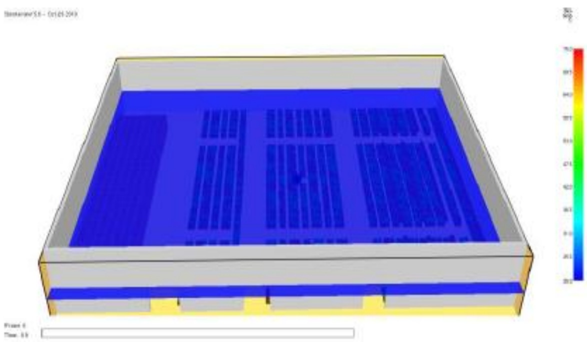


Fig. 7 : Temperature at T- 0 Seconds

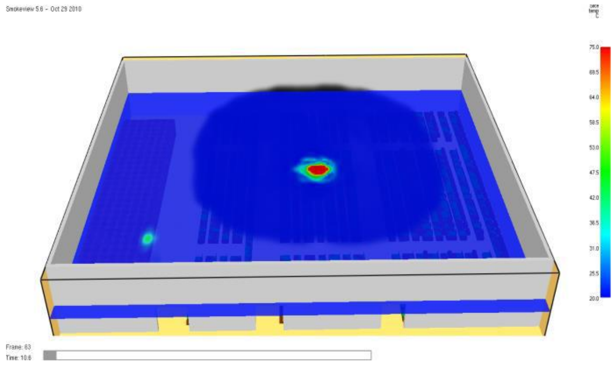


Fig. 8 : Temperature at T- 10 Seconds

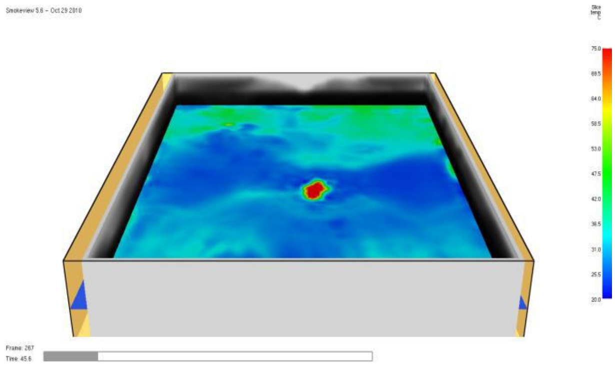


Fig.9 : Temperature at T- 45 Seconds

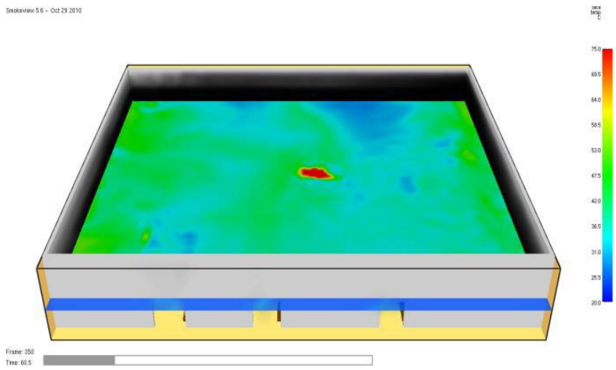


Fig. 10 : Temperature at T- 60Seconds

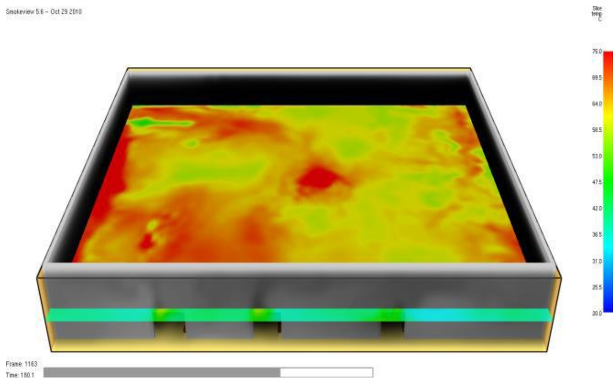


Fig. 11 : Temperature at T -180.7 Seconds

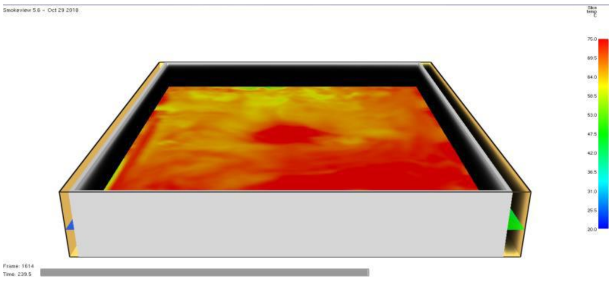


Fig. 12 : Temperature at T-240 Seconds

b) Visibility

The Soot Visibility is defined as the distance a person can see at the time of Fire inside a Room, The visibility distance is calculated by FDS by the

