Assessment on Fire Safety Condition and Modeling on Fire Performance and Escape Route Based on PyroSIM and Pathfinder: A Study on IUT Academic Building

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APPROVAL

This is to certify that the dissertation entitled “**Assessment on Fire Safety Condition and Modelling on Fire Performance and Escape Route Based on PyroSIM and Pathfinder: A Study on IUT Academic Building”**, by Ishmam Husain, Rukaiya Islam, Ashfaqur Rahman Rifat and Samin Rafin Haq has been approved fulfilling the requirements for the Bachelor of Science Degree in Civil & Environmental Engineering.

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DECLARATION

We declare that the undergraduate research work reported in this thesis has been performed by us under the adept supervision of Ijaj Mahmud Chowdhury. We have taken appropriate precautions to ensure that the work is original. We can corroborate that the work has not been plagiarized. We can also make sure that the work has not been published for any other purpose (except for publication).

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DEDICATION

We commit this research proposition to our parents, who for a long time dedicated their significant time, job and exertion to guarantee that we could be who we are today. They persuaded and upheld us to follow our enthusiasm of designing while never thinking back. Our folks have instructed us that persistence is one of the vital characteristics to make progress throughout everyday life. We will always be obliged to them.

Abstract

In recent times fire incidents are one of the major hazards in our country which was happening because of some lacking of awareness on fire safety management, reluctant behavior in building safety codes or guidelines, and inadequate fire extinguishers. Recently back-to-back fire-related accidents also give us a wave of awareness for the safety of our future generations, respective teachers, and staffs who may spend their half of time in educational institutions. So, the safety of educational institutions is essential to each and every one for awarding them and able to make suitable decisions in case of emergencies. The overall purpose of our study was to assess the fire safety of the academic buildings, namely the First Academic Building and the Second Academic Building of IUT. We took our campus as a test subject. The data collection was minimal but sufficient to run the program and get the desired outcome from it. For this we have done firstly, to operate a fire propagation program which will help the research to predict the occupant behavior during a fire. And secondly, to propose a new fire evacuation plan with an improved, efficient, and technologically much more advanced system according to guidelines. For this purpose, simulations using PyroSIM and Pathfinder software. With PyroSIM the conditions of heat and smoke caused by a hypothetical fire source were simulated. With Pathfinder the evacuation scenarios were simulated. The buildings were compared with local guidelines. Some key findings were derived from these endeavors. For the room where the fire source was located, the heat and smoke are less when the windows are open and the room is bigger. With regards to local guidelines, the times of evacuation are acceptable, however, there are significant shortcomings such as lack of markings for emergency pathways, lack of fire alarms, fire exits, etc. For each simulation in Pathfinder, we have got the results for both male and female occupants with their evacuation time and traveled distance to reach the one exit and in the same time simulating PyroSIM it will show the exact time it will take to spread the fire and smoke all over the room and that can give an approximate time to design an efficient fire escape route.

Besides this, there is an improved and efficient fire evacuation proposal, and the findings of major deficiencies for fire safety of our study area are also mentioned. This project there conducted a comparison study between the proposed civil structure dimensions with the already available local guidelines and a management plan for the future also.

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1. Introduction

Fire wellbeing is the arrangement of particles expected to lessen the obliteration brought about by fire dangers to fire security are ordinarily alluded to as fire perils. A fire risk may incorporate a circumstance that improves the probability of fire happens. The infrastructure of buildings plays a vital role in the development of any country. Buildings are subjected to several natural hazards (earthquake) and some manmade hazards (fire) which may cause a collapse of any establishments. This kind of hazard may destroy any building and significant losses.

For any kind of educational institution, fire dangers can be forestalled by taking legitimate fire security the executives. It is significant in light of the fact that there will consistently accumulate many individuals at various ages in a single spot and one single occurrence by fire can influence every one of them straightforwardly or in a roundabout way. There are Labs, which incorporates countless combustible particles that may happen mishap any time. An uncontrolled fire breakout may take an enormous number of misfortune as it isn't just about where the episode involved yet in addition about the existence misfortune and climate. So legitimate administration of fire security can deal with an emergency period.

The objective of fire hazard appraisal to illuminate individuals are utilizing can take appropriate wellbeing estimates when fire flare-up and the essential strides for their security. They can discover the way effectively from where they can undoubtedly arrive at the protected spot of the structure or grounds. In any event they can handle any minor episodes with legitimate activity. By performing the modeling, the users will know where the flammable material is involved, the size of the place, and how much time it will take to create smoke or make the environment hazardous. The main achievement of this study will ensure that fire will not become a huge problem for the users.

According to local and global guideline fire risk management and performance modeling on its propagation, this study is very important for our country as in our country most of the educational institutions do not care about fire hazards so much and it can be one of the most hazardous accidents for the people. For a developing country, there are some limitations to the high cost of installation and maintenance of the fire protection system. But globally people are more concerned about fire hazards and how the proper action will widely spread all over the place so that they can overcome and prevent the fire hazard.

For our research there may be some gap in literature as in Bangladesh by and large the administrative consistence doesn't check. In academic or instructive organizations don't discuss fire safety or about precautions for abrupt fire mishaps.

1.1 Objectives

State the key output(s) that you will be able to find after the study.

1. A fire evacuation simulation using **Pathfinder** on **IUT Academic Building.**
2. Simulate fire propagation time and behavior in several locations using **PyroSIM** within the academic building.
3. Approach for developing a fire evacuation management plan for the Academic Building.

2. Literature Review

2.1 General

According to the 2019 demographic profile, our current population is 159,453,001. The population growth rate is 1.02%. The survey also shows that major cities population – Dhaka = 20.284 million, Chittagong= 4.195 million, Khulna= 963,000 million, Rajshahi 893,000, Sylhet 814,000. The same survey shows that our health expenditure is 2.4%. As the purpose of this article is to prevent educational institution fire hazards, the focus should be on educational institutions. Revising the stats of World Bank collection of development indicators, compiled from officially recognized sources, public spending on education in Bangladesh in 2018 was reported 1.986% (in %GDP) The literacy rate of Bangladesh published in UNESCO, the adult literacy rate is 73.91%. While the male literacy rate is 76.67%, for the female is 71.18%. Currently our country in standing in number 124 in the ranking of literacy rate. (Source – Bangladesh – Literacy rate)

This study focuses on the potential risks of educational institutions facing a fire incident, initially the study requires a list of educational buildings that we have in our country. Educational buildings are very actively functional buildings. It remains operational for a specific part of a day. Which means it is usually crowded with students and teachers and other stuff. The safety of these buildings is a must. Here is a shortlist of educational buildings in Bangladesh.

Table 2.1: Numbers of educational buildings in Bangladesh

Cadet colleges	12
Govt Primary School	38033
Total Govt Schools	63041
High Schools	23500
Medical Colleges	110
Public Universities	45
Private Universities	103
International Universities	3

The basic elements of a normal building are also used in any school, college, or university. Materials and building methods are the same. Following the same code, the structure is built. That's why the risks of facing a fire mishap for an educational building is unquestionable. The risk is higher if the research labs and electric circuits are not well maintained. Even though no news headlines but fire incidents were occurring in labs due to lack of expert supervision are often heard. The ramifications might not be as big as the other big incidents but the risk is undeniable. Lack of reports on incidents like this created a gap in fire research history. The purpose of this research is to fill the gap as much as possible. The study is about educational institutions and it will emphasize on university buildings. Most of the schools and colleges in our country are operating for a certain number of hours and the rest of the day it remains closed which lessens the risk of casualties. But universities, medical schools, boarding schools, and madrasas institutions with dormitories are the ones under the radar.

2.2 Overview of the fire crisis in Bangladesh

After going through recent fire occurrence reports, the number of fire incidents is tripled up across Bangladesh since 1997. The survey says that the daily average with the year 2018 is 53 which is massive. According to Fire Service and Civil Defense Statistics, around 250,000 fires occurred between 1st January 1997 and 31st December 2018. The estimated financial loss was around 6,400 crore BDT to the nation. 2011 saw a massive amount of fire incidents of 19,642 followed by the highest number of casualties – about 365 dead and 1385 injured. 2015 was even deadlier. The estimated loss was 850 crores as a 17,488-fire incident occurred. However, the number of casualties gradually lessened over the last few years until 2018.

These are some estimated survey data of fire incidents and including some physical and economic catastrophe.

In the last few yew years, we've faced many extremely distressful fire incidents that cost us human lives to a huge measure as well as caused economical loss. Some of the incidents are broadly described below.

2.2.1 Gas cylinder explosion in Keraniganj

A gas cylinder explosion occurred in the Prime Pet and Plastic Industry factory in Keraniganj's Chunkutia on December 11, 2019, killing one worker on the spot and injuring at least 34 others, many with critical burns. Some 17 victims of the fire accident were treated at the Burn and Plastic Surgery Unit and Sheikh Hasina National Institute of Burn and Plastic Surgery of the Dhaka Medical College Hospital (DMCH). The victims' relatives and doctors said most of the victims were aged between 15 and 40 and had sustained up to 100% burn injuries. Many of them had suffered inhalation burns. "None of their [burn victims] faces can be recognized while their respiratory tracts are badly burnt too. All of them have burn injuries ranging from 60% to 100% in their bodies," said the burn institute's Chief Coordinator Dr Samanta Lal Sen on Friday. (Hasan Al Javed and Aminul Islam Babu, 2019)[i]At least 21 other victims died while receiving treatment at both hospitals (Dhaka Medical College Hospital (DMCH) and Sheikh Hasina National Institute of Burn and Plastic Surgery (SHNIBPS)) while around 10 victims were still receiving treatment at Dhaka Medical College Hospital (DMCH) and SHNIBPS which was reported last. Doctors said the victims were still in critical condition.

Figure 2.1 Gas cylinder explosion in Keraniganj

Upon investigation, Fire Service and Civil Defense found the owner had continued to operate the factory while neglecting fire hazard issues, as there had been other fires at this factory over the last several years. The factory didn't maintain proper fire maintenance regulations and also the workers also had little or no idea that the factory had no fire safety measures whatsoever which caused the death toll to rise more. (Rabbi & Aminul Islam Babu, 2019)[ii]

2.2.2 Fire breakout in RMG warehouse in Ashulia, Dhaka

A fire broke out at a local supermarket in Ashulia, on the outskirts of Dhaka, on March 24th 2019 evening which took nearly three hours to be brought under control.

Witnesses and later firefighters confirmed that the fire broke out at around 6:15 pm in the warehouse of Anzir Apparels Ltd, a ready-made garment (RMG) factory located on the ground floor of Karim Super Market, a five-story building in Ashulia's Baipail area. The flames quickly spread to around the adjacent areas.

Figure 2.2 Fire breakout in RMG warehouse in Ashulia, Dhaka (Image: Dhaka Tribune)

After getting information about the fire, two units of firefighters from Ashulia DEPZD fire station rushed to the spot and started to douse the fire. Later, they were joined by six more units.

The firefighters were able to bring the fire under control at around 9:10 pm, Abdul Hamid, station officer at Ashulia DEPZD fire station, told the Dhaka Tribune. (Hossain, 2019)[iii]

The Fire Service officials could not give any estimates of damages, or any information on possible casualties.

2.2.3 Fire incident in Bhera market slum, Chittagong

A devastating fire claimed the lives of nine people, including four members of a family and several others injured at a slum in Chittagong's Chaktai area. After five hours of frantic effort and a total of 11 vehicles from four fire stations tamed the fire around 8 am. Of the deceased, seven were identified as Hasina, 35, Ayesha, 37, Sohagi, 19, Rahima, 60; and Rahima's children Babu, 8, Nazma, 16, and Nargis, 18.

Figure 2.3 Fire incident in Bhera market slum, Chittagong (Image: The Daily Star)

Figure 2.4 the debris of fire breakout in Chittagong (Image: bdnews24.com)

Chittagong Fire Service's Deputy Assistant Director Jasim Uddin told the Dhaka Tribune that nine charred bodies were recovered from the debris later in the morning. Fire officials were investigating the possibility that a short circuit caused the blaze as the slum was provided with illegal electricity and gas supplies. The Chittagong district administration said it has formed a four-member probe committee, headed by an additional district magistrate. The administration also distributed Tk 20,000 each to the victim families for funeral purposes of the deceased. (9 killed in Chittagong slum fire, 2019)[iv]

2.2.4 Fire incidents inside Ukhiya and Teknaf camps (Rohingya camps)

Recently on January 12, a woman and a child alongside 4 others were killed in a fire that started from a tent in the transit camp in Ghumdhum. Another person was severely injured in the same fire incident.

Figure 2.5 Rohingya camp under fire

The Rohingya camps in Ukhiya and Teknaf Upazilas of Cox's Bazar are at high risk of catching fire. After a recent fire in the Ghumdhum transit Rohingya camp took the lives of four people, the Rohingya population has been living in constant fear of fires breaking out. The authorities have deployed special firefighting units keeping the risk in mind. Other initiatives have also been undertaken by the administration to keep the Rohingyas safe. The makeshift camps on the hills of Ukhiya and Teknaf have been built with bamboo and tarpaulin. The Rohingyas cook inside these makeshift shanties and tents, making them prone to catching fire during the dry winter season. Besides, the use of gas cylinders provided by different NGOs also increases the chances of a devastating blaze.

Figure 2.6 Crowded living place in Rohingya camp

The densely populated Rohingya camps make them very vulnerable to fire. If one tent catches fire, no one can escape before the fire spreads over the whole camp. The fires are hard to extinguish because of the scarcity of water in the hilly areas.

In collaboration with the International Organization for Migration, several reservoirs are being set up around the camp. The camp has been divided into 8 zones, each of which will hold a 10,000-liter water reservoir to fight any fire. Ukhiya fire service station officer Zahirul Islam said, "Most Rohingyas are not aware of how to extinguish a fire in case of such an incident. We are campaigning in the bazaars, hospitals, mosques, and schools to create awareness among the Rohingyas. We are advising them to cook outside their tents and also to be careful with cigarette stubs." Upazila Nirbahi Officer (UNO) of Ukhiya Md Nikaruzzaman Chowdhury said: “The displaced Rohingyas are living in Kutupalong and Balukhali camps built on 3,000 acres of land inside Ukhiya." "These camps have been divided into 20 blocks," he continued. "Every block has its camp in-Charge. We have kept the fire risk of the Rohingya camps in mind, especially during winter. We have taken several steps to fight it, including making a firefighting squad with 200 Rohingyas who have been trained by an NGO. We are also planning to supply various types of equipment.”

2.2.5 Faulty fire system caused havoc in Bangladesh Bank

The Fire Service yesterday said the fire extinguishing system at the Bangladesh Bank headquarters was faulty and did not work when the fire broke out in the Foreign Exchange Policy section of the central bank on Thursday night, on the 13th floor of the building.

Around 15% space of the chamber of the department's General Manager Md Masud Bishwas was gutted in the fire. "The power connection of the bank is very old. Its [Bangladesh Bank] fire alarm system is not that good as it often rings false alarms," he said. According to him, the bank does not even conduct regular firefighting drills. The fire brigade chief said he would recommend in a probe report that fire extinguishing system inside the bank be upgraded since it is an important establishment for the state. He said that the fire brigade authorities first learned about the incident from locals. Later on, the Bangladesh Bank officials called the Fire Service in this regard, he added. He also said that the fire brigade would recommend that the bank authorities arrange sufficient fire-fighting equipment and rehearsal on what to do in such a situation.

BB Executive Director Ahmed Jamal told reporters that the losses from the blaze were "minimal" and that the fire might have originated due to an electric short circuit.

The flame was first noticed coming out from the south-eastern side of the floor of the 30-story building around 9:30 pm on Thursday, which was completely doused within an hour after 12 firefighting units rushed to the scene. There were no reports of casualties in the incident.

2.2.6 Fatal fire incident in Chawkbazar, Old Dhaka

A devastating fire broke out in Chawkbazar, Old Dhaka when a road accident happened between a pickup van and a private car and the car's gas cylinder exploded. The fire then spread to a group of buildings being used to store chemicals, and quickly expanded to nearby buildings in the densely packed historic district of Chawkbazar.

Figure 2.7 Fire incident in Chawkbazar (Image: Dhaka Tribune)

At least 70 people had been killed in the massive fire that has engulfed several multi-storied buildings at Nanda Kumar Lane in Chawkbazar's Churihatta area of Old Dhaka. Adding to that more than 60 people were admitted to DMCH with varying injuries. Nine of them were being treated in the burn unit — for burns ranging from 10% to 51%. Three of these burnt patients were in the ICU. (Mahmud Hossain Opu, 2019)[v]

Figure 2.8 Ruins of fire incident, Chawkbazar (Image: Dhaka Tribune)

After the fire broke out at Nanda Kumar Lane in Chawkbazar's Churihatta area around 10:35pm, a total of 39 fire-fighting units from 13 stations and locals fought the flames throughout the night and managed to douse them after 12 hours of effort. They were also joined by two Bangladesh Air Force choppers in the morning as Haji Wahed Mansion — the building which had caught fire first — was still burning. According to Fire Service and Civil Defense officials, the fire spread to several adjacent buildings in minutes as they, apart from shops, housed warehouses of plastic materials, chemical compounds, and perfume and body spray — all of which are highly flammable materials and made it difficult for the fire-fighters to extinguish the flames quickly. (Mahmud Hossain Opu A. R., 2019)[vi]

Figure 2.9 Water canon to control the fire spread (Image: REUTERS)

Three committees were also formed by the Fire Service, the Home Ministry's Security Services Division and the Industries Ministry to look into the great conflagration's origin and make recommendations to avoid such incidents in the future. Although initially the cause of the fire was thought to be the road accident and explosion of gas cylinder, later by an investigation by Institution of Engineers, Bangladesh (IEB) concluded that the fire originated from chemicals stored in the Haji Wahed Mansion. The four-storied building which suffered most damage in the fire. The ground floor of the Mansion housed around a dozen shops while the first floor was used as warehouses of high-pressure deodorant canisters and raw plastic granules. Different families lived in the rest of the building. Fire service officials also found a huge amount of highly combustible materials stashed in the basement of Wahed Manzil. The fire crews shivered to imagine what would have happened had the fire reached the basement of the building.

