Fire Safety Analysis and Design of Building Structures Using PyroSim

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Abstract
The study comprises two distinct fire compartments: Condition 1, featuring a well-ventilated bedroom, and Condition 2, characterized by a bedroom lacking ventilation, though with the door kept open throughout the simulation. PyroSim software is utilized for analyzing temperature variation, smoke height, and heat flux. The simulated duration for the ventilated compartment spans 100 hours, 22 minutes, and 28 seconds, while the unventilated compartment endures for 87 hours, 47 minutes, and 50 seconds. In both conditions, bedroom temperatures exhibit dynamic changes from the initial stages. Notably, during the mid and final phases, Condition 1 consistently registers temperatures approximately 50°C higher than those observed in Condition 2. Smoke dispersion patterns also diverge between the two conditions. In Condition 1, smoke height in spaces such as the staircase, living room, and at the main door rapidly decreases from 30 meters to less than 1 meter within 100 seconds. Conversely, in Condition 2, this reduction occurs over a prolonged period, taking approximately 200 seconds. Regarding heat flux, a stable rate is maintained up to the initial 100 seconds in both conditions. Subsequently, in the unventilated compartment, the heat flux escalates rapidly, reaching 90 kW/sqm. In contrast, in Condition 1, while the acceleration is slower initially, surpassing Condition 2 after 660 seconds, the flow of heat flux ultimately exceeds that of Condition 2 in which the heat energy released in the compartment with well ventilation is higher than the compartment with no ventilation.

Key words: PyroSim, Temperature, Smoke Height, Heat flux, Ventilation.

1. Introduction
The purpose of safety analysis and design of building structures is to protect lives and property from the destructive force of fires in purpose-built environments. Among the various fires, fires in buildings, known as construction fires, present significant challenges due to their frequency and potential for extensive damage. However, conducting real-world fire tests involves inherent risks and significant costs. Impractical for extensive research and analysis. As a result, researchers have turned to computer simulations as a valuable alternative. Advanced tools such as PyroSim allow them to reproduce fire scenarios in different building layouts and environments, allowing detailed analysis of key parameters such as temperature variations, smoke distribution and visibility levels. Recent studies have applied this. Information simulation techniques to study fire dynamics in various environments, from tall buildings to cinemas, subway stations and restaurants. By examining factors such as evacuation times, the

effectiveness of fire safety devices and the effect of building layout on the spread of fire, researchers try to identify vulnerabilities and improve safety measures. Synthesizing the knowledge gained from these studies, this article. Aims to provide a summary of recent advances in fire safety analysis and building design. By highlighting emerging trends, methods and best practices, it aims to promote ongoing efforts to improve fire safety protocols and reduce potential fire hazards in built environments

2. Methodology

The floor plan consist of the fire simulation bedroom is 6.03 x 6.18 x 2.9 meters, having bed area of 3.45sqm. The door (d2) is 900 x 2100 mm, while the window measures 2100 x 1800 mm, standing 600 mm above the floor. The major furniture in the room is the bed, closet, and light stand table. The bed measures 1.77x 2.0 m in dimension and 0.45 m in height. There are multiple furniture on sets and a mattress covering the bed. The 4 wardrobe measures 0.5 x 1.1 m in length and 1.9 m in height. Two 0.32x0.4x0.5m bedside light tables are also present. In Figure 1, the floor plan is displayed in 3D.