$$S = C / (Km * rho * Soot) \text{ [in meter]}$$

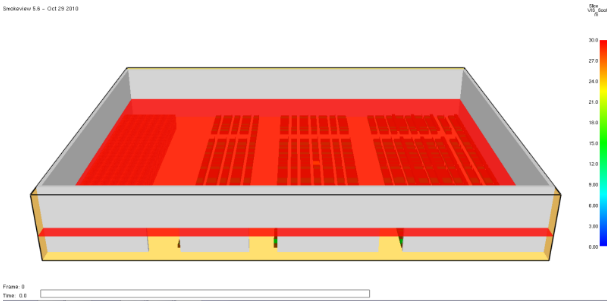


Fig. 13 : Visibility at T-0 Seconds

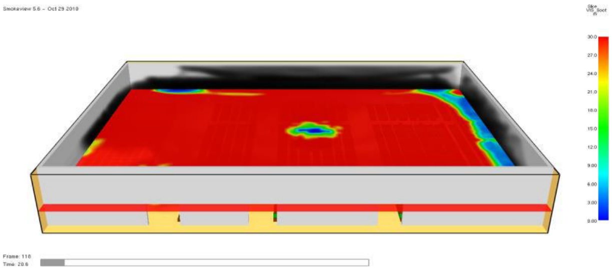


Fig.14 : Visibility at T-20 Seconds

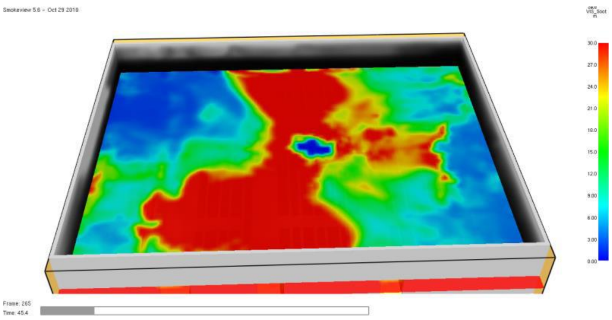


Fig.15 : Visibility at T-45 Seconds

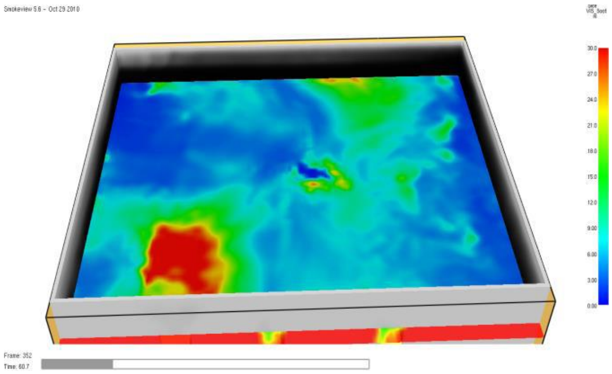


Fig. 15 : Visibility at T- 60 Seconds

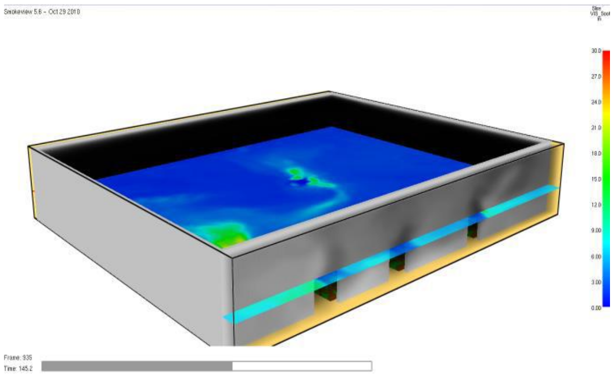


Fig. 16 : Visibility at T-145 Seconds

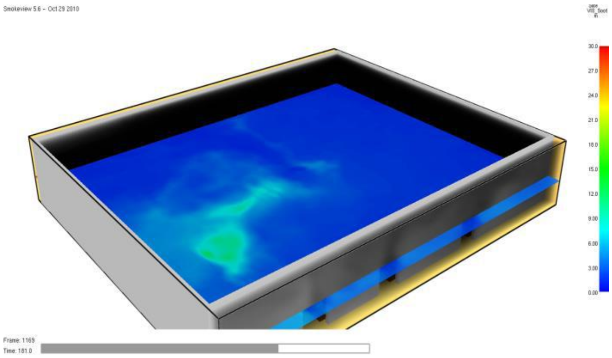


Fig. 17 : Visibility at T-180.7 Seconds

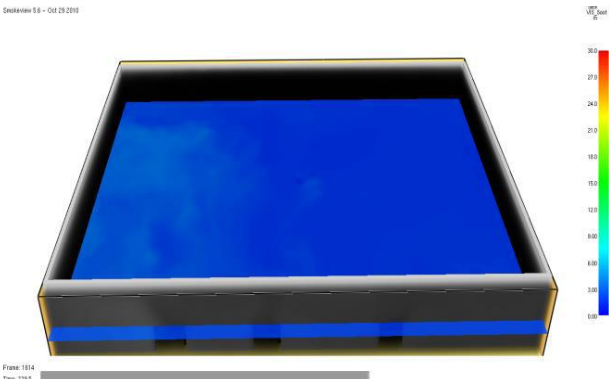


Fig. 18 : Visibility at T- 240 Seconds

c) Specific Enthalpy

Specific Enthalpy (h) of a working Fluid is property which is defined as:

h = U +PV

U-Specific Internal Energy

P- Pressure

V- Specific Volume

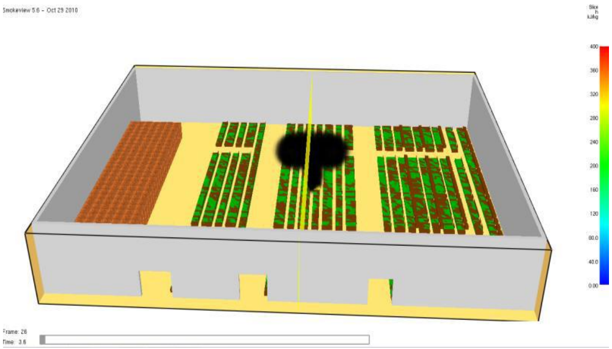


Fig. 19 : Specific Enthalpy h T- 0 Seconds

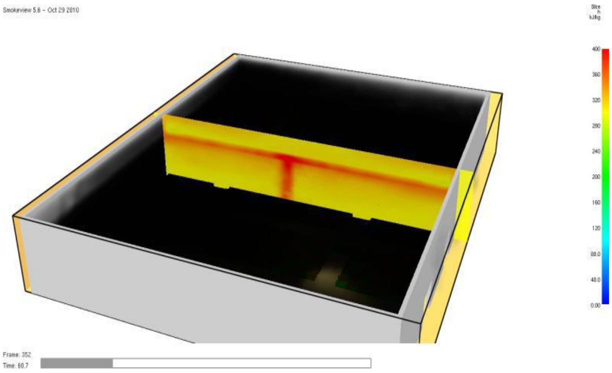


Fig. 20 : Specific Enthalpy h T- 60 Seconds

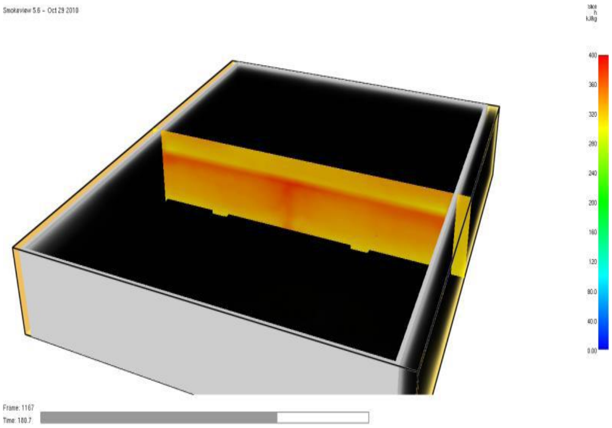


Fig. 21: Specific Enthalpy at T-180.7 Seconds

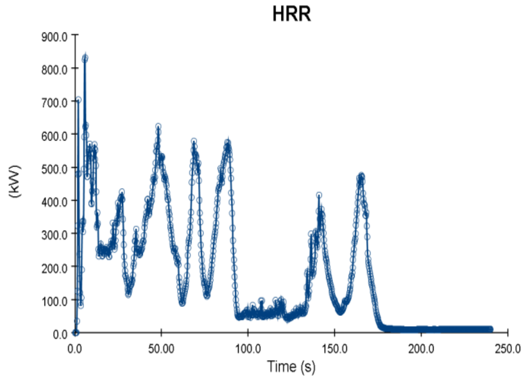


Fig. 22 : Heat Release Rate (HRR) over the time

STEP III: Evacuation Modeling

Evacuation calculations are increasingly becoming a part of performance-based analyses to assess the level of life safety provided in buildings.

- From SFPE Handbook, NFPA 101 and Boycet Research on Disabled People the Speed of People is Considered as-

TABLE 2

TYPE	Speed
Adult Male	1.3M/S
Adult Female	1.25M/S
Children	0.9 M/S
Elderly People	0.8 M/S
Physically Disabled	1.0 M/S