The IEB report blamed the storage of flammables on the first floor of the building for the monstrosity of the fire. (Masum, 2019)[vii]

2.2.7 Fire incident in World University of Bangladesh campus, Dhaka

A fire broke out at the World University of Bangladesh campus on Green Road in Dhaka on September 28th 2020. The fire broke out around 1:10pm on the second floor of the university building and five firefighting units rushed to the spot and put out the flames within one hour dousing the fire around 2pm.

Figure 2.10 World University fire incident (Image: Dhaka Tribune)

No casualties were reported immediately as the university was closed due to the ongoing Covid-19 pandemic students are currently attending online classes and this is why there was no major damage done by the fire. The university's Deputy Registrar Md Kamrul Hossain said: "A room on the second floor of the university building caught on fire. The chairs, tables, documents, and some books were damaged by the fire."

But firefighters couldn't find the cause of the fire and Fire Service headquarters duty officer Ershad Hossain said, "We will know about the cause of fire after investigation."

2.2.8 Narayanganj mosque fatal fire incident, Narayanganj

An explosion from gas leakage underground in Baitus Salat Jame Mosque in Narayanganj District, Bangladesh killed at least 31 people while dozens more were injured. Around 50 devotees sustained burn injuries following a huge explosion at the Baitus Salat Jam-e Mosque in Paschim Talla area of Narayanganj around 8:30pm on September 20th. Among the injured, 37 were admitted to Dhaka Medical College Hospital in critical condition. The death toll rose to 31 on 10 September.

Figure 2.11 Fire destroyed the mosque interior (Image: The Daily Star)

Five units of the fire service department doused the blaze erupted following the explosion after trying for half an hour.

Figure 2.12 Ruins of fire incident in the mosque (Image: The Daily Star)

The cause of the fire explosion is presumed to have been caused by a gas leak from an underground pipeline. Abdullah Al Arefin, assistant director of Narayanganj fire service and civil defense, told the Daily Star that a gas pipe line of Titas Gas Transmission and Distribution Company Limited has gone through the bottom of the mosque. It is primarily suspected that gas leaked from the pipeline and accumulated inside the mosque since the windows were shut due to the mosque being air conditioned. When the air conditioners were turned on, due to sparks the gas could have exploded. It was also reported that because of the impact of the blast, at least six air conditioners also exploded inside the mosque. (Rita, 2020)[viii]

Figure 2.13 Fire mishap ruins (Image: The Daily Star)

Titas Gas Transmission and Distribution Company Ltd had formed a five-member committee to investigate whether a gas pipe leak was responsible to cause sparked fire and led to the subsequent blast at a mosque in Narayanganj later, reports UNB. A press release of the Ministry of Power, Energy and Mineral Resources said the committee, headed by Abdul Wahab, general manager of Titas Gas, was asked to submit its report within five working days. All the concerned power distribution companies were also asked by the power division to examine the power connections and condition of air-conditioners at mosques and other religious institutions located in their respective areas, the release also read. (UNB, 2020)[ix]

Figure 2.14 Crime Scene labeled fire accident spot (Image: Dhaka Tribune)

2.2.9 Fire incident at Daffodil Polytechnic Institute in Kalabagan, Dhaka

A fire broke out at a campus of the Daffodil Polytechnic Institute in Dhaka's Kalabagan at around 11.15 am on September 24 while university classes were going on. Fire Service and Civil Defense Control room duty officer Ershad Ahmed told Dhaka Tribune: "A firefighting unit went to the spot and doused the blaze." The fire originated from an electric short circuit on the main switch board around 11am and the flames were doused after one and a half hours, said Fire Service and Civil Defense officials. No casualties had been reported. (Mehtab, 2019)[x]

According to Arif Miah, an office staff of the campus, the institution uses four floors of this five storied building while every floor is 2,500 square feet. Around 350 students attend classes regularly in this particular campus. Many students were in their classes when the fire broke out. The students were forced to use windows to climb down from the second and third floor of the building with the help of outsiders who extended their helping hands with bamboos. Later, firefighters joined the locals and rescued the rest of the students trapped inside.

Though it was a small-scale fire that caused no casualties, it had exposed the building's lack of fire safety protocols which put hundreds of its students' lives at risk. Abdullah Al Mamun, a fireman of the Mohammadpur Fire Station, said Daffodil Polytechnic Institute never conducted any fire drills to create awareness in case of a fire emergency. There weren't any emergency exits in the campus and all five fire extinguishers in the building was found to be defective. The students could have suffocated from toxic fumes as the fire originated from the main switch board installed beside the main staircase on the ground flood, the smoke quickly travelled up and prevented students from getting down. If the help had not come on time as there were no fire escapes in the building except for a narrow staircase, there could have been casualties

Figure 2.15 Daffodil Polytechnic Institute (Image: Dhaka Tribune)

According to the Fire Service and Civil Defense, the building safety protocol dictates that at least two fire extinguishers have to be installed for every 1,000 square feet of a floor besides emergency exits and other fire safety equipment. At least one fire drills every month is mandatory for educational establishments, says the Bangladesh National Building Code (BNBC). But the administrative office refused to make any statement regarding this matter. (Rahman, 2019)[xi]

2.2.10 Fatal fire in FR tower in Banani, Dhaka

A deadly fire incident occurred at the 22-storey FR Tower in Dhaka's Banani area on 28^{th} March, 2019 in which 26 people were killed including a Sri Lankan citizen and around 100 others injured**.** The fire broke out on the eighth floor of the 22-storey building on Banani around 1:00pm and engulfed other floors immediately. When the fire sparked inside the building, at least six people were seen falling off while trying to escape the blaze. Many others were trying to climb down on the ledges also several people had panicked and leapt from the building, which led to the increased casualties. A Fire Service media briefing booth set up outside the scene of fire said around 11pm that 19 bodies had been recovered from inside the burned building. Other died from serious injuries under treatment. (Report, 2019)[xii]

Figure 2.16 Deadly fire in FR Tower, Banani (Image: The Daily Star)

The fire broke out at FR Tower around 12:52pm according to Fire Service spokesperson Ataur Rahman. The Fire Service Duty Officer Mizanur Rahman claimed the fire was brought under control at around 4:45pm. A fire service official, said around hundreds of people have been rescued from the building. A total of 21 firefighting units were trying to douse the blaze and rescue the people trapped inside the building. Later, Army, Navy and Air forces; police and Rapid Action Battalion (RAB) joined the operation. Helicopters were seen spraying water on the building and firefighters were bringing people out the window panes in groups, using ladders, our correspondent reports from the spot. The efforts of the 300 firefighters deployed helped confine the fire to just four floors of the building. A firefighter named Sohel Rana was seriously injured during the rescue effort being stuck in a hydraulic ladder and succumbed to his injuries after fighting 11 days. (Correspondent, 2019)[xiii]

Figure 2.17 Firemen rescuing victims

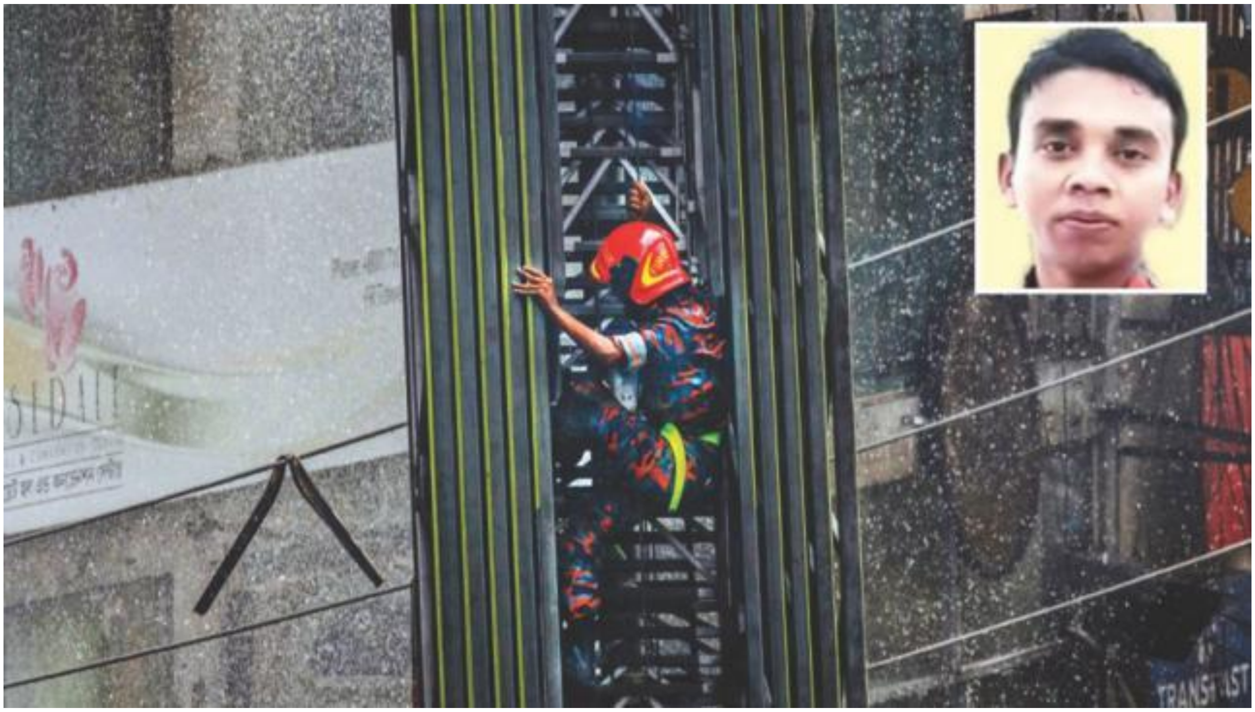


Figure 2.18 Firefighter on the way to rescue the affected people (Image: Dhaka Tribune)

Fire officials and later a government investigation committee suspected that an electrical short-circuit on the seventh floor might have caused the blaze on FR Tower. The deadly blaze left a trail of devastation on the seventh, eighth and ninth floor where almost everything was charred beyond recognition. No mentionable damage was seen up to the fifth floor. Heavy smoke and ash created black layers on the furniture, computers and documents of the 10th and several other uppers floors, which remained outside the reach of flames. It was reported that no fire alarm rang during the fire incident and the building's emergency exit is narrow while some were found sealed off during the incident because of which people failed to use the door. Besides, the smoke created by the fire filled up the staircases and the floors, causing suffocation to people. As the building was made of glasses, smoke could not pass and spread throughout the floors and staircases, making it difficult for people to escape. And it was also found that the building violated several fire regulations codes and design was not approved by RAJUK. (Amin, 2019)[xiv]

2.2.11 Fire at Dhaka University Central Library, Dhaka

A fire broke out at the central library on Dhaka University on July 7, 2019. According to the fire service, the fire broke out at the ground floor of the three storied building of the library around 10.30 am in the morning. Khandakar Abdul Jalil, deputy assistant director of fire service, said. "The fire originated from electric short circuit. Library employees put out the flame themselves before members of fire service reached the spot." (Alif, 2019)[xv]

Figure 2.19 Smoke spread over the area (Image: The Business Standard)

Only the ground floor was damaged and no other floor was damaged in the fire. Also, no casualties were reported. No books were burnt in the fire but the electric connection of the library was severely damaged.

Mahmuda Sabiha, a sociology student, said, “I was reading on the third floor when I saw a huge smoke coming out from air conditioner. We rushed out of the library immediately.” She also said, “While getting down, I saw that the fire broke out on the ground floor.”

Figure 2.20 Fire truck arrived on the spot (Image: Dhaka Tribune)

2.3 Firefighting in Bangladesh

The “Fire Service” and “Civil Defense” was affiliated together in 1982 and become Bangladesh Fire Service & Civil Defense (BFSCD). This department has currently 6500 people working under them and increasing gradually. Every day these workers risking their lives to save national assets. Currently, our country has 427 fire service stations, classified into A, B, C category, and River fire stations. The data below will give a numerical brief of the fire service stations in Table 2.3.1.

Table 2.2: Total Fire Stations: BFSCD

Serial No.	Name of Division	‘A’– classify stations	‘B’– classify stations	‘C’– classify stations	River Fire Station	Fire Station No.
1	Dhaka	19	32	16	5	72
2	Chittagong	18	34	10	2	54
3	Rajshahi	7	36	18	-	61
4	Khulna	5	21	8	1	35
5	Barisal	2	16	5	1	24
6	Sylhet	1	11	1	-	13
7	Total	52	140	58	9	259

BFSCD is the only and most reliable Govt. firefighting organization in Bangladesh. For years our country is facing fire problems and the fierce soldiers of FSCD are taking care of it with excellence. The FSCD currently has over 10,000 regular employees and approximately 30,000 trained volunteers. (Bangladesh Fire Service and Civil Defense Department). Govt. is taking measures to raise the standard of our firefighting reputation. FSCD and Chittagong City Corporation agreed to acquire land for proposed fire stations in the city. The plan is to build six new stations. Two of the proposed stations will be built under Karnaphuly and Khulshi police stations. Another station will be under Halishahar police stations others in KEPZ, Kashgar, and Customs area. Currently, Chittagong has 18 fire stations. Another perspective step for our country was taken in the 14th session of the Bangladesh-China Joint Commission meeting. The meeting concluded with an agreement of China providing 1000 **'Water mist fire motorcycles'** suited with modern technology and necessary parts and tools.

2.4 Possible instruments and fire management practices in the educational institutions

2.4.1 Management practices - Fire Escape Drill

Amongst all the hazards of a building, the existence of fire is a constant since the beginning of mankind. Buildings and structures of every purpose have even a slight risk of fire incidents. That's why every operation inside a building within any organization has an impact on the safety of every single one who's affected by their activities. Simple mismanagement can take a big toll out of any individual. The most obvious reason is humans caused accidents on another word Morale reason. Major causes of fire in an educational institution are human factors such as carelessness, negligence, and lack of fire safety awareness. Also following board headings of Electric appliances and installations, electric devices used in kitchen, dormitory, and other regularly used rooms.

For fire management practices, many research works were carried out in different well know universities. Basic materials of the management system to know about the study area, sample size, and estimation, data collection, questionnaire design, data analysis, etc.

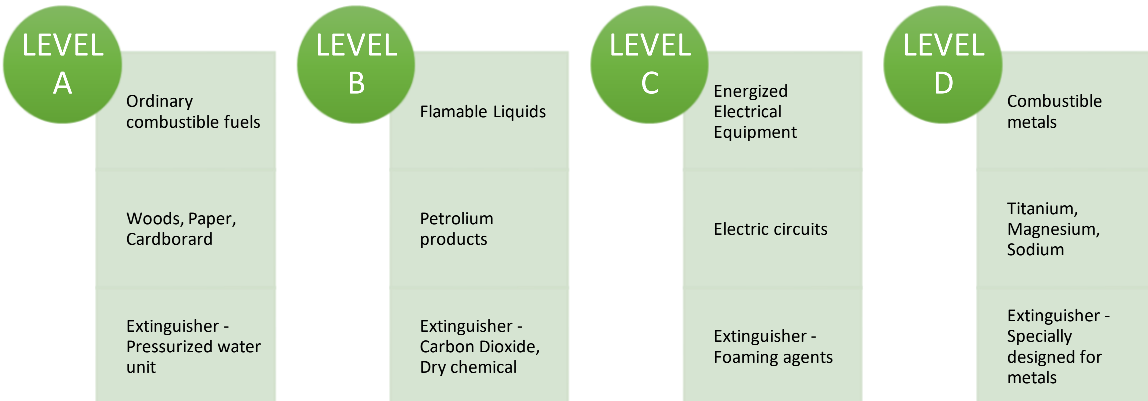
Comparing with global educational institutions, our country is still more remote and old. As most of the fire incident cases have occurred in factories, slums and urban areas with high density, educational institution cases are rare. The location and time of operations of institutes can play a big role here. Globally the **'fire escape drill'** is a very well-known activity. The campuses emphasize the prevention of fire accidents. Universities organize daily practices and procedures to decrease the risk of occurrence. One of the remarkable steps which can be very helpful for our country is automated detection and suppression system. Usually, Boarding schools, Universities, and Madrasas with dormitories and large campuses do not have a well-planned fire escape route. Fire exits and assembly points should be introduced on campuses.

Figure 2.21 Lifesaving lessons at "Fire Safety Day" (Source: https://scarsdale10583.com/)

Figure 2.22 Elementary students learn fire safety (Source: https://www.warwickvalleyschools.com/)

2.4.2 Instruments - Fire Extinguisher

A fire extinguisher is one of the most typically used firefighting equipment. This is one of the foremost required elements of building code in our country. Now this study requires a data survey that can provide brief information about usage and types of fire extinguishers. Taking our institution as standard here is a rough proposal of introducing different types of fire extinguishers depending on the gravity of the hazard.



LEVEL A

LEVEL B

LEVEL C

LEVEL D

2.5 Existing legal provisions and guidelines in Bangladesh

2.5.1 Different part of Exit path

Exit path is a mean of escape when a building is on fire. It has three parts.
(a) Exit access
(b) Exit
(c) Exit discharge

Here, "**Exit access**" means the path to the front of the Exit from any point of the building. Exit is the part which ensure safely evacuation of people from the place of the fire to Exit discharge. Exit discharge is from the point of Exit to the point of the last wall of the shelter for fire safety.