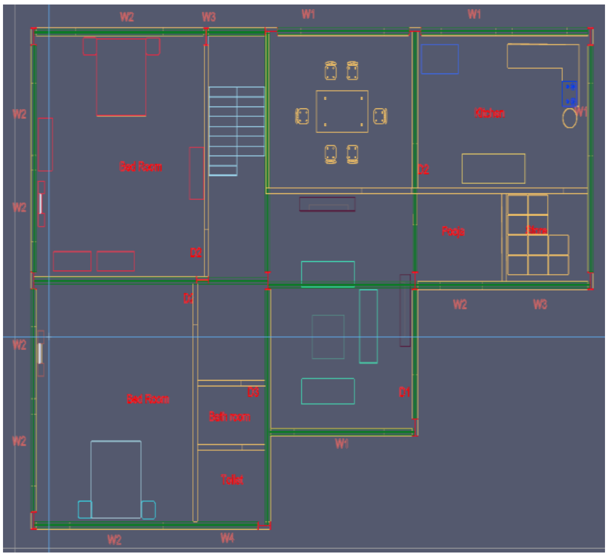

Figure 2.1: Floor Plan

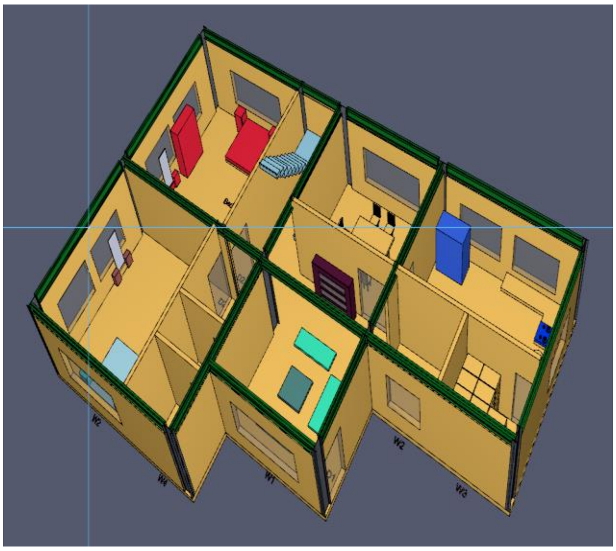

Figure 2.2: 3D floor plan view

2.1. Fire scene setting

In this study, a basic separate room is simulated, with the bed and its clothes-filled wardrobe serving as the primary sources of fuel i.e. fuel Oak reaction and polyurethane reaction is shown in the above fig2.2 in the three dimensional view. The room's wall is 240 mm thick, with 20 mm of cement mortar applied to the surface. There are layers to the substance. The wood used to make the wardrobe, bedside cabinet, and bed body has a density of 570 kg/m3 and a heat of reaction of 430 kJ/kg. The bed body has a Layered mattress and bedding, with a 2 mm thick fabric layer on top and a 100 mm thick foam layer underneath. When dividing the grid, the cell size adhering to the modulus of 2U, 3V, and 5W, and U, V, and W must all be integers, per the specifications of the pyrosim software. Therefore, the simulated object mesh is divided into X * Y * Z corresponding to 110*70*25, with each little square being a parallelepiped of 0.2m, in order to achieve the best simulation accuracy.

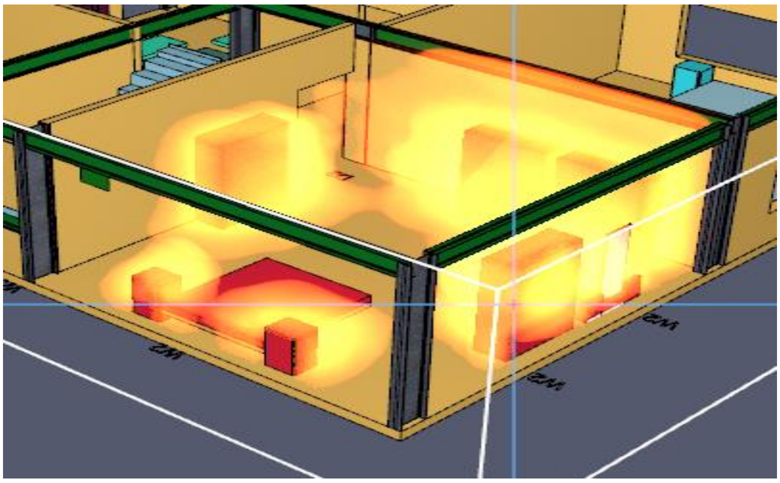

Figure 3.1: Flashover Fire

2.2 Fire conditions

In the current project fire is set to two conditions as given in the below table.

Table 2.1: description of fire conditions

Working conditions type	Description
Condition 1	Windows are kept opened
Condition 2	No windows are provided

The simulation is run based on the two condition, where condition one is fire compartment with the well ventilation with the open door as shown in the below figure. The simulation progress time is set to 1200 second, simulation time Elapsed: 100hr: 22min: 28sec.

