NUMERICAL INVESTIGATION OF FIRE GROWTH BEHAVOIR OF KHULNA NEW MARKET USING FIRE DYNAMIC SIMULATOR

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ABSTRACT

The fire growth behavior of Khulna New Market is studied using a Fire Dynamic Simulator (FDS). A model of Khulna New Market is created using FDS. The fire growth characteristics and fire spreading mechanism are simulated and analyzed by Pyrosim, a FDS. The evacuation model is built and studied by Pathfinder, another FDS, to analyze the evacuation path and evacuation time. The fire is generated using a burner function of Pyrosim. The major parameters for Pyrosim are Heat Release rate (HRR), Temperature Distribution, toxic and harmful gas release rate, and human evacuation(EVAC) and for Pathinder the major parameter is evacuation time. The fire and smoke stops spreading after 600 seconds. Maximum temperature and heat release rate found is 450 ℃ and 1280GW. The male and the shopkeepers escape in minimum and maximum time respectively.

Keywords: *Fire Dynamic Simulator, Pyrosim, Pathfinder, Heat release rate, Temperature distribution`*

INTRODUCTION

Fire is acknowledged as a major hazard in any urban area. An incident involving smoke, heat, and flames that damages numerous building fixtures or fittings is referred to as a large fire incident (*G1205014656.Pdf*, n.d.). A fire accident is especially dangerous in densely populated areas like market places in Bangladesh. Fire can spread rapidly in such areas, causing widespread damage and loss of life. It is causing financial and social loss resulting economic degradation, fatalities, severe burn injuries, destruction of structure, mass deaths and so on. The classification of fire is tabulated in table 1. The denser the population is of an area the more casualties will occur. Tragic events like fires can result in property loss, severe burn injuries that inflict excruciating agony, permanent scars and disfigurement, disability, the need for long-term care, and even death.("Houston Fire Accident Lawyer | Fire & Explosion Accident Lawyer," n.d.) Fire-related hazards cause thousands of deaths annually, and careless management can lead to property destruction and fatalities. Preventative actions and vigilantness are crucial for fire safety. Understanding potential hazards and taking necessary precautions are essential aspects of fire safety (Sampath, 2018). Fire disasters can have catastrophic effects on people, businesses, and entire towns. Every year, home fires claim the lives of about 500 children under the age of 14, frequently as a result of inadequate fire safety procedures or training. These events are also caused by variables like cigarettes, cooking appliances, and poorly kept locations that are prone to fire. In order to protect oneself against flames, people need be knowledgeable of firefighting equipment and evacuation protocols (*Why Is Fire Safety Important?*, 2021).

Table 1: Types of fire.

Fire class	Fuel type
Class A	Ordinary combustibles such as wood, paper, and fabric
Class B	Flammable liquids such as gasoline, oil, and alcohol
Class C	Electrical equipment such as appliances, wiring, and circuit breakers
Class D	Flammable metals such as magnesium, titanium, and sodium
Class K	Cooking oils and fats

A total of 158 people lost their lives in 6454 major and minor fire incidents within Dhaka City along with uncertain number of casualties from 2001 to 2007 (Tazmul et al., 2018). Table 2 shows the amount of people lost their lives in major fire accidents of Bangladesh from 2012 to 2021.

Table 2 Major fire accisents of Dhaka from 2010-2021 (*5 Coronavirus Patients Die In Bangladesh Hospital Fire*, n.d.; *Massive Fire Guts Popular Clothing Market in Bangladesh Capital | News | Al Jazeera*, n.d.; *Old Dhaka Remains a Time Bomb Ticking Away*, n.d.; *Probe Team*, n.d.; *Rana Plaza*, n.d.; *Tazreen Fire Tragedy*, n.d.; *The Forgetting and Normalising of Fire Incidents in Bangladesh*, 2023; *The Rana Plaza Disaster Ten Years On*, n.d.; Correspondent, 2019; Imam, 2010; Kantho, 2019; Rahman, 2020; Rasheed & Al-Saih, 2021; Yuen et al., 2021)

SI	Fire accident	Date	Death	Injured	Financial loss (USD)
01	Tazreen Fashions Fire	November 2012	117	150	42 million
02	Rana Plaza Collapse	April 2013	1100	2600	2.5 billion
03	Nimtoli Fire	June 2010	120	200	-
04	FR Tower Fire	March 2019	25	70	-
05	DNCC market fire	January 2017	112	200	55
06	COVID-19 Hospital Fire	May 2021	44	67	-

There was also insufficient fire safety equipment to handle or face the growing fire, elevating temperature, production of carbon monoxide due to partial combustion of carbon. So, this is essential to study and analyse fire spreading behaviour and emergency evacuation model that is able to reduce the evacuation time in case of any fire accident. The number of fire accidents are increasing over time for many reasons among which lack of safety measures is one of the major reason (*The Forgetting and Normalising of Fire Incidents in Bangladesh*, 2023). The reasons of fire accidents in industrial area are tabulated in table 3. The loss from these accidents can be mitigated by predicting fire spread behaviour properly which can be done by understanding the fire spread mechanism(Ahn & Kim, 2011).