The Exits we can consider in different part of **Means of escapes** are given below:

- Door, Stair connecting corridor or passage, Smoke and fire free enclosed area, hanging porch, Fire safety stairs or a combination of these exits from which people can enter a road, an open roof or a specific safety shelter which will have to be safe from fire affected area, smoke or fire.

- Horizontal exit like a safety shelter or a building safe from fire affected area, smoke and adjacent areas.

Life, Escalator, moving walkway cannot be considered part of **Means of escape**.

2.5.2. <u>General Requirement:</u>

- Buildings and warehouses constructed for general use of public must have enough number of exit paths so that users can move out safely and quickly without the help of others during any incident of fire or any other kind of hazards.
- Exit can never be used in any way which disrupts its use as a **Mean of escape**.
- The corridor to Exit and Exit access cannot be used as a Supply or Return air duct.
- If the floor of an Exit path changes more than 300 mm anywhere, a ramp has to be used. The exits which won't be used by disabled or old people, there it is allowed to step down to 200 mm.
- Every Exit should be clearly visible and every Exit access should be clearly marked. The places where there are more than one Exit and Exit access and the places people work in the dark, the location and directional signs of the Exits must be illuminated.
- Every owner or leaseholder of a building must ensure the safety of the user of the building and if any building have insufficient Exit access, the authority can order for proper improvement.

2.5.3. <u>Location of Exit:</u>

- No exit should lead to any adjacent room or area unless it's a part or extension of the previous area or used for dangerous purposed and unless it's directly connected to a specific Exit area.
- The location of the exit path in a building must be designed in such a way that during usage of the building no part of the exit path could be locked.
- Buildings like auditorium which are built for mass public gathering must have a side adjacent to the road which could be used as a Main Exit Discharge and in these kinds of buildings the Main exit discharge can be used to evacuate at least half of the users; If these kinds of buildings are multi-storied then every floor must have an Exit which can be used by at least two-third of the users in that floor.
- Exits should be design in such a way that ensures barrierless Means of escape from every section of the building.

2.5.4. <u>Number of users:</u>

- The exit access of a building for maximum users will be maintained by the Table-1
- In auditoriums and institutions where there are fixed seats, the number of users will be determined by the total number of seats in the building. If the seats are handling less, we have to determine the number of users by taking 500mm width for every user.
- Floor area for per user must not exceed 0.3 square meter according to the above calculation
- Number of users of the mezzanine floor would have to be added to the number of users in the downstairs.

- If roof is used for any kind of public gathering, then the exit accesses should be determined according to the number of users.

2.5.5. <u>Size of Exit:</u>

The size of Means of exit must be enough for the number of users and this will be applicable from Table-2.5.1; the width and size of every part of Exit will be determined by Table-2.5.2 and article 6 of this guideline.

Table 2.3: Number of Different Users

Classification of Building		Floor area for users per head (sq. meter)
A.	Residential	18 grosses
B.	Educational Institution	
	Classroom	2 nets
	Preschool	3.5 net

Table 2.4: Width of Exit users per head

Classification of Building	Without Sprinkler System (mm per head)			With Sprinkler System (mm per head)		
	Stairs	Ramp and Corridor	Door	Stairs	Ramp and Corridor	Door
A Residential B Educational Institution	8	5	4	5	4	4
The width of the Exit will be determined by the number of users on each floor of the building						

2.5.6. <u>Corridor and Passage:</u>

- In whichever direction a user starts from in a corridor or a passage, it must lead to an Exit; The distance of a closed alley should not be more than 10 meters if there's no Exit in that direction.
- The width of the corridors and passages would be determined by the number of users on each floor of the building and its least measurement have to be according to below:
    i. 1.1 meters if the number of users is more than 50
    ii. 0.9 meters if the number of users is less than 50
    iii. 1.8 meters in educational institutions (Occupancy B) where the number of users exceeds 150
- The width of the Exit corridor and passage, could not be less than the sum of the width of the doors that would be used to exit the corridor and passage.
- The uninterrupted height of the corridor and passage could not be less than 2.4 meter
- The least fire rating of the corridor of Exit access has to be 1 hour.
- The least fire rating of the door to the Exit corridor has to be half an hour.

2.5.7. <u>Assembly Aisle:</u>

- In assembly buildings where there is seat, table, machineries, exhibitions etc. there must be an obstacle free aisle to the Exit.
- Exit can be horizontal or may have a highest ramp of 1:8 slope. Its least width has to be 5 mm per user.
- If Exit is step by step, then the least depth of the trade has to be 275 mm and the height of the rise has to be between 100-200 mm
- In case of horizontal or slope aisles, if there are seats in both side of the aisle then the least width has to be 1 meter and if there are seats in only one side the least width has to be 0.9 meter.

2.5.8. Doors:

- Each use of a room or a space must have access to one Exit door and the number of users of every Exit door and the travel distance cannot exceed than the values given in Table 2.5.3

Table 2.5: The maximum number of users and maximum travel distance for an Exit door

Classification of Building	Maximum number of users	Maximum travel distance (meter)
A Residential	12	23
B Educational Institution	50	23

- If number of users and travel distance is more than the given value in Table 2.5.3 then at least two exits must be ensured.
- The width and height of the Exit door must be respectively 1 meter and 2 meters at the least.
- Sliding or Hanging doors can't be used as an Exit door.
- Every Exit Access door should be side-swinging, in case of risky establishment or if the number of users is more than 50 then the swing of the door should be to the outside of the room or to the direction of travel; If the swing of the door disrupts the width of the corridor but the disrupt less path cannot be less than 0.9 meter; only sliding doors are allowed for pressurized rooms.
- Exit doors be directly opened to the flight of a stair; if Exit door is opened to the stair, then at least 0.9 meters width must be kept after the width of the door to the outside direction and the floor of the room and the flight of the stair must be on the same level.
- Assembly, Education Institution or Institutional building or for those building which will have more than 200 users, revolving doors cannot be used; in other case less than half of the door can be revolving doors in escape route; but sliding doors using technology which cannot be opened by hand in case of emergency will not be acceptable.
- Every door in escape route should be able to be opened without keys from the direction where users will be coming from.

2.5.9. Stairs:

- The required width of the stair of Exit will be determined by the table 2.5.1 and table 2.5.2 from Article 5 but it cannot be less than the width described in table 2.5.4.

Table 2.6: Width of fire safety stairs

Classification of Building	Least width of stair (meter)
A. Residential	
A1, A2 A3, A5 A4	1.0 1.5 According to rule 7.1(d)(10)
B. Educational Institution	
Number of users up to 150 Number of users more than 150	1.5 2
Note: If a building has only one stair and it is also used as a fire safety stair then the width of the stair will be according to the least width of stair described in rule-58(d)(1) and the width found in table 4	

- The least measurement of the landings and the platforms of Exit stairs cannot be less than the determined width of the stairs; but in case of straight run stairs, the landing between to flights to the direction of the travel isn't mandatory to be more than 1.2 meter.
- Spiral and spherical stairs can only be used as an emergency evacuation route inside homestead and for mezzanine floor up to 25 square meter and the width of these kind of stairs will have to be 650 mm. The depth of each trade will be 200 mm (which will be measured from 300 mm distance to the narrowest part of the stairs), each trade will have to be the same; riser cannot be more than 225 mm; at the same time the difference between the height of the risers can be up to 5 mm and for the highest and lowest riser the difference can fluctuate up to 10 mm.
- If the obstacle less width of Fire Exit stair is 1 meter, then it will have to have a continuous hand-rail in one direction; and if the width is more than that it has to have 2 hand-rails on both direction; if the obstacle less width of this kind of stairs is more than 2.2 meter then it will have to have a hand-rail in the middle as well.
- Each Exit stair must be made with fire resistant materials, but solid wood hand-rails are acceptable.
- If lift shaft is perforated and is built with proper fire-resistant materials according to the building type, the Exit stairs can be constructed around the lift shaft.
- External stairs will not be considered as Fire exit stairs unless they ensure an open ground level evacuation, are divided from fire resistance system from inside the build or a wall and are made of fire-resistant materials.

2.5.10. <u>Ramp:</u>

- The least width of the Exit ramp will not be less than the corridor width described in subsection 6.

- The slope of the Exit ramp cannot be more than 1:12 and the surface of the ramp have to be made with non-slippery materials or have to be constructed in such a way that the ramp is not dangerously slippery.
- If the slope of the ramp is more than 1:15 then guard or hand-rail have to be provided on both sides.

2.5.11. Horizontal Exit:

- The part of the building on fire and horizontal exit has to be divided by a door that locks automatically.
- The width of this type of exit cannot be less than 1 meter.
- If horizontal exit has slope, the slope cannot be more than 1:12 and this type of exit cannot have any steps.
- If horizontal exit is used from only one direction, then it should open to the outside; if it is used for movement on both directions then doors that open from either sides or two different doors have to be used.
- The net least floor area of a shelter subtracting stairs, shaft etc. will be determined by taking 0.28 square meter per user.

2.5.12. Number of Exits:

- The number of Exits directed in this sub-section will apply to all kind of practical buildings.
- For the buildings directed in Table 2.5.5 one exit route will be enough if the building doesn't have more than one floor under the exit route.
- In case of all other buildings except buildings in Table 5.5.4, the number of Exits must be determined according to the way given below by using the number of users on each floor of the building-

  Number of users up to 500 – at least 2 Exits

  Number of users from 501 up to 1000 – at least 3 Exits

  Number of users more than 1000 – at least 4 Exits

  Table 2.7: A building with Exit route

Classification of uses	Highest Number of Floors	Number of users in each floor and condition for travel distance
A1	4	Number of user 12 and distance is 23 meters
A2, A3, A4, A5	10	Number of units in each floor is maximum 4 and travel distance is 23 meters
B, C, D, E, F, G	2	Number of user 50 and distance is 23 meters

- For building with more than 10 floors or height more than 33 feet and Educational

Institutions, Health Service, Commercial Buildings, Institutional Buildings, Assembly Buildings, Industrial Factory Buildings, Warehouses or in case of dangerous buildings having more than 500 square meter area on each floor must have at least 2 Exits and in this case the staircase room have to be fire safe and must open to an open space or a determined safe space.

2.5.13. Length of Travel:

- If more than one Exit exists in a building then the Exits have to be situated in such a way that the highest distance between the Exit and from any point of the floor area of the building being in use is as follows:

  Classification of Building   A, B, C, D, E, J – 25 meters.

- If more than one Exit is required in the same building then the Exits must be situated as far as possible from each other and in whichever direction the user travels, he must find an Exit.

2.5.14. Exits for Warehouses:

- Following other regulations, if the buildings classified under warehouses have users more than 10 or a floor area of more than 1400 square meter then there must be at least two different Means of escape.
- During working hours, the locks of the doors of the warehouses have to be such types that are easier to unlock during dangerous situations.

2.6 Effective tools for fire hazard analysis

Till now two fire hazard analysis software was discussed. One is PyroSIM and another is Pathfinder.

2.7 PyroSIM

Fire Dynamics Simulator (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow. The computer program solves numerically a large eddy simulation form of the Navier–Stokes's equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires, to describe the evolution of fire. FDS is free software developed by the National Institute of Standards and Technology (NIST) of the United States Department of Commerce, in cooperation with VTT Technical Research Centre of Finland. Smoke view is the companion visualization program that can be used to display the output of FDS. (Fire Dynamics Simulator, 2021) Fire Dynamic Simulator (FDS) plays an important role in fire investigations. In general, the comparison of the simulation results from FDS and the actual fire scene can help the engineers and professionals in improving their design to have a safer building. Multiple strengths of FDS are proved by looking at different fire experiments. Where a small room or a large pool fire in a largescale experiment is a risk, FDS can be used as a tool. The model results were compared with the experimental data from Factory Mutual (FM Global). The advantage of the modeling is to reduce the cost and eliminate the danger from a real test or experiment. In addition, the analysis can be run for a longer time. (Mashayekh, 2020)

PyroSIM and pathfinder are software that are widely used for simulation purposes. They have been used in various journal papers such as the paper titled "Fire Simulation in House Conditions" by author RADOJE B. JEVTIĆ. This paper was written to show the possible fire spreading in house conditions based on simulation in PyroSIM software. (JEVTIĆ, 2015) Another paper titled "Research on fire safety evacuation in a university library in Nanjing" by authors MING-XIN LI, SHUN-BING ZHU, JING-HONG WANG, ZENG ZHOU. Here, the pathfinder was used for simulation and then fire safety was evaluated by comparing the risk time and evacuation time. (MING-XIN LI, 2017)

Another example would be the paper titled, "Numerical simulation of dormitory building fire and personnel escape based on PyroSIM and Pathfinder" by authors Xinfeng Long, Xueqin Zhang and Bo Lou. In this paper using PyroSIM the fire origin room temperature and heat flow was found taking into consideration the conditions of the windows being open and closed respectively. And pathfinder was used in this paper to find the best evacuation time. (Xinfeng Long, 2017)

2.8 Pathfinder

Pathfinder is a commercial evacuation simulation software developed by Thunderhead Engineering to simulate evacuation processes using evacuation dynamics. It can use two ways to model the simulation process. The first process uses a flow model, the SFPE method of Mowrer and Nelson[xvi]. The second method uses an agent-based model, the Reynold's steering behavior model redefined by Amor[xvii], to represent human movement during evacuation process.

Pathfinder software has been widely used in evacuation simulation and disaster prevention research studies such as Wang et al used Pathfinder software in the paper titled "Emergency Guidance Evacuation in Fire Scene Based on Pathfinder" to establish a high-rise building evacuation model in fire scene.(H. Wang et al, 7th International Conference on Intelligent Computation Technology and Automation, 2014)[xviii] Another example where pathfinder was used as an evacuation simulator by Hao Chu, Jia Yu, Jiahong Wen, Min Yi & Yun Chen in the paper titled "Emergency Evacuation Simulation and Management Optimization in Urban Residential Communities" to simulate the evacuation of urban residents in case of fire and compared the results with several other evacuation simulation software.(Chu et al, Sustainability, MDPI, Open Access Journal, 2019)
This software was also used in the research article titled "Risk Assessment of Pedestrian Evacuation under the Influence of Fire Products" by Liu et al to simulate the pedestrian evacuation and assess the risk under influence of fire products. (Yuechan Liu et al, 2020)

2.9 Chapter Summary

This chapter includes a brief pre-simulation study on fire incidents in Bangladesh. A summary data table is attached below which shows the fire management system in our country is still at an orthodox state, which requires to get much more systematic and more efficient. Despite of the system being old, the fire fighters still managed to mitigate the possible damage, controlled the incidents which could have been much worse.

This chapter also narrated the Fire Management Guidelines constituted in "Bangladesh Imarat Nirman Bidhimala". We evaluated a comparison between our research subject and the guideline, our subject building was our well-developed Academic Building. We have two academic buildings and the construction of both building was done following the guidelines.

The next chapters will delineate our research methods and results of our simulations, which will be following an end result that is a proposal of a new improved fire management system in our academic building premises.

Table 2.8: Data Table

Date	Location	Fire source	Casualties
March 23, 2017	Bangladesh bank HQ	Fire system failure	No casualty report
December – January 2018	Ukhiya and Teknaf Rohingya camps	Use of quick combustible materials for cooking.	20 incidents. Unknown casualties
February 17, 2019	Bhera Market slum, Chittagong	Not confirmed	9 casualties
March 4, 2019	RMG warehouse in Ashulia, Dhaka	None provided	Unknown possible casualties
December 11, 2019	Plastic industry factory, Keraniganj	Gas cylinder explosion	20 killed, 15 injured

3. Methodology

3.1 Study Area

This study requires a full briefed description of the institution building we are doing our research on. Since the study is about educational institution, we will be emphasizing on the most important component of an educational institute that is the classroom. We are using our own university as a standard data collection source. Our university has two academic building with 5 floors in each. The building is a concrete build well-structured building with a strong foundation. Each building has 5 floors. As the scope of work for us is very much narrowed down due to not being able to be physically present in the building, in this study we will be doing our research on only one floor taking it as the standard for the rest of the building.

As we mentioned earlier, the study will be done using two effective software's, Pathfinder and PyroSIM. We will be describing how we use the tools. Here in Table 3.1.1 is a geometric feature of the building we will be doing our research on:

Table 3.1: Geometric feature of the buildings

Features	Quantity
Number of stories	5
Area of 1st Academic Building	700 sq. meters
Area of 2nd Academic Building	870 sq. meters
Number of rooms in the building	30
Number of rooms in the first floor	6
Fuel sources	2

The building has total 11 lab rooms, 10 classrooms, 24 teaching and administration member rooms, 2 conference rooms, 2 council rooms and 1 seminar room. A fire hazard requires an immediate evacuation which depends on few things. In case of fire emergency, gender, physical characteristics like height, shoulder width, age distribution, walking speed plays a significant role on evacuating. Based on all these factors we have formed an occupant allocation chart that is given below. One of the prime variables of evacuation, the changing walking speed contingent upon age, physical fitness and gender as exhibited through the research information of was chosen as it looks like the segment of the classroom and office room inhabitants intently. Another key factor is the 'pre-evacuation time', which demonstrates the extra time taken because of the absence of prompt response to fire. The pre-departure time for people in office room is probably going to be higher than occupants in classroom of conference room for organizing decrease of material harm alongside the reality that it has been expected that about 20% of the students or teachers will help each other for clearing. The following Table 3.1.2 gives number of occupants according to their gender and age in the building.