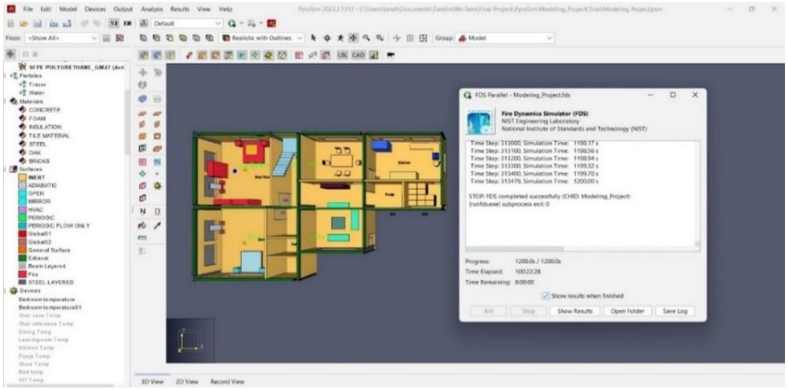

Figure 2.3: Condition 1 simulation

And condition two is fire compartment without ventilation with the open door as shown in the above figure. The simulation progress time is set to 1200 second, simulation time Elapsed; 87:47:50.

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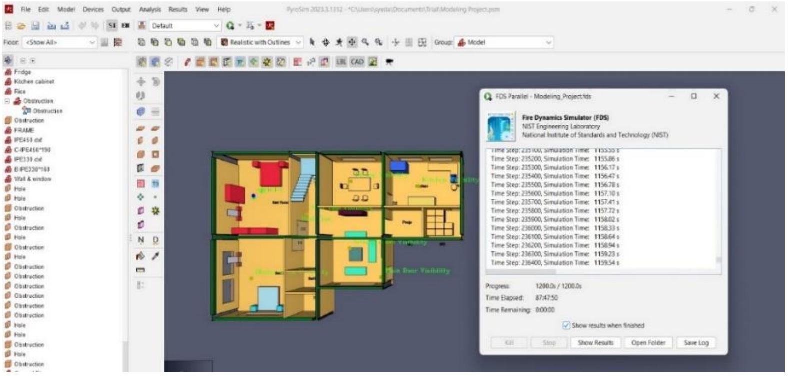

Figure 2.4: Condition 2 simulation

And condition two is fire compartment without ventilation with the open door as shown in the above figure. The simulation progress time is set to 1200 second, simulation time Elapsed is 87hr: 47min: 50sec. The simulation time for condition 2 is 13hr: 34min: 38sec less than condition 1.

3. Results and Discussion

- Smoke visibility, temperature, carbon dioxide levels, heat flux, and visibility are calculated within the software using dedicated devices. These parameters can be visualized through 2D and 3D slices, allowing for precise analysis of temperature distribution over time.
- Temperature devices are strategically placed in specific areas like bedrooms, master bedrooms, staircases, dining areas, kitchens, and living rooms to monitor temperature fluctuations. However, for assessing smoke visibility, 3D Slices are employed within individual rooms, providing comprehensive insights into visibility patterns.
- Devices such as temperature, soot visibility and heat flux are used to measure the quantities of temperature in (°C), smoke in meter and heat flux in KW/sqm.

3.1 Temperature device

The temperature records in the bedroom is given in the below table 2.

Table 3.1: bedroom temperature

Time (s)	Condition 1(°C)	Condition 2(°C)
0.00	20.00	20.00
50.40	26.81	26.89
100.80	36.74	90.10
150.00	74.92	134.99
200.40	135.60	194.08
250.80	210.58	238.74
300.00	303.32	252.42
350.40	416.07	265.85
400.80	412.18	265.51
450.00	518.17	323.41
500.40	525.47	312.81
550.80	528.67	438.66
600.00	521.87	457.93
650.40	537.73	492.21
700.80	507.00	494.17

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750.00	544.72	488.22
800.40	536.96	511.29
850.80	519.74	475.27
900.00	556.70	492.81
950.40	533.91	465.16
1000.80	532.31	432.87
1050.00	534.16	488.95
1101.60	560.13	493.84
1150.80	539.66	457.78
1200.00	552.86	456.84