Table 3 Causes of fire hazards in Industrial Area(Tazmul et al., 2018).

Causes of fire hazards	Frequency	Percentage
Electric short circuit	57	28.5
Boiler explosion	52	26.0
Storage of flammable materials	43	21.5
Transformer explosion	14	7.0
Canteen/kitchen	9	4.5
Overheating	7	3.5
Lack of awareness	18	9.0
Total	**200**	**100.0**

Markets and shopping malls, factories, high-rise buildings, residential areas with densely packed houses (Slum), areas with poor infrastructure are in higher risk of fire accidents due to several reasons. Marketplace is one of the most vulnerable among them. The reasons behind this risk are High concentration of flammable materials, dense crowds, narrow walkways and alleyways, poor infrastructure and lack of fire safety measures. In this paper, fire spread characteristics and evacuation modelling processes are studied using Fire Dynamic Simulator (FDS); particularly Pyrosim and Pathfinder. A real fire scenario can be predicted and simulated by FDS as it shows a reliable result with real cases(Hadjisophocleous & Zalok, 2008).

Khulna new market is one of the most crowded places in Khulna city. According to local vendors the more than 1000 people gather in Khulna New Market in a regular day. At weekend, the number is more than 1500. And in national holydays the number rises up to 2500. Which shows that during weekends and holydays the market goes through the riskiest situation. The market is highly congested and has narrow alleyways, making it difficult for people to evacuate in the event of a fire. The total area of Khulna new market is 44100 square metres (*Tourist Geography Of Khulna*, n.d.).

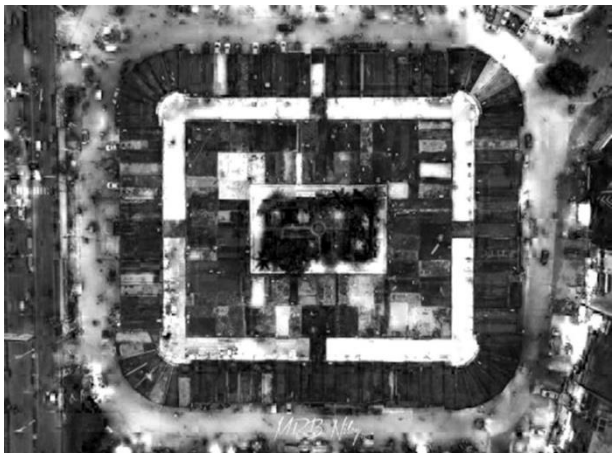

Figure 1:Top view of of Khulna new market(bdbangladesh, n.d.).

The fire behaviour inside structures must be scientifically characterized and systematized as a theory in order to be applied to fire safety design of buildings for both fire safety and emergency evacuation. Predicting fire behaviour in buildings is heavily reliant on combustibles' characteristics, such as their number, composition, or exposed surface area. The number of combustibles relies on the use of the space, whereas the exposed surface area depends on the kind of combustibles and how they are stored. Fire growth rate is one of the properties of combustibles that is crucial for the design and assessment of evacuation safety (fire spread speed). In this paper the fire spreading parameters are studied are Heat Release rate (HRR), Temperature Distribution, toxic and harmful gas release rate and human evacuation. FDS and EVAC are reliable and validated for evacuation modelling particularly for fire accidents (Khan et al., 2017).

METHODOLOGY

In this section the step-by-step methodology is described. All necessary numerical data are mentioned in this section. At the beginning a model was designed with actual dimension of Khulna New market along with shop classification. Secondly, the mesh was made in PyroSim. Then a burner function and combustion load were added. Finally, evacuation model was built using Pathfinder.