Table 3.2: Number of occupants in the building

Category	**First Floor (Number of occupants)**	**Second Floor (Number of occupants)**	**Third Floor (Number of occupants)**	**Fourth Floor (Number of occupants)**	**Fifth Floor (Number of occupants)**
Male	90	160	70	105	179
Male who will assist others	20	45	17	32	50
Female	26	37	18	27	18
Female who will assist others	8	10	3	10	6
Elderly Male	3	4	2	6	5
Elderly Female	0	0	0	0	0
Total Occupants on each floor	147	256	110	180	258
Total Number of occupants in the building	951				

3.2 Evacuation Scenario Using Pathfinder

Pathfinder is a movement/partial behavior evacuation model simulating software where an individual has various attributes and a complete set of walking rules and collision-avoiding mechanisms between this individual and others or other obstacles. Pathfinder provides us with a graphical user interface for simulation design and execution as well as a 2-D and 3-D visualization tools for analyzing results. It uses a 3-D geometry model and input parameters can be assigned through distribution laws and the only occupant behavior that is included is collision avoidance. (Ronchi, (2010))[xix]

During the pathfinding process, different way points are created for the agents who has to follow the path they create. The steering systems is used to move the occupant according to their intended path interacting with the environment and other occupants. The rules that are followed by the agents are: seek, avoid walls and avoid other occupants. The occupants find the lowest cost steering point along their path to the exit. Pathfinder has two ways to simulate the evacuation process. The first methodology is an agent-based model in which the model represents human evacuation process resulting in congestion and queue arise. The second is a flow model, the Society of Fire Protection Engineers (SFPE) method based on the calculation of the means of the capacity of the considered environment. We will be using both steering and SFPE method in our simulations and compare the results.

In pathfinder, we can set corresponding parameters such as walking speed, delay time, shoulder width, outlet selection etc. for our escaping occupants and simulate a virtual evacuation of our occupants. We are using two different occupant profiles in pathfinder one representing males and one female. The input parameters for shoulder width and walking speed for male and female profile are given in Table 3.2.1 and 3.2.2. (Chen, 2019)[xx] Pathfinder allows us to assign a specific exit or the nearest one to every occupant. We are assigning occupants to take the nearest exit.

Table 3.3: Shoulder width of the occupants

Gender	Shoulder Width (cm)
Male	41.0
Female	38.0

Table 3.2.2: Walking speed of occupants

Gender	Walking Speed (m/s)
Male	1.32
Female	1.27

Pathfinder calculates movements at discreet time steps and it calculates occupant's steering speed step by step. This model would provide both a qualitative and quantitative results. The simulation will also provide us with evacuation times, room usage and door flow rates as well as a 3-D representation of the whole evacuation process. We will be able to determine the maximum and minimum evacuation time as well as average time needed for occupants. We will also get the maximum distance an occupant has to travel to find the nearest exit and see the usage flow rate of each exit.

Validation: We would do a verification test on one of our case scenarios to validate our results taking reference from Example 2 given in the SFPE engineering guide, 2003. In the example and our scenario, the controlling component is the exit doors that in the base of the staircases. (Engineers, 2003)[xxi]
To calculate the total movement time, we must calculate $T_{TOTAL} = T_{1+} T_2 + T_3$ where: $T_1$is the time it takes the first occupant to reach the controlling component, $T_2$the time it takes the maximum

number of occupants that would use the exit to flow through the controlling component. And T_3 the time it takes the last occupant to move from the controlling component to the exit.
The calculation for T_1 has four parts:
T_A: The time it takes the occupant nearest the door on the second floor to travel from their initial location to the stairway staircase,
T_B: The time to move down the stairs from the platform,
T_C: The time to walk across the platform,
T_D: The time to move down the stairs from the door,
We assume a low-density velocity calculation for the first occupant to reach the stairs and the landing. We take the other data from out study area and use the given values in pathfinder which are not otherwise found and compare our result with the expected result from this test and analyze the different evacuation time that is found.

Simulation Scenarios:

For the simplification of the study, we are simulating four different evacuations scenarios in four cases for our study area which is the 1st and 2nd Academic building of IUT.

Case I: For the 1st case scenario we have simulated a typical classroom of the 2nd academic building having an area of 104 square meters and only one exit with 81.28 cm door width. There are 35 male student and 15 female students in the room totaling 50 occupants.

Case II: For the 2nd case scenario we have simulated the ground floor of the 2nd academic building having an area of 870 square meters with 7 rooms and a corridor. There are two exits in the floor with the main exit (Exit 1) having door width of 400.0 cm and the side exit (Exit 2) having door width of 225.0 cm. There are 50 students in each classroom and 25 students in each laboratory on the floor. The total number of occupants on the floor is 225 among them 160 occupants are males and 65 occupants are females.

Case III: For the 3rd case scenario, we have simulated the evacuation behavior of the occupants in the 2nd academic building up to the 4th floor with each floor having the area of 870 square meters with 6 rooms and a corridor. We have run two scenarios in this case, (1) first we run a simulation with 250 occupants in each floor including the ground floor totaling to 1250 occupants in the building with 880 male occupants and 370 female occupants. There are two exits in the ground floor with the main exit (Exit 1) having door width of 400.0 cm and the side exit (Exit 2) having door width of 225.0 cm. All our occupants will use either one of these exits to evacuate. (2) In the second simulation we take 250 occupants in each floor excluding the ground floor totaling to 1000 occupants in the building with 704 male occupant and 296 female occupants. We use this simulation to compare and validate our result using the equation given in the methodology. As the intention of the problem, it is assumed that all occupants on higher floors will exit from doors at the base of the stairs. For both simulations, each floor is served by two sets of stairs one having 195 cm width and the other having 117 cm width. Each stairway connects to a platform of 8.7 square meter and 6.1 square meters respectively. Both stairways have a rise of 18 cm and a run of 30 cm. The stairs have handrail on one side. The distance between the floors is 3.42 meters.

Case IV: In the 4th case scenario, we have simulated the evacuation of the occupants of the 1st Academic building up to the 4th floor. The ground floor has an area of 697 square meter with two exits. The middle exit (Exit 1) has a width of 400 cm and the side exit (Exit 2) has a width of 225 cm. All the upper floors have an area of 676 square meter. As the 1st academic building hosts all the departments of the university and some laboratories, we have assumed each floor has 13 teacher's room and 3 laboratories for the simplification of the simulation. In the evacuation simulation we have assumed 150 occupants in each floor totaling 750 occupants for the whole building at maximum occupancy. For the simulations, each floor is served by two sets of stairs one having 195 cm width and the other having 117 cm width excluding handrails. Each stairway connects to a platform of 8.7 square meter and 6.1 square meters respectively. Both stairways have a rise of 18 cm and a run of 30 cm. The stairs have handrail on one side. The distance between the floors is 3.42 meters.

Simulation Assumptions:

There are a number of influential factors in an evacuation simulation. To simplify the study, we have taken the following assumptions for all the four case scenarios that we have simulated in our study:

(a) The emergency will not cause personal harm or injury to the occupants.

(b) The emergency does not cause adverse effect to the road facilities in order to evacuate.

(c) The occupants will react to the fire alarm/emergency immediately and there's no delay in response.

(d) There are no disables people among the occupants.

(e) No occupant is in panics and can evacuate orderly.

Based on the layout data and occupant's data of the study area, a three-dimensional model of the buildings of the study area was built. After that we simulate the evacuation process for the four cases scenarios mentioned earlier and generate four evacuation simulation results.

3.3 Detecting fire hydrant using PyroSIM

PyroSIM permits us to intelligently see and change properties related with all objects in a model. PyroSIM is a graphical UI for the Fire Dynamics Simulator (FDS). PyroSIM causes you rapidly make and deal with the details of complex fire models. Bringing in any of the documents like IFC, DXF, DWG, FBX will significantly decrease the measure of time spent reproducing the engineering math.

In our research the simulation part will be done using two software. PyroSIM is one of them. With this tool we will use our DWG layout as the template, putting components like windows, doors, tables, chairs and everything. Then we will place an imaginary fire hydrant from where the fire shall occur and then run the program. After a while it will show us the exact time the, it will take to spread the fire and smoke all over the room and that can give us an approximate time to design an efficient fire escape route.

Case study:

We are simulating four scenarios in our study area which consist of the First Academic Building and Second Academic Building. In the First Academic Building there are 5 floors with each floor having an area of 50m x 13.25m and a height of 3.311m. In the Second Academic Building, there are 5 floors with each floor having an area of 50m x 18.74m and a floor height of 3.23m.

The fire is taken as a 2MW fire and the source of the fire is assumed to be a smartphone explosion. The fire spread properties have been set at 5m/s. The simulation parameters have been set at 600s. The Location of fire source is taken in Room 107 for First Academic Building and in Room 101 for Second Academic Building.

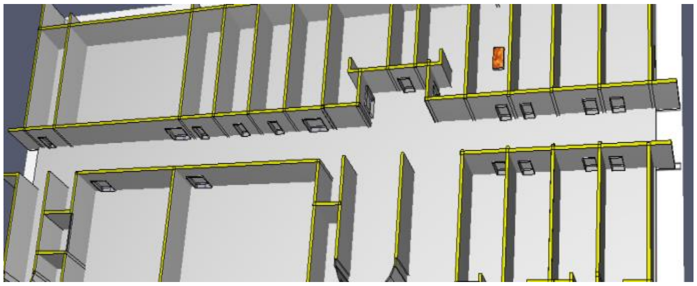


Fig 3.1: Location of fire in First Academic Building

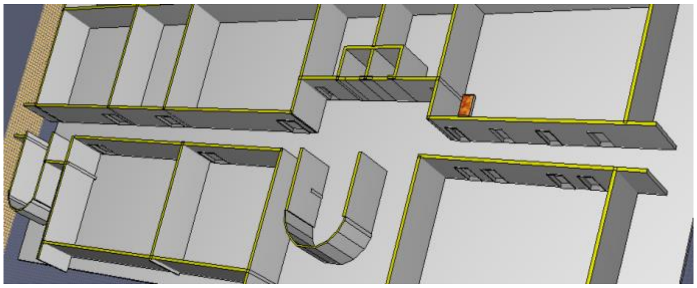


Fig 3.2: Location of fire in Second Academic Building

Case I: The fire source is considered to be in Room 107 of First Academic Building with all doors open and all windows closed.

Case II: The fire source is considered to be in Room 107 of First Academic Building with all doors open and all windows open.

Case III: The fire source is considered to be in Room 101 of Second Academic Building with all doors open and all windows closed.

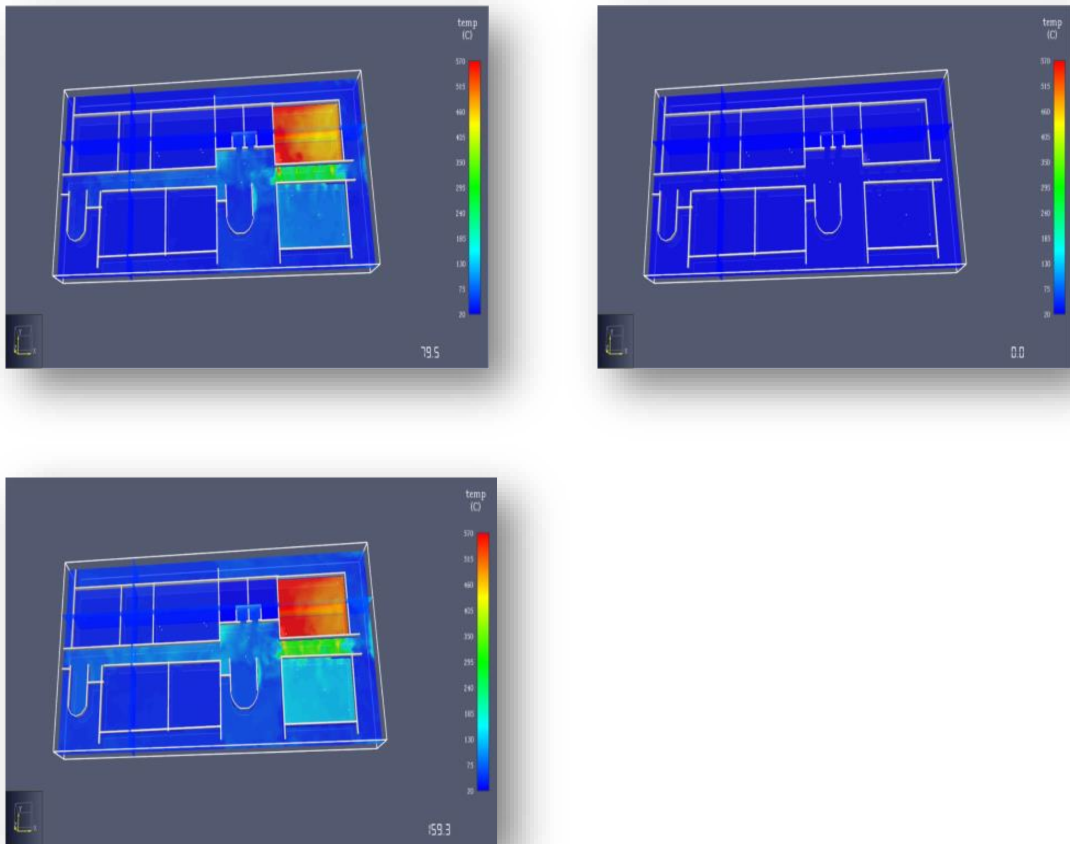


Fig 3.3: Temperature on different time interval

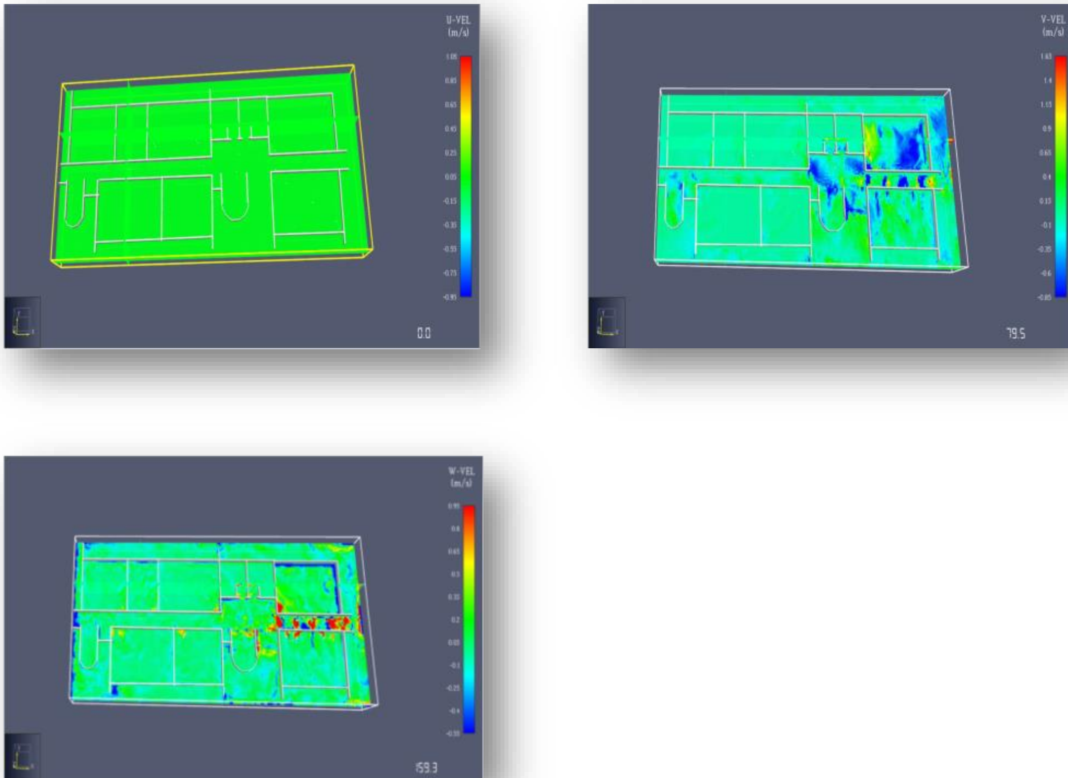


Fig 3.4: Smoke speed (m/s) towards X direction

Scenario IV: The fire source is considered to be in Room 101 of Second Academic Building with all doors open and all windows open.