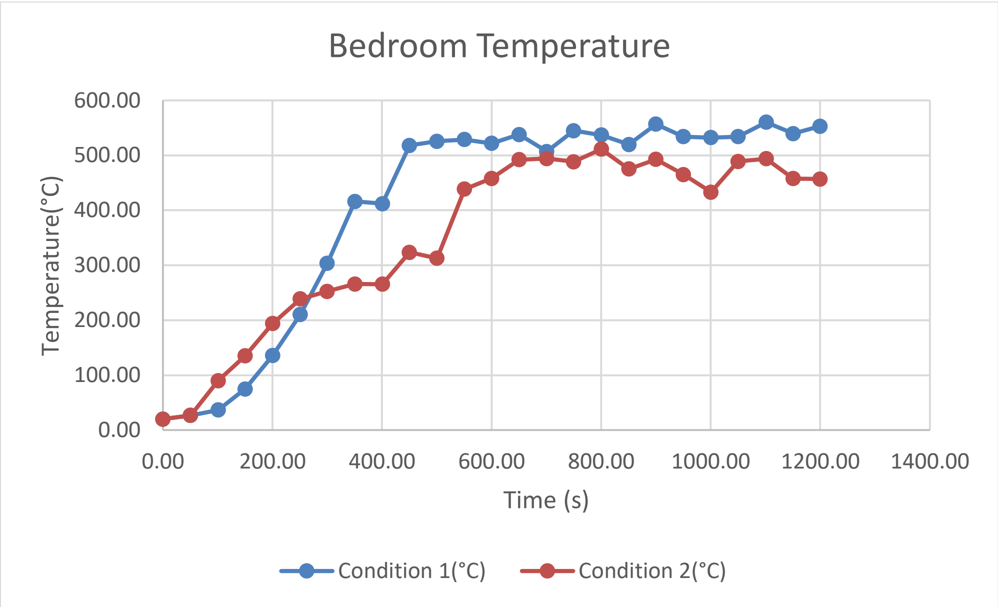

Figure 3.1: Bedroom temperature graph

- Based on the provided graph, the maximum temperature difference observed between bedrooms is 48.8°C. Specifically, the bedroom with adequate ventilation reached a temperature of 560.13°C.
- While the bedroom lacking ventilation recorded a temperature of 511.3°C. Notably, it's worth mentioning that despite the absence of ventilation, the door to the poorly ventilated bedroom and well ventilated room remained constant temperature after the 660 seconds, where condition 1 temperature is in range between the 500°C – 600°C and 400°C – 510°C for condition 2.

3.2 Soot visibility

- In the event of a fire within a building, ensuring clear visibility through the absence of soot is vital for guiding occupants to safety. Soot visibility is commonly assessed in meters, with optimal evacuation conditions achieved when visibility extends to a considerable distance without obstruction by soot particles.
- The following graph provides a comparative analysis of soot visibility under two distinct conditions, focusing particularly on the staircase, living room, and main door Areas, as these are crucial for identifying the safest evacuation route. At time 0 seconds, both conditions start with a visibility measurement of 30 meters.

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- As time advances, Condition 1 remains relatively stable at this initial visibility level. However, around 150 seconds, we observe a significant drop in visibility for Condition 1, reaching a reading of only 0.14 meters. Beyond that point, Condition 1 continues to decrease gradually, eventually stabilizing at a range just above zero (around 0.05 meters) from the time marked as 200 seconds and onwards. Condition 2 starts at 30 meters visibility, however it Condition 2 experiences a more rapid decline. By 101 seconds, it drops significantly to 0.92 meters. From the 200 seconds mark onwards, Condition 2 maintains a visibility range of approximately 0.04-0.06 meters. Interestingly, Condition 2 stabilizes much earlier than Condition 1, settling into this low visibility range as depicted by the below figure 3.3.