2.1 Model Design

The numerical analysis was performed on a model of a typical crowded marketplace of Khulna. The area of the model is 44100 square metres. It is a squire shaped building which has two floors and the dimensions are length = 210meter, width = 210 meter and height = 6.75 meter. The shops of Khulna New market are classified into four particular types based on fuel types. The wall thickness of the model is 0.25 meter. This market has a total of 186 shops. According to the inventory and equipment of the shops, they were classified into four categories.

Table 4 Types and number of shops of Khulna New Market.

Shop Type	Number of shops	Average length(m)	Average Width(m)	Height(m)
Restaurant	30	4	3.5	3
Clothing and Shoes	60	4	3.5	
Electronics	50	4	3.25	
Cosmetics	46	4	3.25	

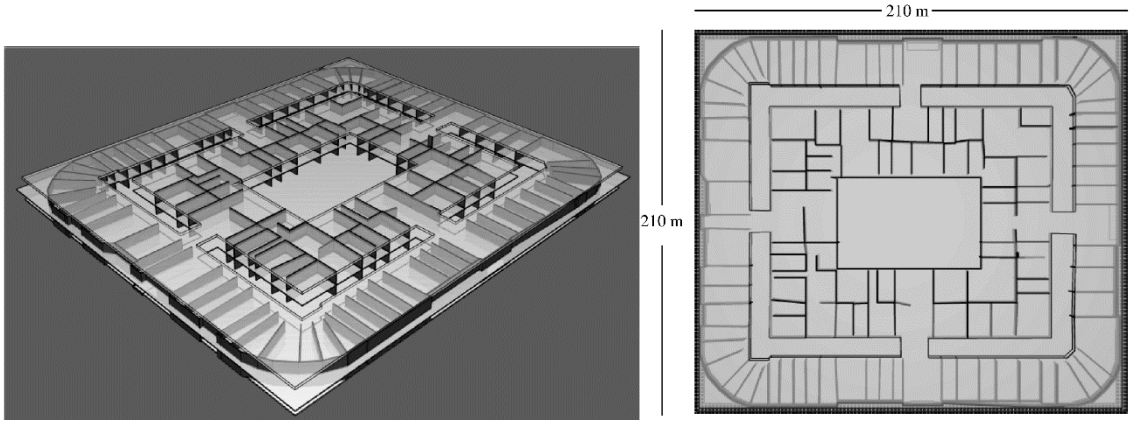

Figure 2: Khulna New Market (Top view and isometric view)

2.2 Mesh Analysis

A uniform rectangular grid (215×215×10.2) was used for calculation. The rectangular grid was divided into 9 meshes of equal cell sizes. The cell size was $1m^{3.}$ We kept some extra space of meshes around the model to make see the soot density and temperature distribution outside the market. Inside the market the meshes were divided into 9 parts to make the numerical analysis faster and more accurate.

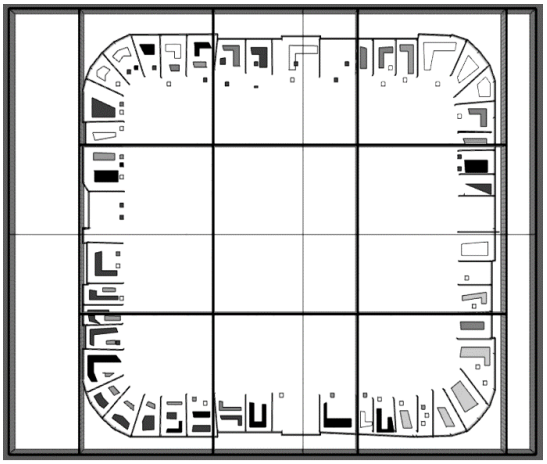

Figure 3: Different size of Mesh

2.3 Burner And Combustible Load

The fire was started in the kitchen of a restaurant of the market and spread accordingly. The fuel generally used is Propane. There is a sufficient amount of propane gas is kept in the restaurant for cooking. As a result, the heat release rate per unit area (HRRPUA) is constant which is 500 kW/m^2(*Kim - HRR of Burning Items in Fires.Pdf*, n.d.). The burner area is $2m^2$.

2.4 Evacuation Model

For evacuation calculation, 5 types of agents or occupantswere used. The agents are shopkeepers, adult males, adult females, elderly visitors and children. For all types of agents, the agent distribution process selected was random. All the properties including their body diameter, height, and velocity are taken differently .

Table 5 : Occupants parameters for different types(Qin et al., 2020).