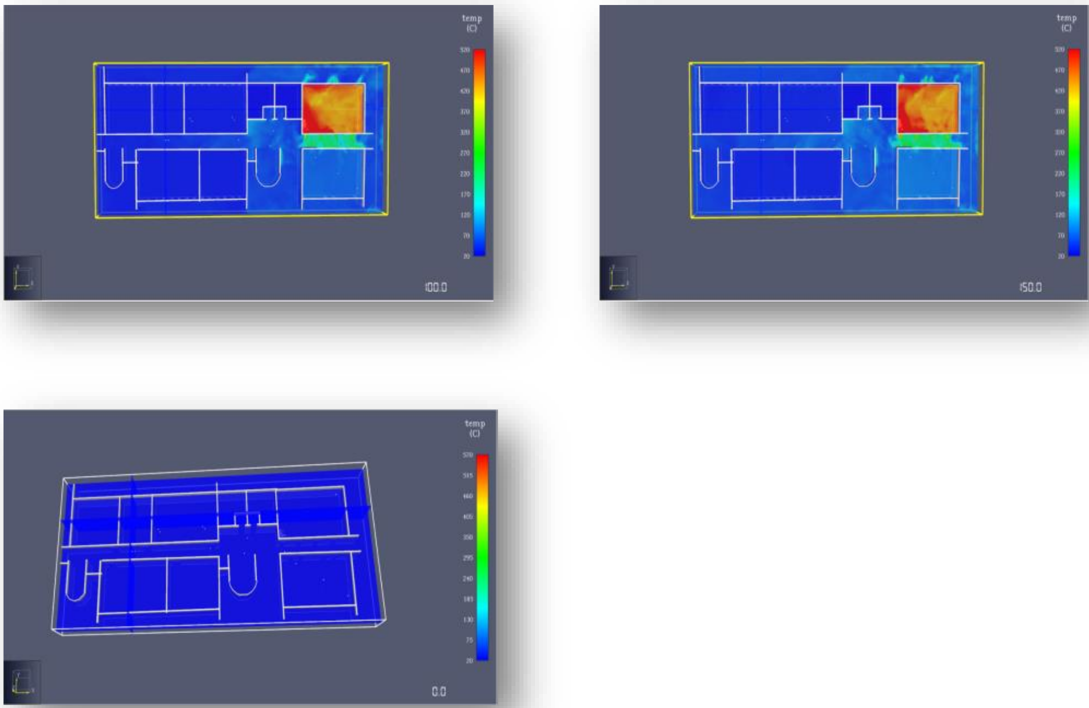


Fig 3.5: Temperature on different time interval

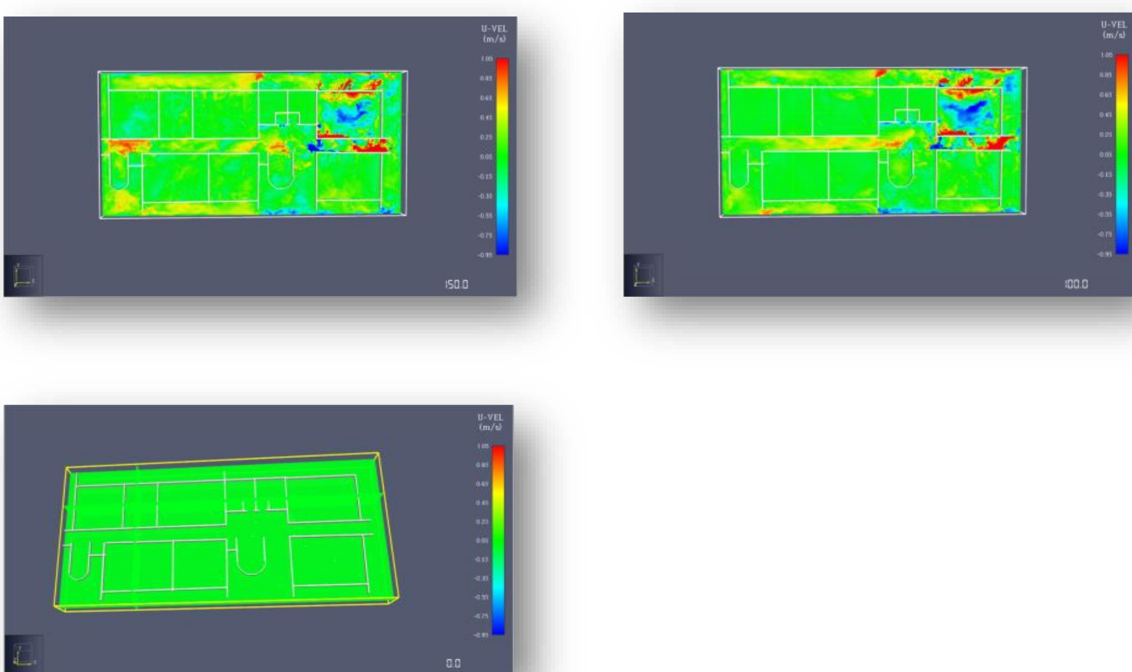


Fig 3.6: Smoke speed (m/s) towards X direction

We have simulated four scenarios for PyroSIM, taking two scenarios for open and closed conditions in First Academic Building and two more scenarios for open and closed conditions in Second Academic Building. The fires are located in a room at ground floor in each scenario. The heat and smoke escape faster when the windows are closed than when open, hence for the room containing the fire source the heat and smoke are less in open condition. Also, the heat and smoke are less in the room with the fire source in the Second Academic Building due to the size of the room being bigger.

4. Result & analysis

4.1 Pathfinder Simulation Results

Case I:

Setup Notes: Detailed scenario for Case I is presented in the methodology of this paper. We are simulating this problem in two modes: Steering mode and SFPE mode. Below Figure 4.1 shows the problem setup for Case I

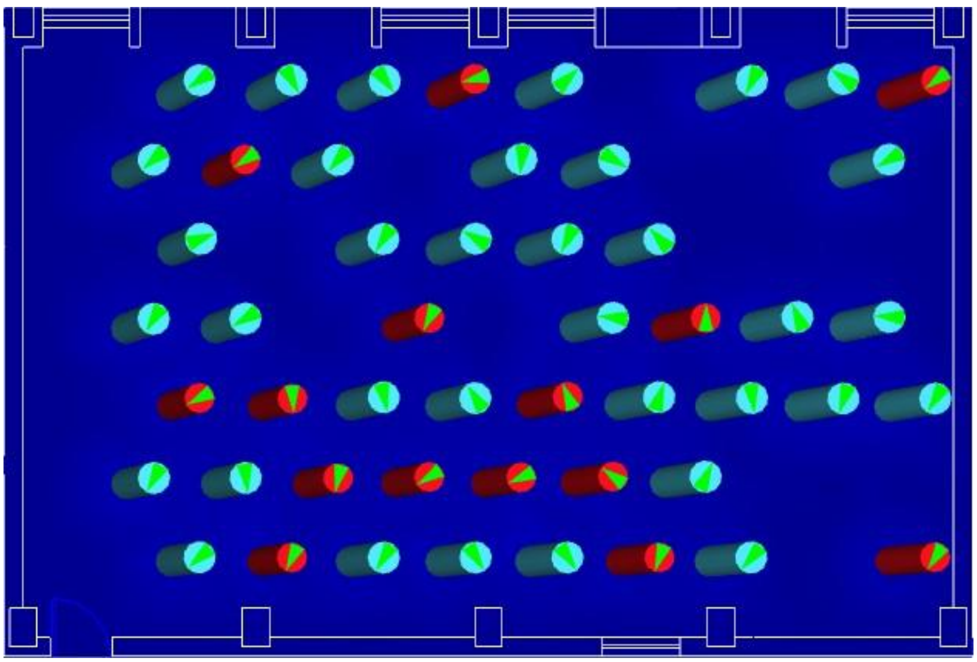


Figure 4.1: Case I problem setup

Results: For each simulation modes, the following tables list the results for both male and female occupants with their evacuation time and travelled distance to reach the one exit. The tables give details of the result with maximum, minimum and average evacuation time and distance for each occupant profiles. We also obtain the table and graph of flow rate of the door of our room. (Ye, 2020)[xxii]

Table 4.1: Results of Case I for Male profile

Male Profile		
	Evacuation Time(s)	Movement Distance(m)

Mode	Minimum Evacuation Time(s)	Average Evacuation Time(s)	Maximum Evacuation Time(s)	Minimum Movement Distance(m)	Average Movement Distance(m)	Maximum Movement Distance(m)
Steering	1.8	28.7	52.6	1.7	9.3	19.2
SFPE	1.3	39.6	72.8	1.6	7.2	11.6

Table 4.2: Results of Case I for Female profile

Female Profile						
	Evacuation Time(s)			Movement Distance(m)		
Mode	Minimum Evacuation Time(s)	Average Evacuation Time(s)	Maximum Evacuation Time(s)	Minimum Movement Distance(m)	Average Movement Distance(m)	Maximum Movement Distance(m)
Steering	3.5	23.0	51.1	2.7	7.9	20.8
SFPE	4.3	33.6	74.3	2.5	6.4	12.6

Table 4.3: Door flow rates of Case I problem

Door Flow Rates				
	Door 00(Exit)			
Mode	First in(s)	Last out(s)	Total Use(pers)	Flow Avg. (pers/s)
Steering	1.8	52.6	50	0.98
SFPE	1.3	74.3	50	0.69

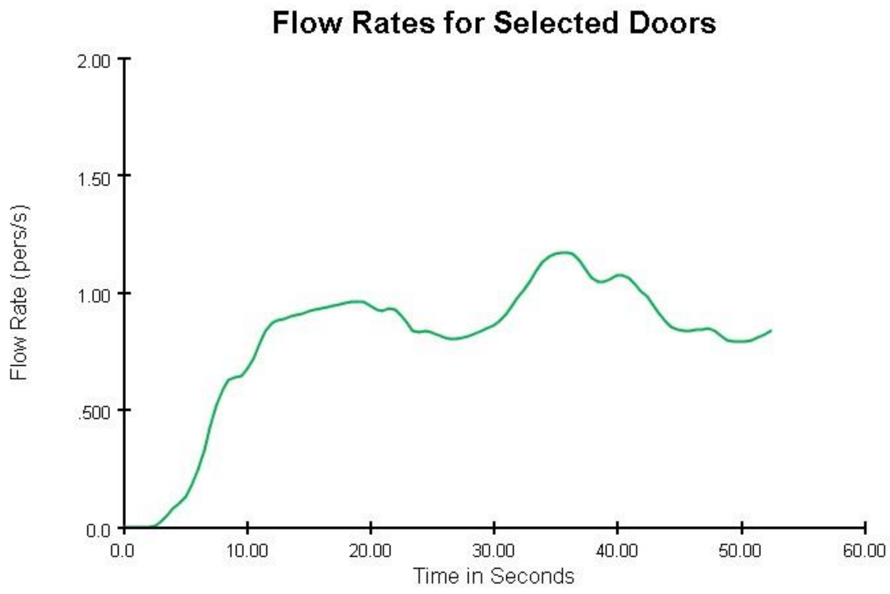


Figure 4.2: Door flow rates in Steering method

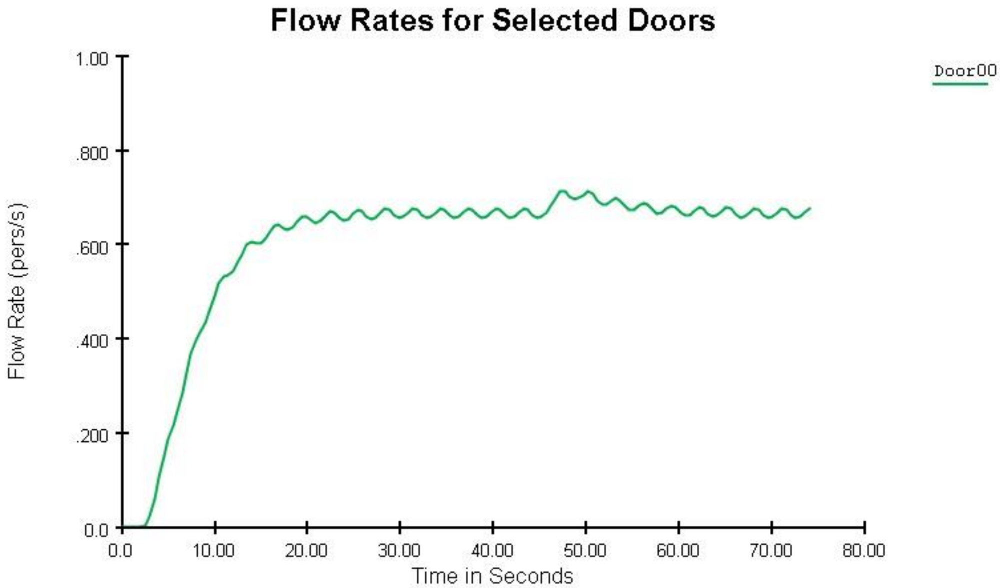


Figure 4.3: Door flow rates in SFPE method

From the simulation of Case I, we find that there's some time difference for the evacuation between two modes used here. Because steering mode doesn't represent queue and occupants tend to avoid one another it takes less time to evacuate in this mode. On the other hand, in SFPE mode occupants make no attempt to avoid each other and can interpenetrate and also door imposes a flow limit so it takes more evacuation time representing a close realistic value.

Case II:

Setup Notes: Detailed setup notes and dimensions for Case II have been presented in the methodology of this paper. We are simulating this problem in both Steering and SFPE mode and we have two exits with different width. The problem setup for Case II is given in Figure 4.4

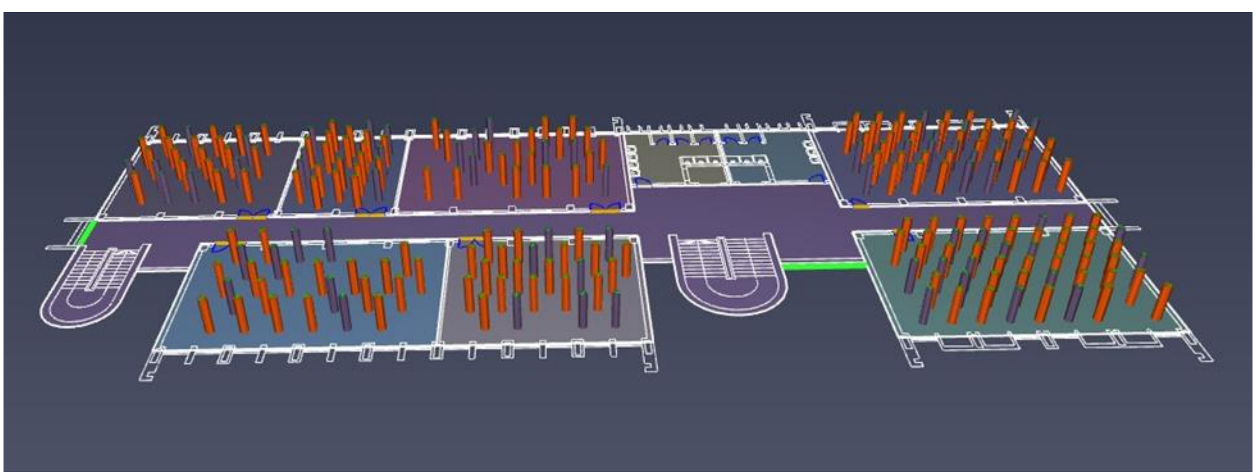


Figure 4.4: Case II problem setup

Results: For each simulation modes, the following tables list the results for both male and female occupants with their evacuation time and travelled distance to reach both exits. The tables give details of the result with maximum, minimum and average evacuation time and distance for each occupant profiles. We also obtain the table and graph of flow rates of the exits of the floor.

Table 4.4: Results of Case II for Male profile

Male Profile						
	Evacuation Time(s)			Movement Distance(m)		
Mode	Minimum Evacuation Time(s)	Average Evacuation Time(s)	Maximum Evacuation Time(s)	Minimum Movement Distance(m)	Average Movement Distance(m)	Maximum Movement Distance(m)
Steering	7.1	29.6	66.5	8.0	18.5	32.4
SFPE	5.7	30.0	78.8	7.1	15.2	30.9

Table 4.5: Results of Case II for Female profile

Female Profile						
	Evacuation Time(s)			Movement Distance(m)		
Mode	Minimum Evacuation Time(s)	Average Evacuation Time(s)	Maximum Evacuation Time(s)	Minimum Movement Distance(m)	Average Movement Distance(m)	Maximum Movement Distance(m)
Steering	6.0	30.5	67.1	6.8	18.3	35.5
SFPE	5.5	31.2	78.4	6.8	15.0	26.4

Table 4.6: Door flow rates of Case II problem

Door Flow Rates								
	Exit 1				Exit 2			
Mode	First in(s)	Last Out (s)	Total Use(pers)	Flow Avg. (pers/s)	First in(s)	Last Out (s)	Total Use(pers)	Flow Avg. (pers/s)
Steering	6.0	67.1	150	2.45	8.1	38.4	75	2.48
SFPE	5.5	78.8	151	2.06	7.1	35.7	74	2.59

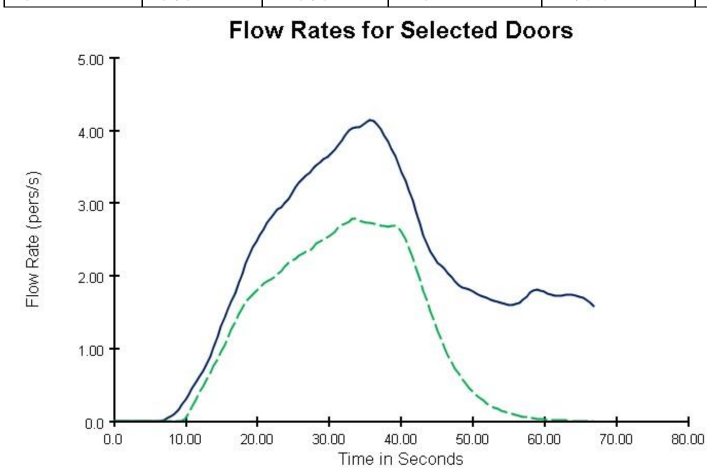


Figure 4.5: Door flow rates in Steering method for Case II

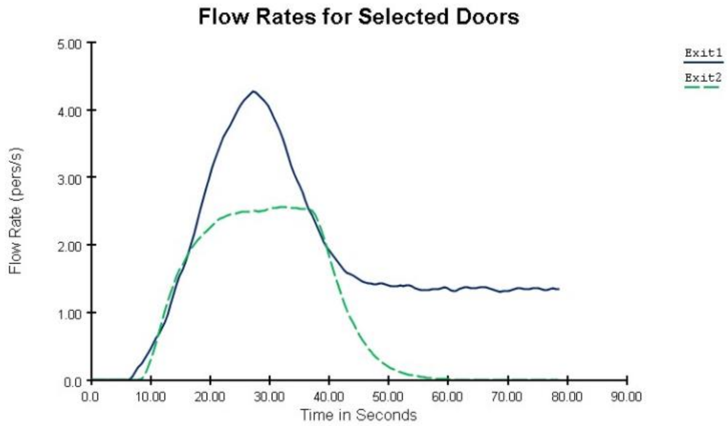


Figure 4.6: Door flow rates in SFPE method for Case II

From the simulation of Case II, we also find here that there's some time difference for the evacuation between two modes used here. Because steering mode doesn't represent queue and occupants tend to avoid one another it takes less time to evacuate in this mode. On the other hand, in SFPE mode occupants make no attempt to avoid each other and can interpenetrate. In SFPE method, the occupants tend to move in queue which can be seen in figure 4.7. Also in this method door imposes a flow limit so it takes more evacuation time for the occupants.