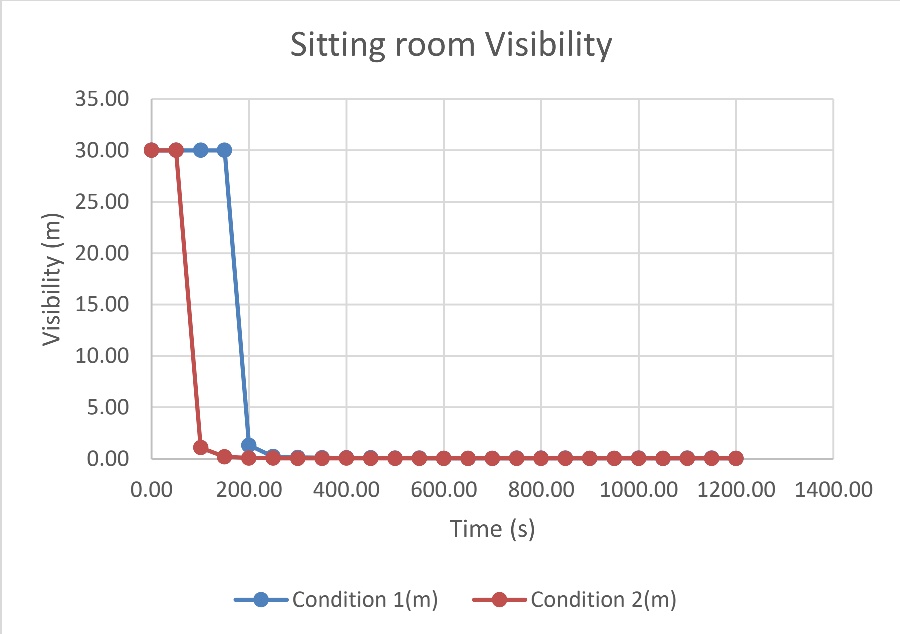

Figure 3.2: Main door Soot Visibility

3.3 Heat flux

Heat flux is define as the rate of heat transfer per unit surface area. It determines the quantity of heat energy generated through a surfaces such mattress and wood cupboard, usually measured in kilowatts per square meter (KW/m^2). Heat flow is an important parameter in fire simulations because it helps to estimate the intensity of exposure to ambient heat. Surfaces Understanding the distribution of heat flow in a room can help make decisions related to fire protection measures, material selection and assessment of structural integrity.