Type of Occupants	Number of occupants	Height(m)	Velocity(m/s)	Priority
Shopkeeper	394	1.75	1.47	0
Adult Male	277	1.78	1.47	0
Adult Female	437	1.58	1.39	1
Elderly Visitor	137	1.78	1.00	0
Children	97	1.3	0.80	2

We used default behavior for all the occupants. Also, we made all the occupants wait the first 10 seconds after the incident occurred. Also, the shopkeeper will be a little bit longer as they will immediately try to save the products of their shop. Also, the shopkeeper's speed was made lower as they attempted to take their products along with them which made them slower. Elderly people, Children, and Females were given priority during the whole evacuation model.Priority was added in the profile tab of the software according to age and gender.

RESULT AND DISCUSSION

All numerical analysis was done on an open boundary mesh with a constant heat release rate of different materials. All numerical analysis was done by default without adding an extra source of air or an exhaust fan. As the whole thing is a very lengthy process, the model was scaled to 50% of its actual size.

After the initial fire generation, a gradual accumulation of soot within the market space was observed. About 600s later the temperature distribution shows that the temperature reached above 950 degrees

Celsius near the fire pool area. While on the other side of the market temperature elevation was much less. In Figure 4 the temperature distribution was shown at different times.

The fire was initially generated in a corner of the inner part of the structure. As there is a gap between the inner and outer parts of the building, the primary trajectory of fire spread was directed toward the inner part. As some of the shopkeepers keep their products on the roadside the fire eventually goes to the corner of the outer part near the fire pool area.

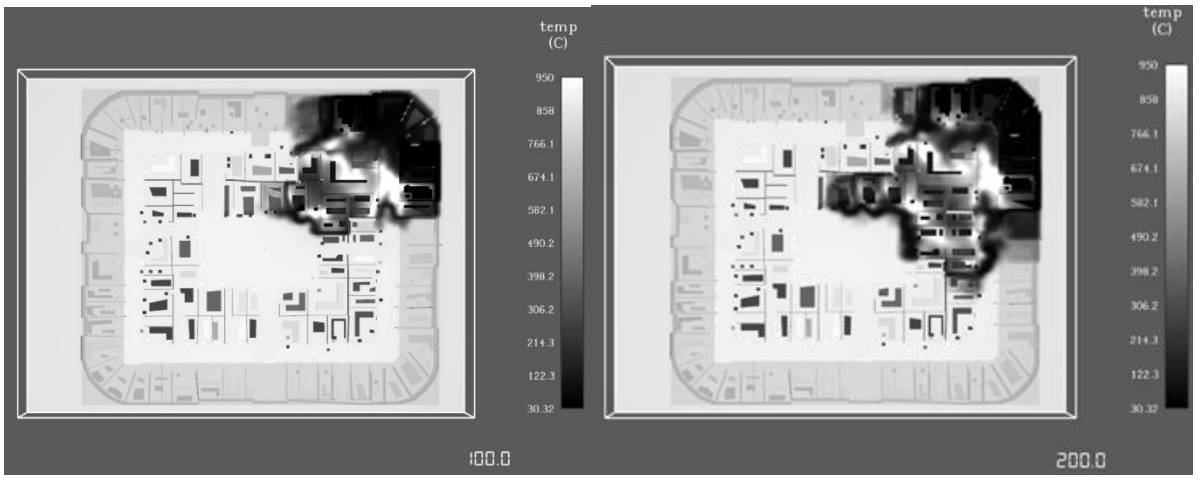

Figure 4: Temperature distribution at 100s (left) and 200s (right)