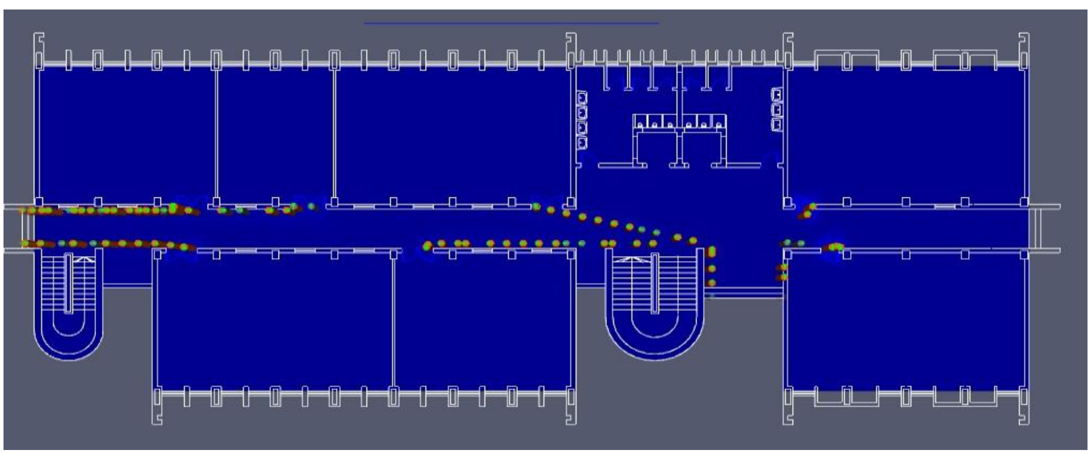


Figure 4.7: Figure of evacuation simulation of Case II problem in SFPE mode.

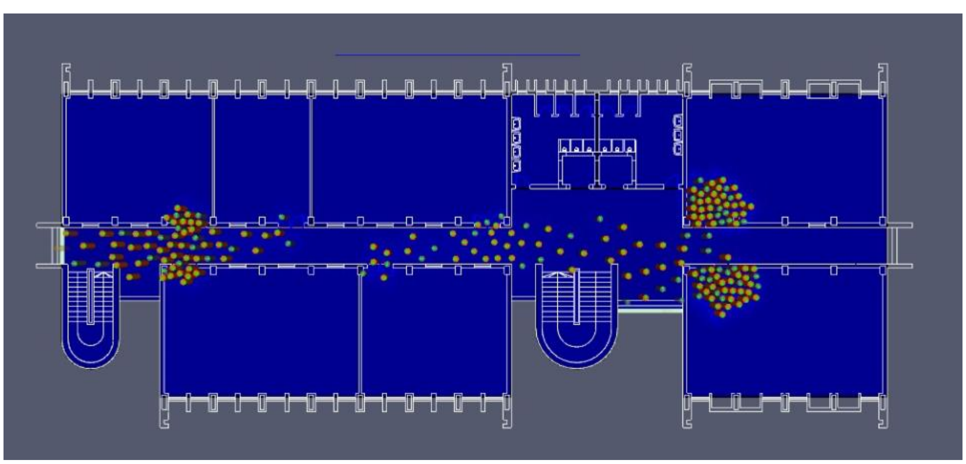


Figure 4.8: Figure of evacuation simulation of Case II problem in Steering mode.

Case III:

Setup Notes: Detailed setup notes and description for Case III have been presented in the methodology of this paper. We are simulating this problem in both Steering and SFPE mode and we have two exits with different width. The 2^{nd} simulation data would be used to compare and validate the results. Figure 4.9 shows the problem setup for Case III

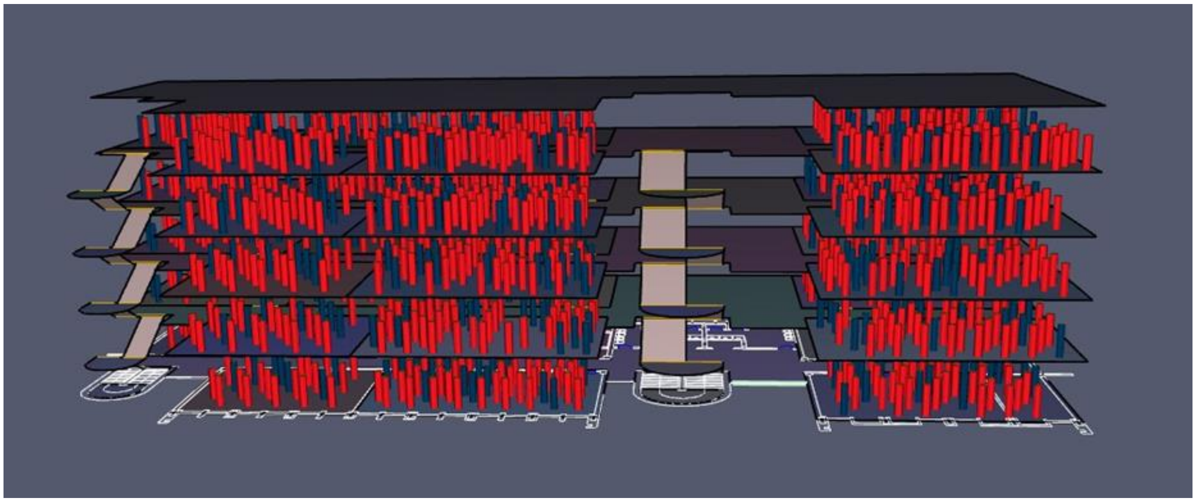


Figure 4.9: Case III problem setup

Results: We have found the following results for both male and female occupants with their evacuation time and travelled distance to reach both exits for each simulation mode for Case III problem setup including the ground floor. The tables give details of the result with maximum, minimum and average evacuation time and distance for each occupant profiles. We also obtain the table and graph of flow rates of the exits of the floor.

Table 4.7: Results of Case III for Male profile

Male Profile						
	Evacuation Time(s)			Movement Distance(m)		
Mode	Minimum Evacuation Time(s)	Average Evacuation Time(s)	Maximum Evacuation Time(s)	Minimum Movement Distance(m)	Average Movement Distance(m)	Maximum Movement Distance(m)
Steering	7.2	184.6	461.8	7.4	54.1	158.9
SFPE	5.5	172.5	417.6	6.0	36.8	87.6

Table 4.8: Results of Case III for Female profile

Female Profile						
	Evacuation Time(s)			Movement Distance(m)		
Mode	Minimum Evacuation Time(s)	Average Evacuation Time(s)	Maximum Evacuation Time(s)	Minimum Movement Distance(m)	Average Movement Distance(m)	Maximum Movement Distance(m)
Steering	6.0	182.9	457.7	6.6	52.9	189.6

SFPE	4.9	179.1	415.9	6.0	36.3	85.3

Table 4.9: Door flow rates of Case III problem

Door Flow Rates								
	Exit 1				Exit 2			
Mode	First in(s)	Last Out (s)	Total Use(pers)	Flow Avg. (pers/s)	First in(s)	Last Out (s)	Total Use(pers)	Flow Avg. (pers/s)
Steering	6.0	446.0	794	1.80	8.1	461.8	456	1.01
SFPE	4.9	417.6	821	1.99	7.2	366.5	429	1.19

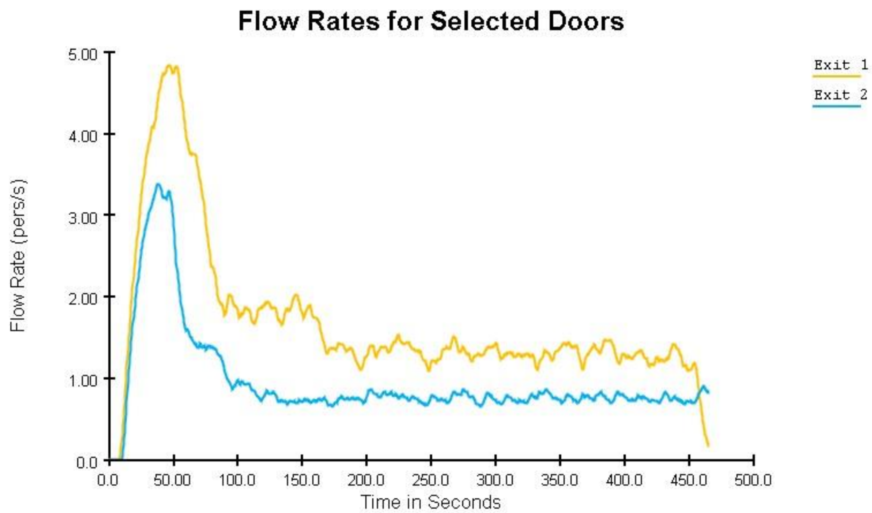


Figure 4.10: Door flow rates in Steering method for Case III

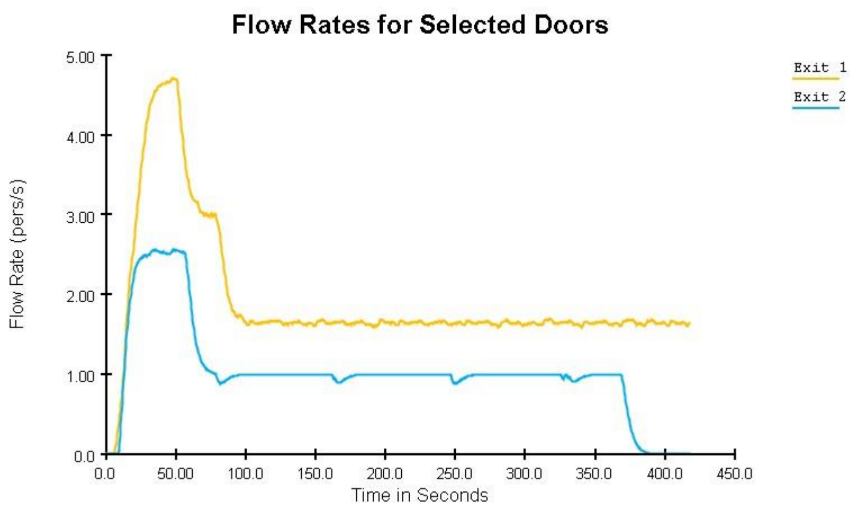


Figure 4.11: Door flow rates in SFPE method for Case III

From the simulation of Case III, we find here that the evacuation time of two modes is different and SFPE mode is quicker than Steering mode. It is because steering mode represents occupants moving individually which forms congestion and queues. Occupants also tend to avoid one another so to evacuate a full building it takes longer times for occupants to climb down the stairs and evacuate through one of the exits. On the other hand, in SFPE mode occupants make no attempt to avoid each other and can interpenetrate and also the occupants tend to forms queues in line and move taking the shortest route which in a large evacuation scenario is very helpful as it keeps order among the occupants. This is why we also find that in SFPE mode the occupants had to travel significantly less distance compared to steering mode in order to find their exit. So SFPE mode will provide us with quicker evacuation time even though this method door imposes a flow limit so it takes more evacuation time for the occupants.

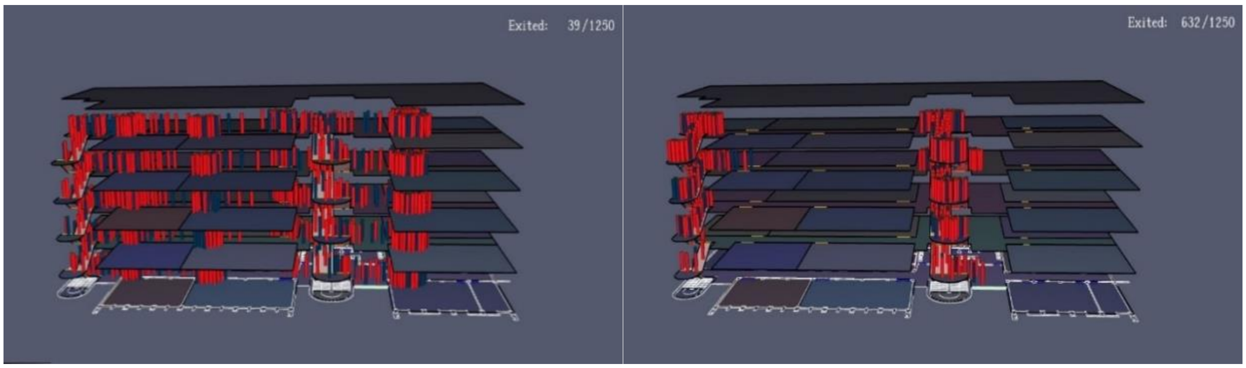


Figure 4.12: Figure of evacuation simulation of Case III in Steering mode

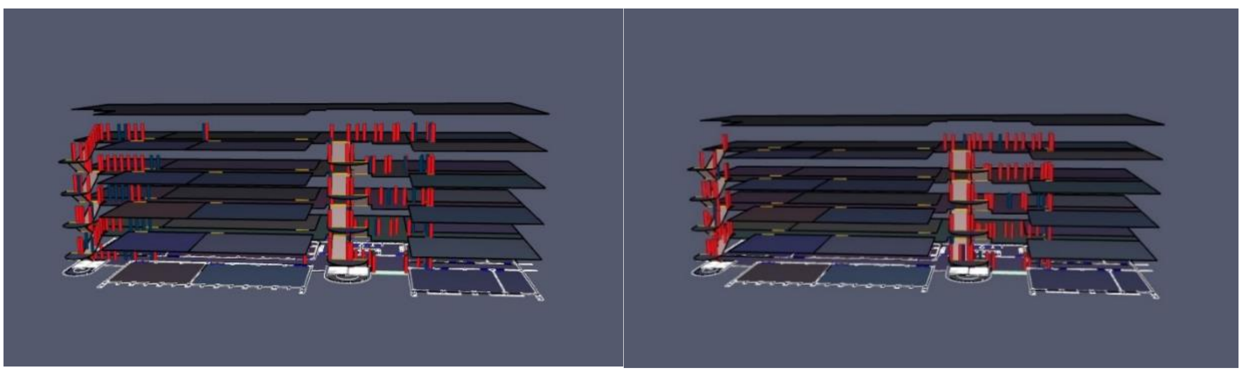


Figure 4.13: Figure of evacuation simulation of Case III in SFPE mode

Verification test of Case III: In order to find out the verification of the results we ran the second simulation of Case III where we take 250 occupants in each floor excluding the ground floor totaling to 1000 occupants in the building with 704 male occupant and 296 female occupants. As the intention of the problem, it is assumed that all occupants on higher floors will exit from doors at the base of the stairs. Figure 4.14 shows the problem setup.

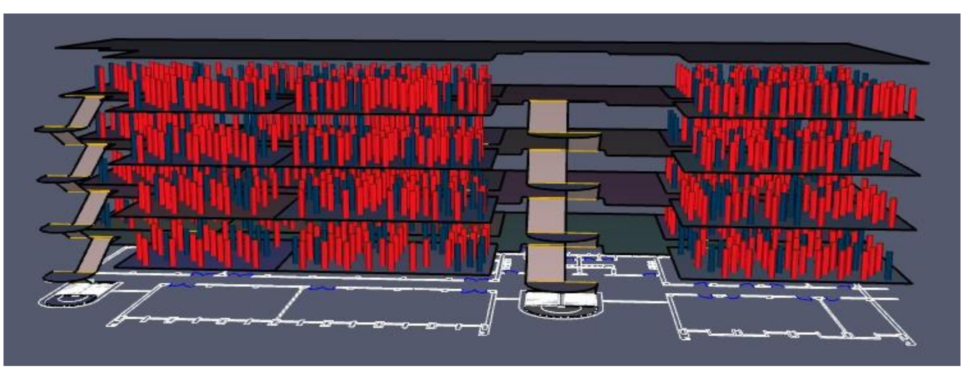


Figure 4.14: Problem setup of Case III verification test

Expected Results: As we are using two different staircases with different stairs width and exit width in our simulation, we are assuming two-third (667) of the occupants would be using the larger staircase whereas one-third (333) of the occupants would be using the smaller staircase. As we are using two different occupant profiles with two different velocities, we are using the weighted velocity of the two different profiles in our calculations. We are assuming a low-density velocity calculation for the first occupant to reach the stairs and landing.