Standard velocities for Various age groups

- Density of different section of People is Considered on Demography and Survey Done on occupation of Auditorium

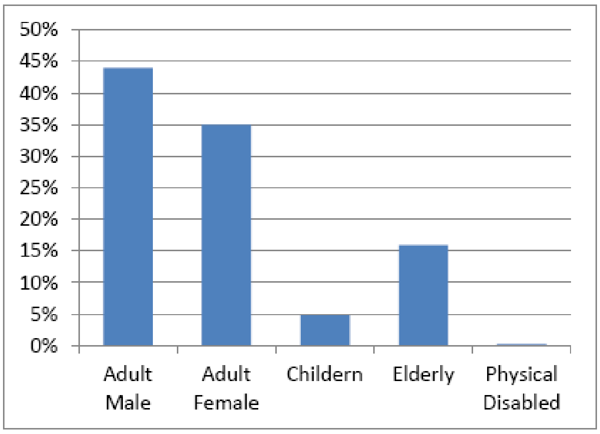
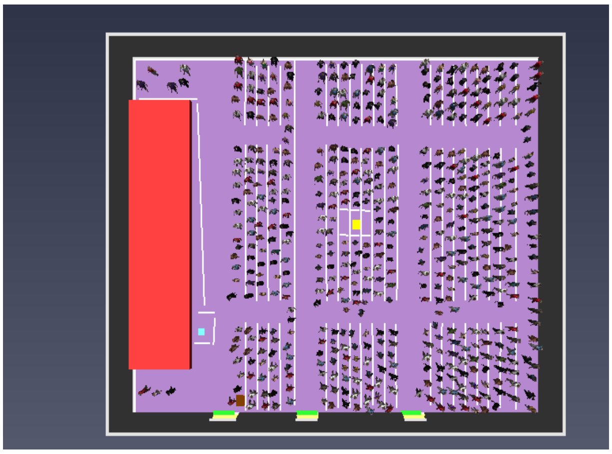


Fig. 23 : Assumed Occupation Density of Auditorium (Disabled Persons 0.20% is Considered)

Assumptions-

- 35 Seconds Delay time in Identifying the Fire
- 35 Seconds in cover-up delay of Stress and other Human Behavioral Aspects of occupants

Model created



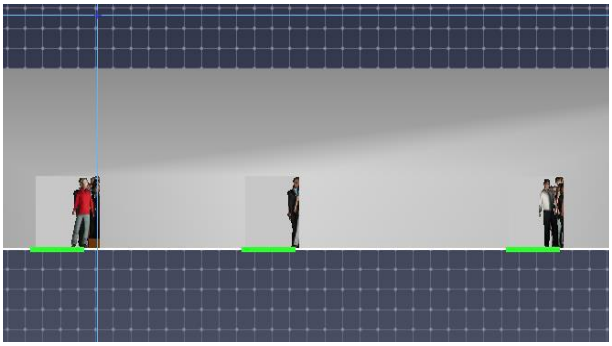


Fig. 24 (a) : Plan, Fig. 25 (b) : Front Elevation of Geometrical Model

Simulation Parameters:

I. SFPE Behavior Mode

II. Basic Collisions are Considered

III. Occupant Parameters

☑ Height:	6.0 ft
☑ Reduction Factor:	0.7
☑ Comfort Distance:	1.0 ft
☑ Persist Time:	1.0 s
☑ Collision Response Time:	1.5 s
☑ Slow Factor:	0.1