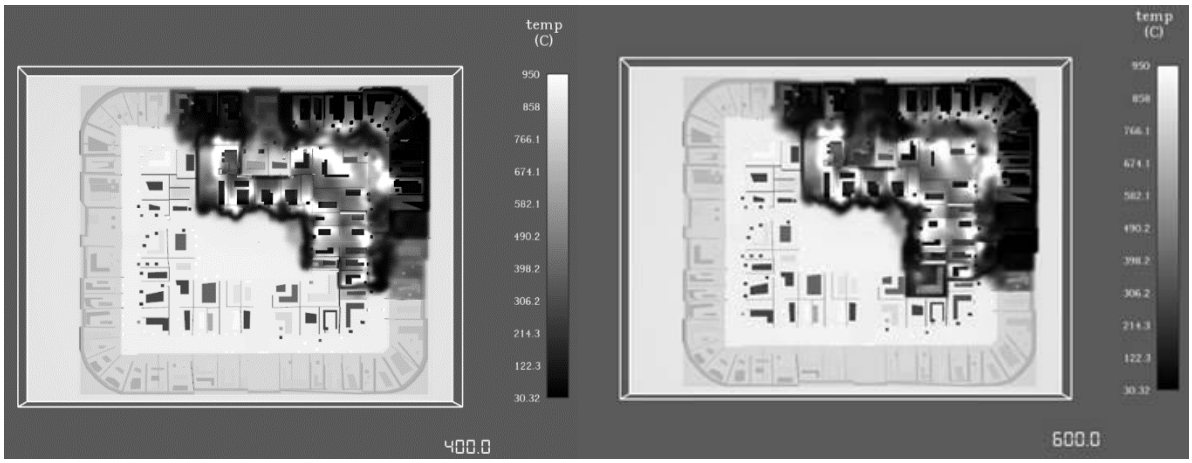

Figure 5: Temperature distribution at 400s (left) and 600s (right)

In Figure 6 many devices were added to the model to find the temperature distribution in different parts of the area. We have pointed out 8 areas to find the temperature distribution graph of these particular regions. The resultant graph is given below in Figures 4 and 5. A comparison was made between the temperature of the four gates of the market. Among the four gates gate 4 shows the maximum increase of temperature due to being closer to the fire generating area. Whereas the temperature increment of the other gates was very low. Figure 8 shows the temperature comparison in the four corners of the structure of the outer building. It shows that corner 3 has reached a very high temperature while other corners didn't increase much. The temperature of corner 3 was high because its position is the closest to the pool fire and the other corners were in a far distance.