<u>For Exit 1:</u> For T_A we assume an occupant must walk 6 meter to reach the center of the stairs. For T_B and T_D we will assume the occupant must walk 4 meter to move down the stairs. For $T_C$we will assume the occupant must walk 3 meters, an average length of travel, to traverse the platform. These is giving the following calculations:

$$v_{level} = 1.30\ m/s$$

$$v_{stairs} = 1.05\ m/s$$

$$T_A = \frac{d}{v_{level}} = \frac{6}{1.30} = 4.6\ s$$

$$T_B + T_D = 2\left(\frac{d}{v_{stairs}}\right) = 2\ \left(\frac{4}{1.05}\right) = 7.6\ s$$

$$T_C = \frac{d}{v_{level}} = \frac{3}{1.30} = 2.3\ s$$

$$T_1 = T_A + T_B + T_C + T_D = 4.6 + 7.6 + 2.3 = 14.5\ s$$

The time for 667 people to move through a 195 cm exit, T_2 is:

$$T_2 = \frac{P}{F_{s(\max)}W_e} = \frac{667}{1.32 \times (1.95 - 2 \times 0.15)} = 306.24\ s$$

The time for the last person to move from the stairs to the exit,T_3 is:

$$T_3 = \frac{d}{v_{level}} = \frac{1.5}{1.30} = 1.15\ s$$

The total evacuation time, T_{TOTAL} is:

$$T_{TOTAL1} = T_{1+} T_2 + T_3 = 14.5 + 306.24 + 1.15 = 321.89\ \approx 322\ s$$

<u>For Exit 2:</u> For T_A we assume an occupant must walk 6.5 meter to reach the center of the stairs. For T_B and T_D we will assume the occupant must walk 4 meter to move down the stairs. For T_C we will assume the occupant must walk 3 meters, an average length of travel, to traverse the platform. These is giving the following calculations:

$$v_{level} = 1.30\ m/s$$

$$v_{stairs} = 1.05\ m/s$$

$$T_A = \frac{d}{v_{level}} = \frac{6.6}{1.30} = 5\ s$$

$$T_B + T_D = 2\left(\frac{d}{v_{stairs}}\right) = 2\ \left(\frac{4}{1.05}\right) = 7.6\ s$$

$$T_C = \frac{d}{v_{level}} = \frac{3}{1.30} = 2.3\ s$$

$$T_1 = T_A + T_B + T_C + T_D = 5 + 7.6 + 2.3 = 14.9\ s$$

The time for 333 people to move through a 117 cm exit, T_2 is:

$$T_2 = \frac{P}{F_{s(\max)}W_e} = \frac{333}{1.32 \times (1.17-2\times0.15)} = 289.9\ s$$

The time for the last person to move from the stairs to the exit, T_3 is:

$$T_3 = \frac{d}{v_{level}} = \frac{1.5}{1.30} = 1.15\ s$$

The total evacuation time, T_{TOTAL} is:

$$T_{TOTAL2} = T_{1+} T_2 + T_3 = 14.9 + 289.9 + 1.15 = 305.95 \approx 306\ s$$

Results: We have listed the results for both exits with the number of occupants that used the exit for both simulation mode in the following table 4.1.10.

Table 4.10: Results of Case III problem setup without ground floor

Mode	Exit 1 used by (Pers)	Exit 2 used by (Pers)	Maximum time req. for exit 1(s)	Maximum time req. for exit 2(s)
Steering	639	361	438.1	455.6
SFPE	679	321	428.6	341.0

From the simulation results we find that the evacuation time that we find from the simulation differs a little from the expected results but within tolerance. We find the root cause of the difference is the number of people assumed to use the each exits in the calculation is not equal to the number of people using that exit in the simulation. Because of this, the evacuation time for both exits is different for the simulation. Another cause for the different pathing can be that when queues form on the upper floor, people waiting in the queues can decide to leave their current queue when another door begins to flow even if the flow is intermittent. The resulting back and forth behavior do not drastically change the total evacuation time but it can be unexpected and the delay is not calculated in the expected results. So, the variations of the results from the calculation can be accepted.

Case IV:

Setup Notes: Detailed setup notes and description of Case IV scenario have been presented in the methodology of this paper. We are simulating this problem in both Steering and SFPE mode and we have two exits with different width. The problem setup for Case IV is given in the Figure 4.15

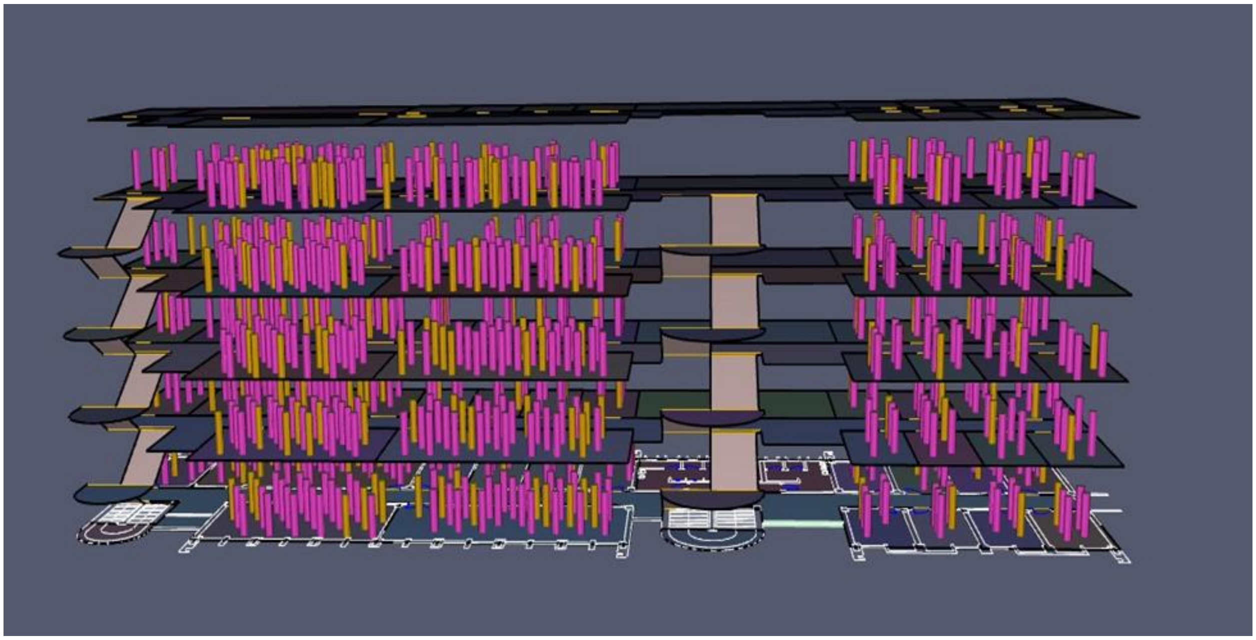


Figure 4.15: Case IV problem setup

Results: We have found the following results for both male and female occupants with their evacuation time and travelled distance to reach both exits for each simulation mode for Case IV problem setup. The tables give details of the result with maximum, minimum and average evacuation time and distance for each occupant profiles. We also obtain the table and graph of flow rates of the exits of the floor.

Table 4.11: Results of Case IV for Male profile

Male Profile						
	Evacuation Time(s)			Movement Distance(m)		
Mode	Minimum Evacuation Time(s)	Average Evacuation Time(s)	Maximum Evacuation Time(s)	Minimum Movement Distance(m)	Average Movement Distance(m)	Maximum Movement Distance(m)
Steering	2.3	135.6	390.8	2.2	48.5	121.5
SFPE	1.7	96.0	256.8	2.1	35.2	63.4

Table 4.12: Results of Case IV for Female profile

Female Profile						
	Evacuation Time(s)			Movement Distance(m)		
Mode	Minimum Evacuation Time(s)	Average Evacuation Time(s)	Maximum Evacuation Time(s)	Minimum Movement Distance(m)	Average Movement Distance(m)	Maximum Movement Distance(m)
Steering	6.8	140.8	389.2	4.9	47.6	99.2
SFPE	3.3	98.5	254.1	3.5	35.3	60.2

Table 4.13: Door Flow rates of Case IV problem

Door Flow Rates

	Exit 1				Exit 2			
Mode	First in(s)	Last Out (s)	Total Use(pers)	Flow Avg. (pers/s)	First in(s)	Last Out (s)	Total Use(pers)	Flow Avg. (pers/s)
Steering	6.2	279.8	319	1.17	2.3	390.8	431	1.11
SFPE	5.0	144.5	328	2.35	1.7	256.8	422	1.65

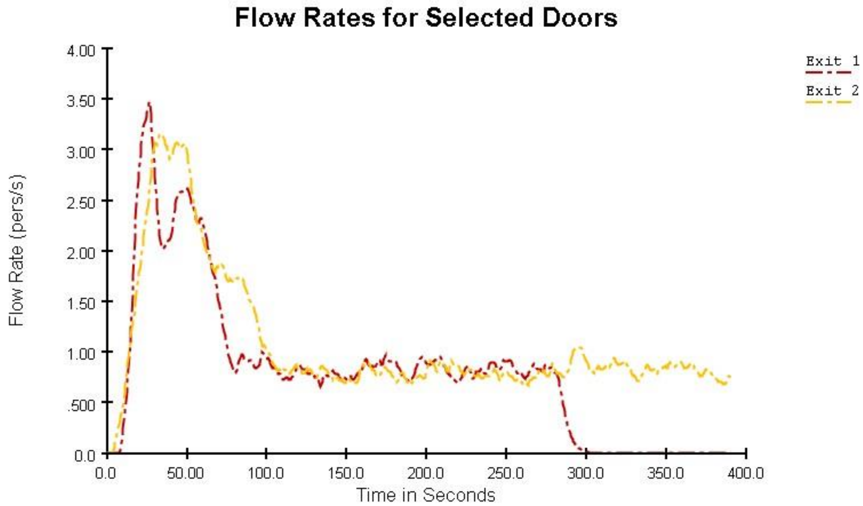


Figure 4.16: Door flow rates in Steering method for Case IV

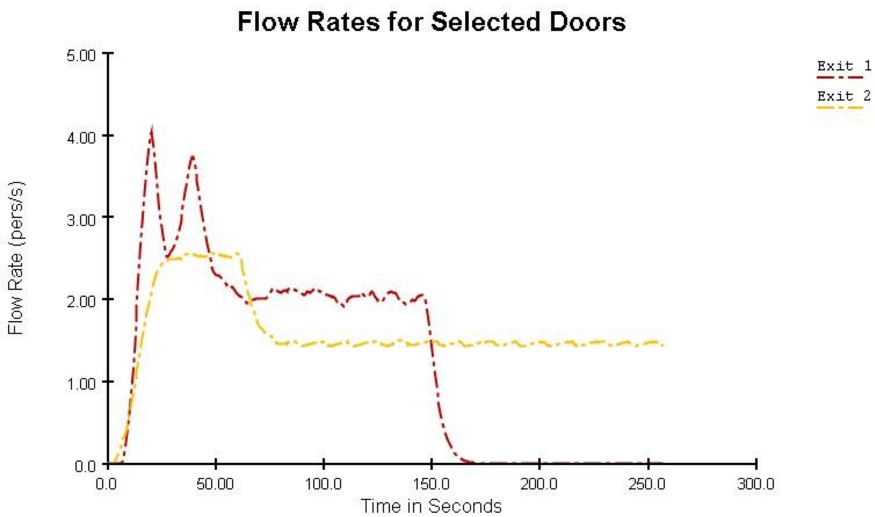


Figure 4.17: Door flow rates in SFPE method for case IV

From this simulation of Case IV, we find there's a significant difference between the evacuation times of two modes. Evacuation time required for steering mode is more than that of SFPE mode. It is because in steering mode occupants' forms congestion and queues in fronts of exits as they move individually and not in a group. On the other hand, in SFPE mode occupants move in line in queues and they move in a group making no attempt to avoid each other and can interpenetrate which in a large evacuation scenario is very helpful as it keeps order among the occupants. We also find that in SFPE mode the occupants had to travel significantly less distance compared to steering mode in order to find their exit than steering mode. In the case of 1st academic building, we find here that more than half of the occupants intends to take the side stairs and side exits in order to evacuate. It is because the door of the laboratories is closer to the side stairs than to the middle's stairs. Because of these occupants instinctively choose the side exit as closer to them and use this exit to evacuate. But the side stairs and the side exit width are smaller than the middle exit so it the evacuation time required here is significantly more. In the evacuation plan for the 1st academic building, the middle stairs should be used and highlighted as the emergency exit so more occupants would use this exit to evacuate. This will decrease the required evacuation time for the 1st academic building even more.

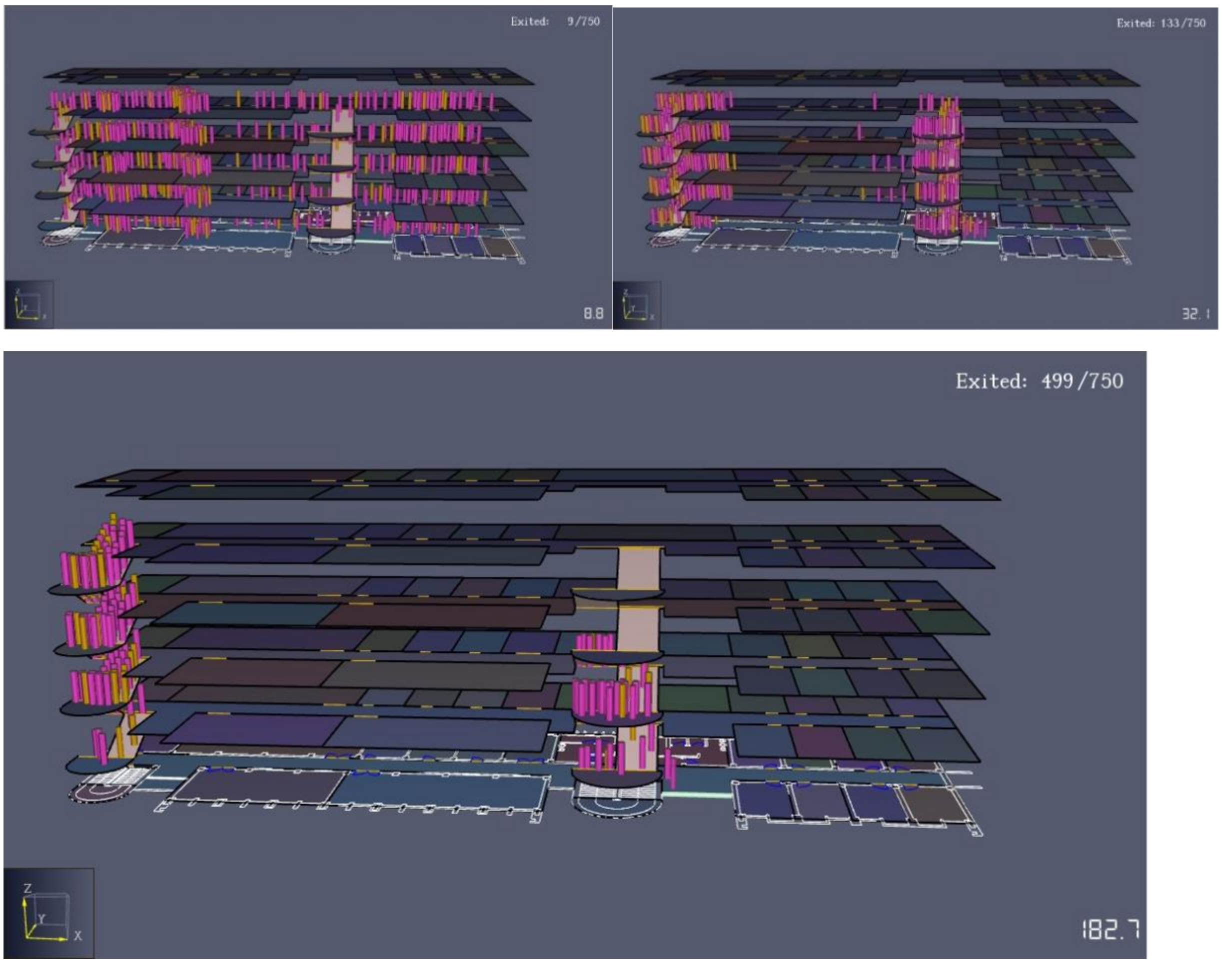
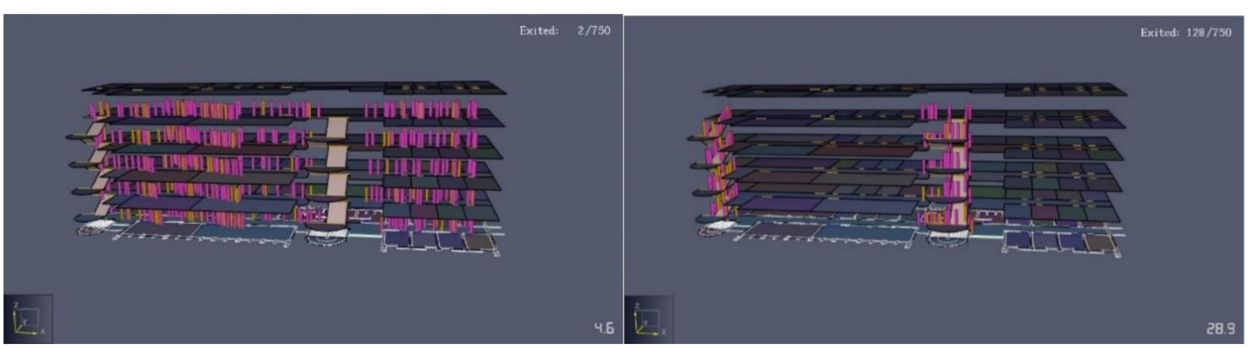