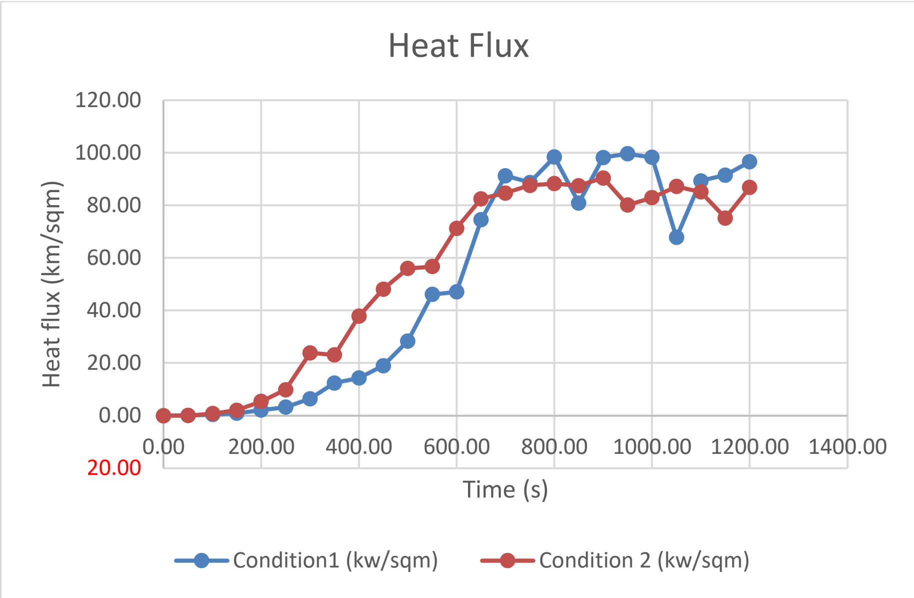

Figure 3.3: Heat flux

The heat flux under two different conditions with respect to the recorded time. Here's a more detailed, the first column represents the elapsed time in seconds. It starts at 0.00 seconds and progresses in increments. Condition 1 (kw/sqm): At time 0 seconds, both conditions start with a heat flux measurement of 0.00 kw/sqm. As time advances, Condition 1 experiences an increase in heat flux. By 200 seconds, it reaches a peak value of 2.09 kw/sqm. From there, it continues to increase gradually, reaching 98.40 kw/sqm by 800 seconds. The heat flux values under Condition 1 represent the amount of heat energy transferred per square meter per second. Condition 2 (kw/sqm): Like Condition 1, Condition 2 starts at 0.00 kw/sqm. However, Condition 2 experiences a more rapid increase in heat flux. By 200 seconds, it reaches a significantly higher value of 5.38 kw/sqm. From there, it continues to increase rapidly, peaking at 98.30 kw/sqm by 1000 seconds. The heat flux values under Condition 2 indicate even higher heat transfer rates compared to Condition 1. In summary, both conditions exhibit increasing heat flux over time, with Condition 2 consistently having higher values.

4. Conclusion

In conclusion, the temperature in the bedroom is higher in the condition 1 than the condition 2 where the maximum temperature difference is 48.8°C in bedroom compartment, but the temperature in other space such as stair case, living room, master bedroom, dining and kitchen is higher in condition 2 than the condition 1. The overall maximum temperature generated is 560.13° which is in bedroom compartment after simulating for 20 minutes. Primarily the soot visibility is focused in specific area such as stair case, living room and main door with respect to the time, solely purpose for estimating optimum time for occupants rescue operation from the fire compartments where soot results shows there is rapid decline of visibility in distance from human eye contact, i.e. from 30 meters – 0.04 meters before 200 seconds creating difficult environment for rescue operation. Both the conditions generate the different heat flux in which condition 1 possess heat flux of 99.6 KW/sqm at 950 seconds and condition 2 gives heat flux of 90.4 KW/sqm at 900 seconds. From the initial period to 650 seconds heat flux in condition 2 dominant the heat flux produced in condition 1 and from the figure 3.3 and it is observed that after 650 seconds the heat flux for the conditions lies between the 80 KW/sqm – 100 KW/sqm.

Reference

1. Wang L.Y. (2015) Experimental Research and Numerical Simulation of Conflagration Inoor. Shandong University of Science and Technology
2. Cui T.J., Ma Y.D. (2013) Fire Simulation and Evacuation Plan of Construction Subway Station Based on FDS. Journal of Natural Disasters, 22: 178.
3. Liu X., Cai Z.Y., Ma S.J., et al. (2019) Research on Numerical Simulation of High-rise Building Fire Based on FDS. Value Engineering, 38: 131-133.
4. Glasa J., Valasek L., Weisenpacher P., et al. (2013) Cinema fire modelling by FDS, 410: 12013-12016 .
5. Long X.F., Zhang X.Q., Lou B. (2017) Fire Simulation Analysis of Dormitory Building Based on Pyrosim. Journal of Safety and Environment, 17: 1348-1353.
6. Fu Y.G., Dong H.R. (2019) Research on Fire Simulation of Basic Model Based on FDS. Construction Technology, 50: 369-371.
7. Gong Z.C., Zheng Z.Q. (2019) Research on Fire Numerical Simulation of a Hot Pot Restaurant Based on FDS. China Water Transport (second half of the month),19: 87-88.
8. He M.L., Liu J., Zhao H. (2015) Research on Fire Simulation of Tenglong Apartment. Journal of Hubei Institute of Technology, 31: 12-16.
9. Wang P.F. (2018) Research on Fire Simulation and Risk Prediction of Brick-wooden Ancient Buildings (groups). Changan University.
10. cgrattan K., Hostikka S., Mcdermott R., et al. (2013) Fire Dynamics Simulator, User's Guide. Nist Special Publication.
11. Yang J., Pan X.H., Wang Z.L., et al. (2018) Numerical study on the smoke flow characterization and phenomenon of plug - holing under lateral smoke exhaust in tunnel fire. Journal of AppliedFluid Mechanics, 11: 115-126 .