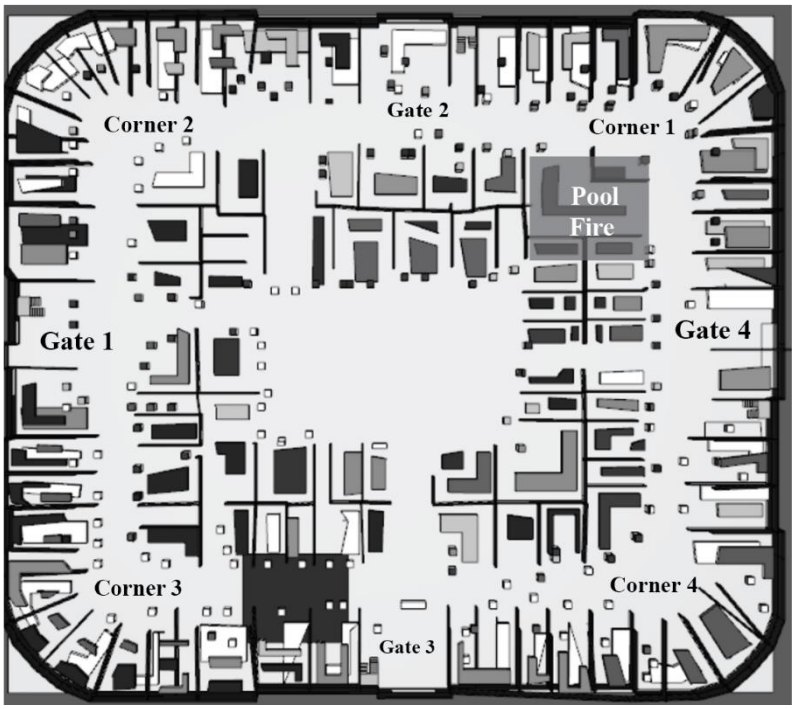

Figure 6: Defined regions for implemented temperature devices

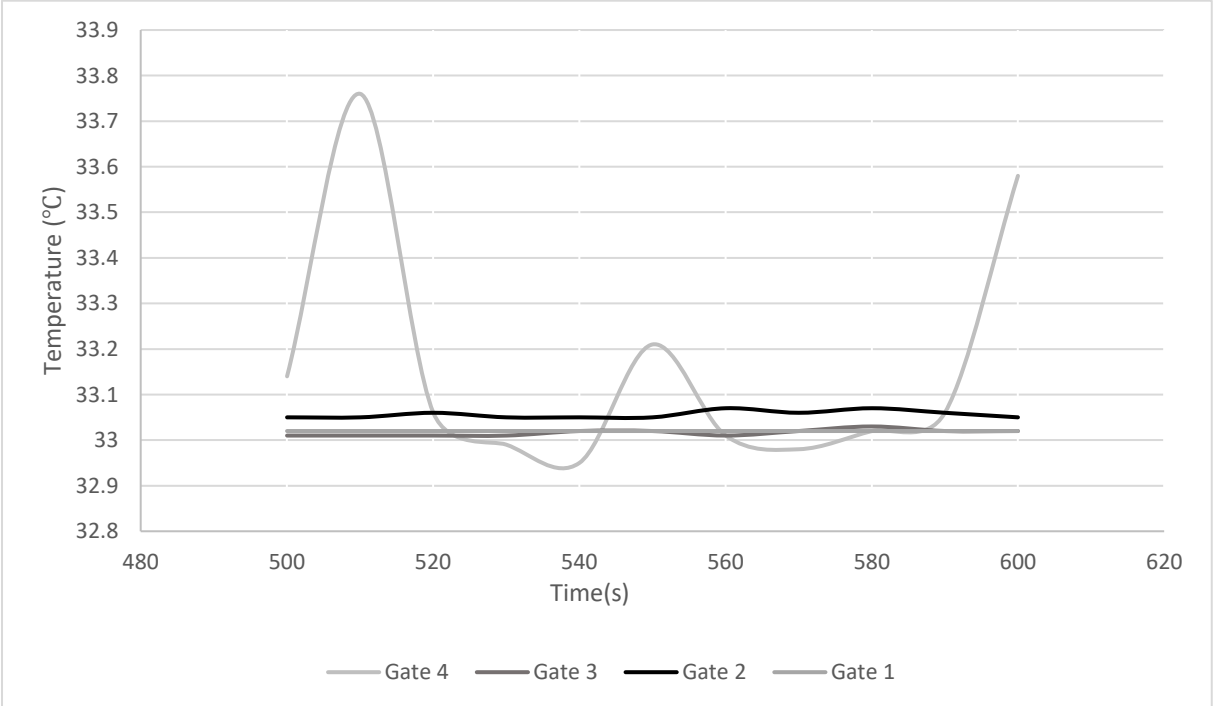

Figure 6:Temperature distribution of four gates.

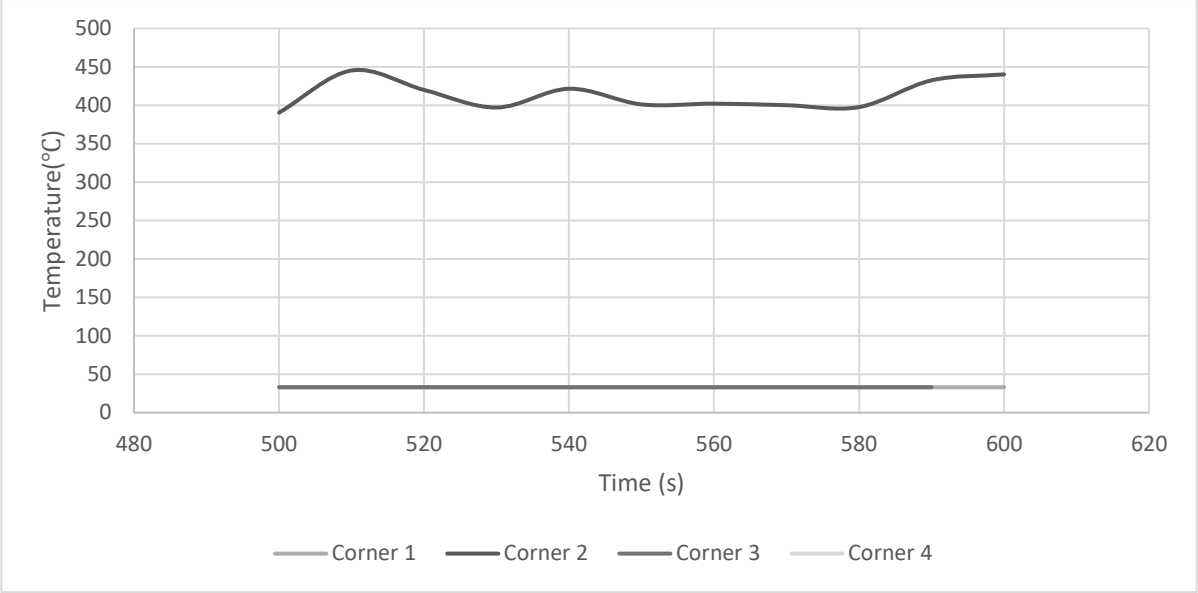

Figure 7: Temperature distribution of four corners.

Figure 9 shows that the value of heat keeps increasing as the more time goes more materials burn. At one point when the materials start to burn away the heat release rate will start to decrease. We took the Heat Release Rate of the whole volume of the market as a result of which the value of the heat release rate was very high.