Fig. 26 : Human Parameters

Evacuation Simulation Results:

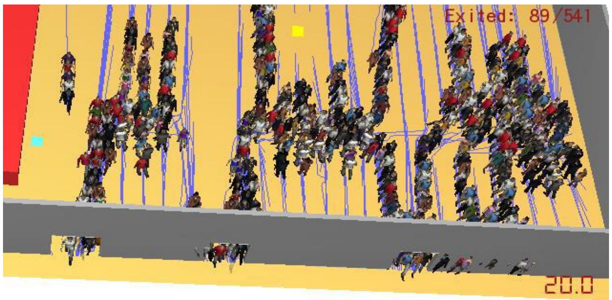


Fig. 27 : T- 20 Seconds; 89 Exited

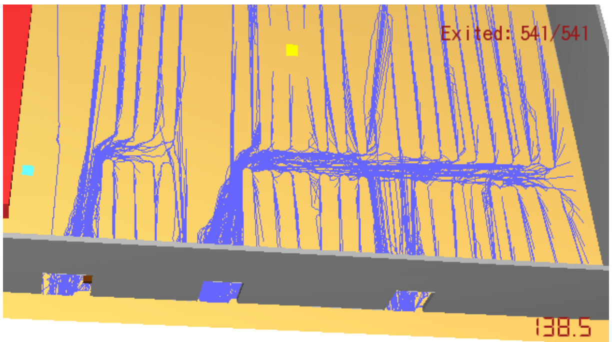


Fig. 28 : T- 139 Seconds; 541 Exited

Thus total time for Evacuation considering Initial Delay and Human Behavioral Aspects is

Rt = 208.5 Seconds

STEP IV: Assessment of Results

- From Evacuation simulation the Time taken by Occupants to a Safe Environment Rt is calculated as 209.5 Seconds
- From Fire& Smoke Simulation the time taken to attain Unbearable Temperature is (i.e. is 55C) 180 Seconds
- From Fire & Smoke Simulation, Time taken to blind the Visibility and Suffocate them by Soot is 120 Seconds
- Thus on Mean , the Critical time to attain unbearable smoke and Temperature is 150 Seconds
- Thus ASET= Ct – Rt:

  ASET = 150- 208.5 Seconds

  Extra time needed for ASET= - 58.5Seconds

It had been calculated that People cannot escape safely from Auditorium at the event of Fire accident from Auditorium in given Critical Time and there is huge chances losing People Life.

Recommendations:

- Fire rated Furniture should be Used
- A Enhanced New Smoke Exhaust system with Separate Power should be Installed Immediately
- Fire Extinguishers and Smoke Detectors are placed at important points in Auditorium
- Emergency and Radium Coated Signage should be Installed
- PA address system should installed to alert the Occupants as soon as Fire is discovered alerting People in 3 languages as many Deaths and slowing of Evacuation is caused by Irreverent Behavior of Crowd and Stampede in Process of Evacuation
- Mock Drills should be Conducted to limit the Panic
- It may be good , If few seats are reserved to Physically Disabled People near Exit Doors in Auditoriums and Theatres
- Proper maintenance should be done and make sure no Combustible waste Materials should not accumulate

CONCLUSION

This Case Study shows how Vulnerable and Death Spots are our Buildings. This is not only confined to Old Constructions but even to New Constructions. The most important thing discovered is even a small Errors liking Locking the Doors, Fixed Ventilators, Improper Operation & Maintenance causing Fire accidents. It is time to Replace Generative design of Buildings with Performative Generative Designs or more advanced one like Integrated Designs. The Simulation programme's likes Energy Plus, COMFEMN, CONTAM, FDS, EXIT89, Radiance, ANSYS, ODEAN BEES and other simulation tools should be used right from Initial stage to save Life, Property, Energy in an Environmentally and Financially Viable way. The government should make mandatory on performance based design codes

REFERENCES

[1] NFPA 92B, Guide for smoke management systems in malls, atria, and large areas, NFPA (1995).

[2] CIBSE, Relationships for smoke control calculations, TM 19, Chartered Institution of Building Services Engineers, London (1999).

[3] D.A. Purser, Toxicity assessment of combustion products, In: P.J. DiNenno (editor), SFPE Handbook of Fire Protection Engineering, 2nd edition, NFPA (1995).

[4] J.H. Klote and J.A. Milke, Design of smoke management systems, American Society of Heating, Refrigerating and Air-Conditioning Engineers (1992)

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