Figure 4.18: Figure of evacuation simulation of Case IV in steering mode



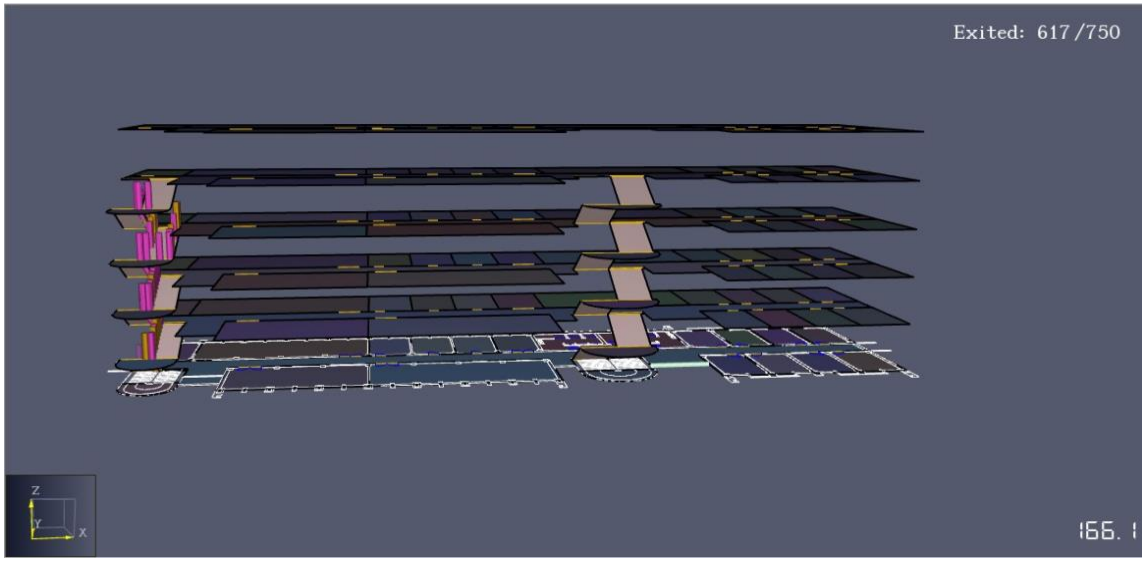


Figure 4.19: Figure of evacuation simulation of Case IV in SFPE mode

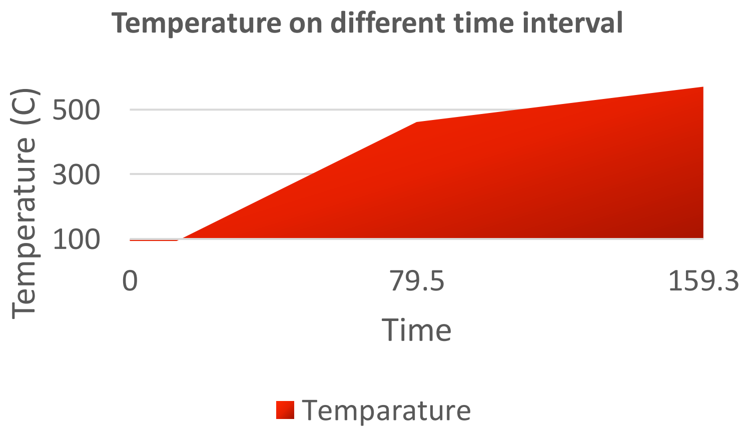
4.2 PyroSIM Simulation results

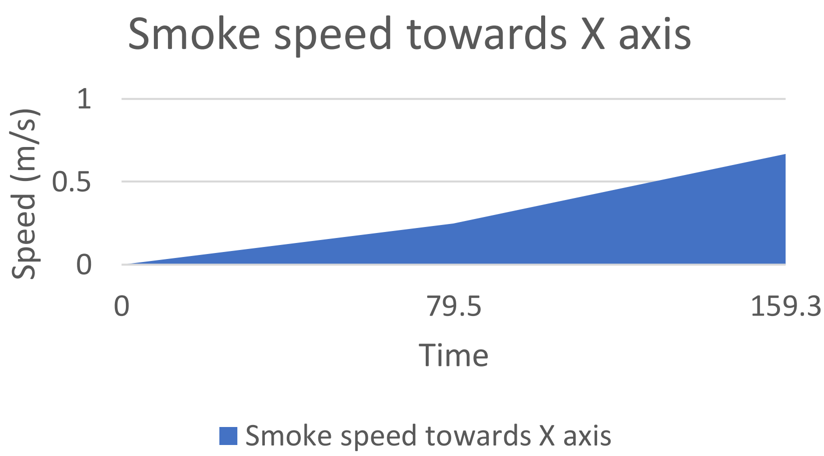
Results:

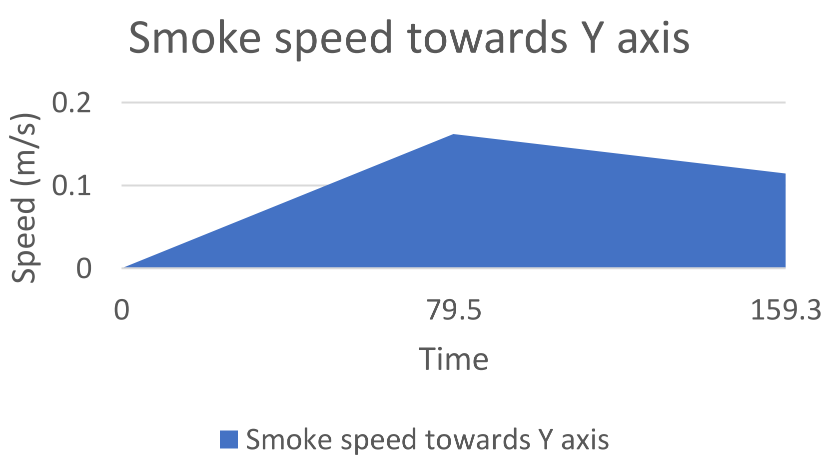
Case I:

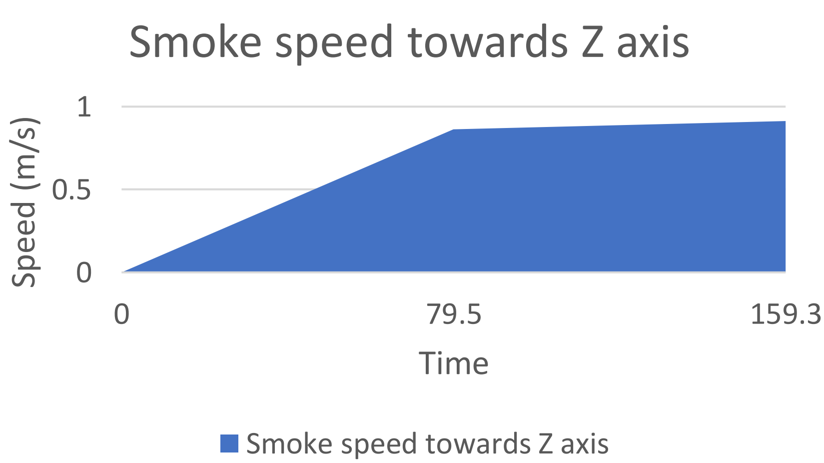
On the previous chapter (3.3 Detecting fire hydrant using PyroSIM) the heatmaps and initial plan design shows a basic idea of our university academic building floor plan. Which was drawn by using official AutoCAD design provided by the authority.

The heatmap shows the intensity of smoke by specific time intervals and how long the smoke will be present. The graphs below are the number and chart format of the graphic outcome in the previous chapter.

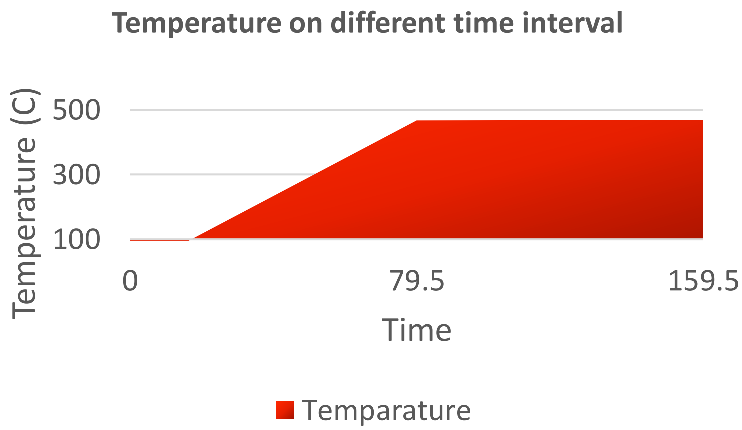


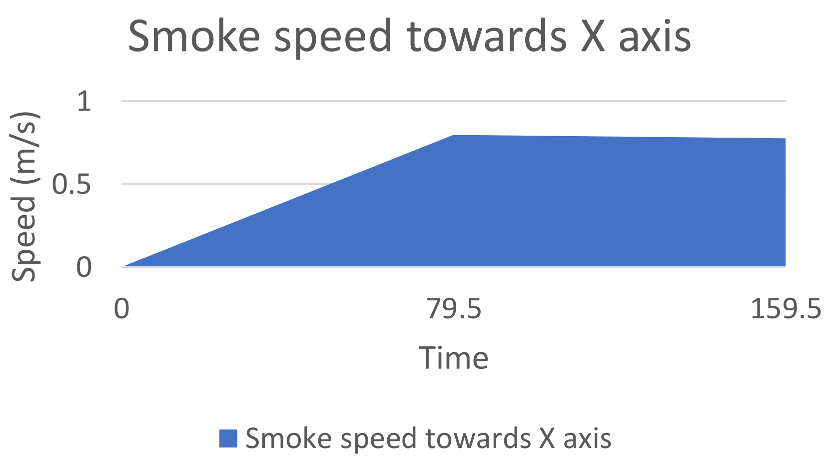

Smoke speed towards X axis
Speed (m/s)
1
0.5
0
0
79.5
159.3
Time
Smoke speed towards X axis


Smoke speed towards Y axis
Speed (m/s)
0.2
0.1
0
0
79.5
159.3
Time
Smoke speed towards Y axis


Smoke speed towards Z axis
Speed (m/s)
1
0.5
0
0
79.5
159.3
Time
Smoke speed towards Z axis

Case II:





Due to open window smoke will be extinguished through window and ventilation towards Y and Z axis.

4.3 Chapter Summary

This chapter is the outcome of our entire research which includes two different simulations ran by the team to conclude towards our one of the core objectives that is to propose an improve fire management system in our university premises, which might inspire the educational institution to implicate on their civil structures as well.

Our test subject was the 1st and 2nd Academic Building of IUT, where we prefixed a time based on our observation when the occupant density or crowd density reaches at its maximum level. The data helped us to create a scenario in the Pathfinder software using demo occupants. Pathfinder figures developments at prudent time steps and it ascertains tenant's controlling pace bit by bit. This model would give both a subjective and quantitative outcome. The reenactment will likewise give us clearing times, room use and entryway stream rates just as a 3-D portrayal of the entire departure measure. We will actually want to decide the greatest and least departure time just as normal time required for inhabitants. We will likewise get the most extreme distance an inhabitant needs to venture out to discover the closest exit and see the use stream pace of each way out.

Then the other half of the research team conducted the simulation on PyroSIM. Before running the program, we had to create a demo image of our Academic Building floors. AutoCAD plan designs were required for this operation. After successfully replicating the floor plans, a fire hydrant was fixed from where the fire would occur and create a scenario that will give us the desired result of how long it takes to fill the room with smoke. Since our model was based on a full-fledged floor plan, the estimated simulation end time was stated at 600s which had a run time of 14 hours. But after 150s the simulation showed that it will be covered completely with smoke. Hence, we divided the scenario into three stages 0s, 79s and 159s.

5. Proposed Improved Fire Evacuation Management Plan

Before we proposed our Improved Fire Evacuation plan, we had to evaluate the reasons for the necessity of an improved plan. So, in order to come up with an improved and efficient fire evacuation proposal, in this project, we conducted a comparison study between the proposed civil structure dimensions with the already available local guidelines. The result of this study has been shown below in the table-

Table 5.1 Comparison between local guideline and current civil structure components

Building construction act	**Current condition of IUT**	**Remarks**
Exits should be design in such a way that ensures barrierless Means of escape from every section of the building. (article 03.04)	The university area has an open sky roadway which can be used as an escape route.	✓
According to guidelines the exit floor area for users should be at least 2 sqm per head (article 05)	Reviewing plan drawing, IUT classroom has more than a 2 sqm floor area per head.	✓
Width of stair should be 2 m (article 7)	Main entrance stair is 2 m Staircase 2 is 1.9 m	✓ ✗
Exit doors should be at least 4 mm per head. (article 5 table 2)	Exit doors are 4 mm per head	✓
If fire exit stair greater than 1 m; 2 handrails on each direction is required.	One handrail	✗
Width of corridor should be 1.1m(article 06.01)	Corridor width is 2.2 m	✗

After reviewing the comparison, the team concluded to some major deficiencies in IUT Fire management system. Here are the points:

- No assembly points.
- No fire alarm.
- No emergency exit point.
- No emergency exit door.
- No handrails.

The comparative study also reflected the requisite of a fixed Main Exit for evacuation plan. After close consideration the team decided to declare the main exit of the building as the primary Fire Exit door. Here are the reasons why it should be the main exit –

- The middle staircase of IUT has a width of 4 meters with one sided hand rails. The local regulation for fire safety stair's width for educational institutions with user more than 150 on each floor is 2 meters. So, our main staircase complies with the regulation.
- Both sides have walls, so after installing fire door smoke propagation control will increase.
- The regulation also requires to have handrails on both sides for stairs with more than 1 meter width. So, our main staircase will need to construct handrails on the other side to make it a proper fire safety staircase.

The Exit Door proposal requires a well-directed exit route as well. The figure below is a demo plan view of the ground floor of 2nd Academic Building. The yellow mark shows the exit routes of two exit doors. The marks will be painted with neon painting so that it will be visible in dense smoke.

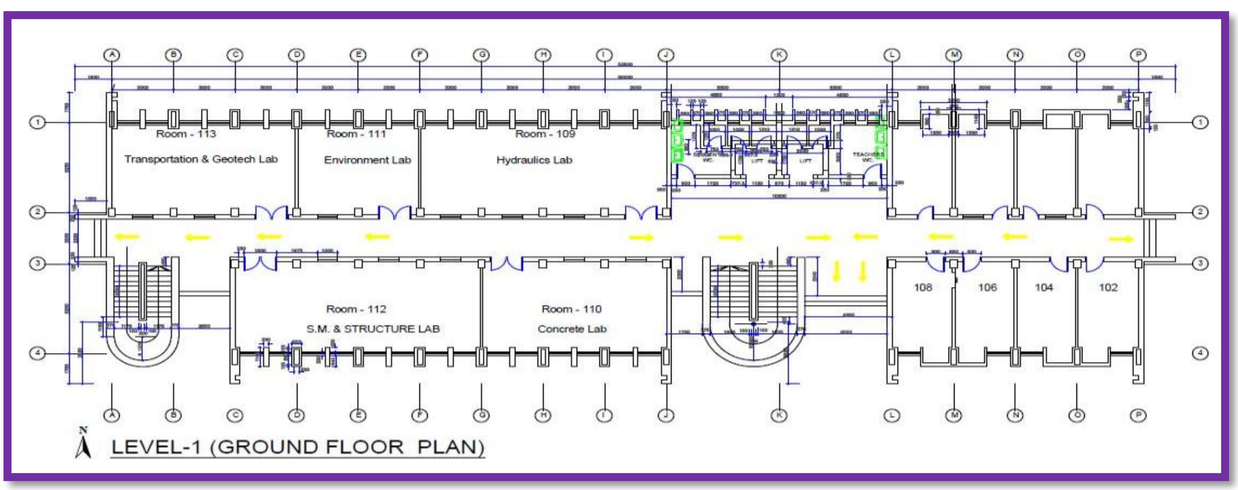


Figure 5.1 Probable Fire Evacuation Route towards fire exits

6. Conclusion:

From the very beginning of our study, we have seen that how can be a fire incident dangerous for any country or any institution. For any building, the infrastructure always plays a vital role in any kind of hazard whether it will earthquake or fire-related incidents. As we have simulated PyroSIM and Pathfinder for the data of the second academic building of IUT and the results.

- We have found by PyroSIM the Smoke velocity on the different periods and by Pathfinder, in SFPE and steering mode we are having two modes. SFPE mode is better for larger-scale evacuation in an orderly manner because as we know in steering mode occupants don't move in line or groups and don't interpenetrate.
- In SFPE mode occupants tend to move in a line and can interpenetrate with other groups in steering mode it shows congestion and queue arises exit of the route and in SFPE mode there will be no congestion. In this study, the pathfinder software is used to simulate various evacuation scenarios in our study area's first and second academic building of IUT.
- We have used Pathfinder to simulate the evacuation process of the occupants of the academic building in case of a fire emergency and compare the results to see if it complies with the local guidelines for fire safety.
- We have also found the ratio of male female walking speed for simulation so that we will be able to determine the maximum or minimum evacuation time.
- We also find that it is better to evacuate according to SFPE guidelines in groups and an orderly manner than evacuating individually in a crowded process.
- Beside this we have found that there are lacking in the width of stairs, presence of two handrails in fire exit stairs, width of corridors and limited number of fire extinguishers as per guideline and the absence of assembly point, fire alarms, emergency exit doors.
- Finally, we have also proposed a management plan as per local guideline.

So, in the end, we can say that our academic building needs a massive improvement as per guidelines in a fire safety concern. IUT being an international university needs to maintain a certain standard of safety and protocol in the academic building.

7. Recommendation:

Due to a shortage of time, we have only work for the first and second academic building. By using our data and methodology it can be done for dorms, auditoriums, and others infrastructure too. Also, we are proposing at least minimum checkups with guidelines like must fire extinguisher should be available on every floor.

The research led us to a revelation about the research gap regarding fire escape propagation on a level where it can be conducted with minimum materialistic cost and maximum efficient result. This study was completed without almost zero financial cost and the result is helping

the university authority rethink about the fire management system of the civil structures. We strongly recommend the idea of running simulations like this on any structure.
We are approaching the middle stair because there are two-way walls and we can give handrails there as per guideline. If we choose corner stairs occupants who stay at other corners will be inconvenient for them due to smoke and as per statistics, 90% of people died due to smoke rather than direct fire burning.

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