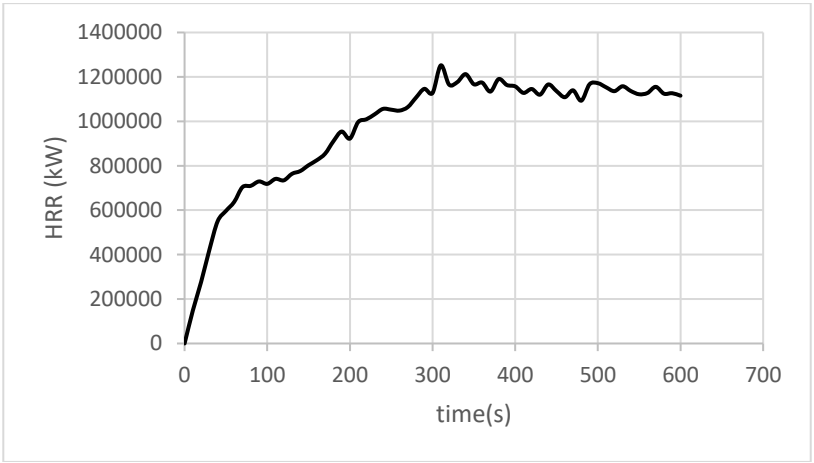

Figure 8: Heat Release Rate vs. Time

In the evacuation model, it was observed that the females and the children evacuated the market earlier as they were given higher priority factors in the analysis.Volunteers and males prioritize assisting females and children in emergency situations due to the physical differences, leading to quicker evacuation and increased safety, contributing to the observed faster evacuation of female and children.While the older people took more time than the other occupants due to their lack of speed and ability. Because of the lower priority level, male took more time to evacuate which seems more realistic in real-life scenarios. The shopkeepers took the most amount of time as they tended to prioritize the safeguarding of their respective shops.

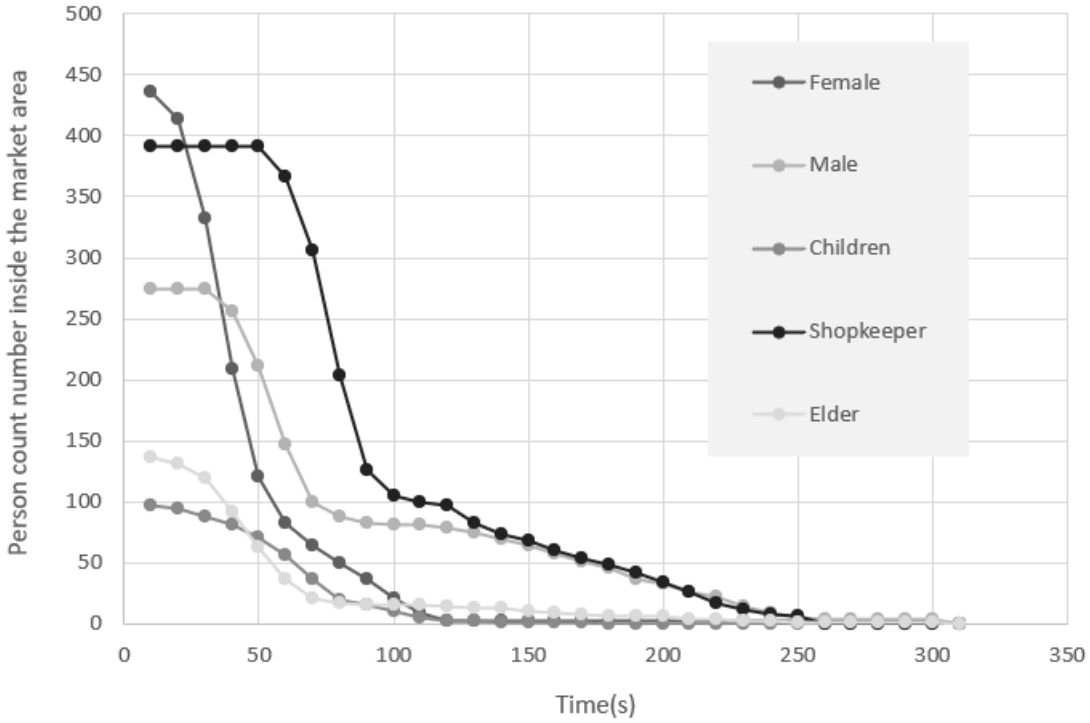

Figure 9: Number of people inside the market area vs. time

From Figure 2, it can be seen that the market consists of two rectangular-shaped building. There is an opening between the two building as well as in the center. This design reduced the spreading rate of soot and mitigated the rapid propagation of the fire to the opposite side of the market, resulting in a notable reduction in the temperature increase rate. According to Figure 8, the smoke didn't reach the whole market. Also during the analysis, it was observed that the volume fraction of the CO is very low as most of the area is open to the environment.

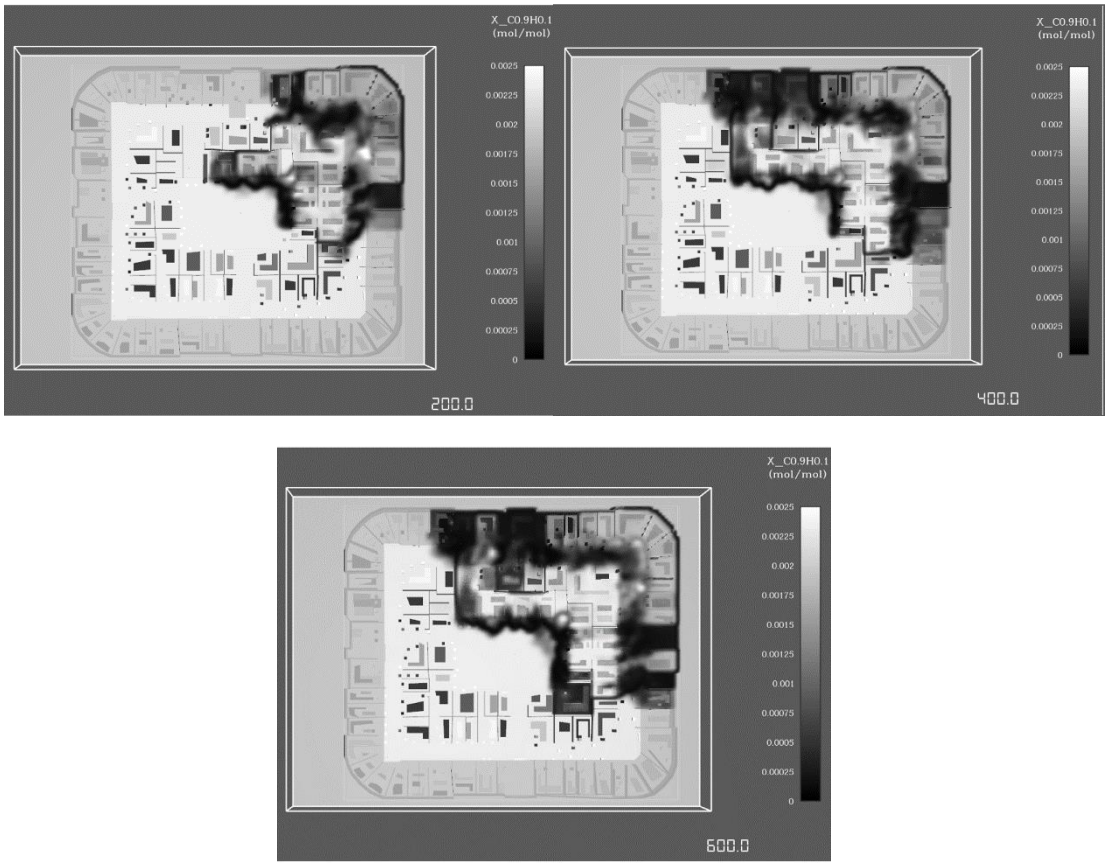

Figure 10: Volume fracction of harmful soot at 200s (top left), 400s (top right) and 600s (bottom)

CONCLUSIONS

The study of fire growth behaviour in market a place was analysed in this paper. The Fire Dynamics Simulator (FDS) models were designed and fire spreading behaviour and evacuation time were estimated. The simulation was made using 9 mesh. The major assessment parameters were heat release rate, temperature distribution, smoke spreading rate, and human evacuation. Total number of shops and the proper dimension ensure the accuracy of this simulation for fire safely design. The evacuation model estimated that the shopkeeper and old were more at risk. The Numerical analysis in fire studies has improved their accuracy and cost-effectiveness when compared to actual fire test expenses. Therefore, using numerical simulation to examine fire propagation can aid in understanding the effects of fire and creating appropriate fire protection and prevention systems for Khulna New Market.

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