Fire Distribution Analysis For The Faculty Of Engineering, University Of Sri Jayawardenepura

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***Abstract*— This study investigated the different modelling methods for the fire and evacuation process. Then identified different fire sources in the manufacturing laboratory of the faculty. This paper discussed, the applications of the Fire Dynamic Simulator (FDS) and discussed the outputs from FDS. The theoretical basis of related governing equations for the fire phenomena simulation and the theoretical background of human egress have been discussed. Furthermore, it identified the different fire sources of the manufacturing laboratory with the risk rating. Also, this paper explains how to perform a fire risk assessment and from that, an acetylene gas leak fire accident was selected for the simulation purpose. Then the theoretical background was discussed for Turbulence jet modelling. The smoke visibility capability calculates the distance a lighted sign can be seen in a smoke-filled environment, as well as smoke visibility obtained from the FDS smoke view results viewer. Finally, there will be some suggestions to improve the fire safety of the faculty manufacturing laboratory. This paper was created based on some research papers and books related to fire protection Engineering.**

Keywords – FDS, Modeling, Coupling, Evacuation, FDS, Graphical User Interface, Pyrosim, Pathfinder, Obstruction, Slice plane, Risk Analysis, Qualitative

I. INTRODUCTION

Designing a fire safety system for a building is very important and should be done in a specific way. The questions are, what to do and how to do it. There are many methods to perform fire safety system design. When discussing engineering methods to determine fire safety designs, modelling is one of the effective methods to perform a fire safety design. Different modelling software is developed for fire scenarios, smoke control, evacuation and egress modelling. FDS (Fire Dynamic Simulator), Pyrosim, CFAST, STEPS, Pathfinder and ANSYS are some of the software

The study is about fire safety design for the selected faculty premises buildings. The objectives are as follows:

- Identify different modelling methods for fire safety design.
- Identify the different fire sources on the premises and their nature.
- Perform a fire scenario simulation with evacuation and identify the safer place to evacuate.
- Suggest some fire safety systems for the faculty buildings.

As a start, the investigations in this study are based on the manufacturing laboratory of the faculty. There are many software solutions available for fire simulation and separately there are many documented theories in fire dynamics. There are also questions about, what kind of input data is required in a simulation, and how to perform a fire risk analysis to identify high risks. PyroSim is a commercial software that was developed for FDS. It has a Graphical User Interface and it is an efficient method of the input FDS representation of buildings with complex geometry.

After performing a fire simulation, FDS model results are important for fire safety designs. At each discrete time phase, FDS determines the temperature, strain, density, velocity, and chemical composition within each numerical grid cell. Apart from that, FDS computes heat flux, Temperature, mass loss rate, and various other quantities for solid surfaces.

II. LITERATURE SURVEY

The most common fire modelling software is FDS. It is developed by NIST (National Institute of Standards and Technologies). FDS simulations are based on small size grids or cubes. In any fire simulation, the building/Domain is divided into small cubic particles and evaluate the possible hazards. Fire modelling software can be divided as in Table I.

TABLE I. FIRE SCENARIOS AND SMOKE CONTROL MODELING SOFTWARE

Software	*Description*
FDS (Fire Dynamic Simulator)	It is a Fortran program that reads input parameters from a text file, computes a numerical solution to the governing equations, and writes user-specified output data to files. [1]
Smoke view	Smokeview is a companion program that reads FDS output files and produces animations on the computer screen. Smokeview has a simple menu-driven interface.
CFAST (Consolidated Fire and Smoke Transport)	In fire modelling the domain can be vertically subdivided into zones & CFAST is a two-zone fire model used to calculate the smoke dispersion, fire gases dynamic and temperature.
Pyrosim	Pyrosim is a Graphical User Interface developed for FDS, which is an efficient creation of input FDS representation of buildings with complex geometry.
CONTAM	CONTAM is a multizone indoor air quality and ventilation analysis program designed to help determine airflows, contaminant concentrations, and personal exposure in buildings.[3]
ANSYS	ANSYS simulations can used to observe the fire smoke propagation.

TABLE II. EVACUATION AND EGRESS MODELLING SOFTWARE

Software	***Description***
Evac	Evac is an evacuation simulation module for FDS development. It can also be used to simulate only the human egress process without any fire effects.
Pathfinder	Pathfinder is an agent-based movement simulator developed by Thunderhead Engineering. It includes an integrated user interface and animated 3D results. Pathfinder allows to evaluate evacuation models more quickly and produce more realistic graphics than other simulators.[4] Also, it is an effective user interface with the option to import FDS geometry.
Exodus	EXODUS can be used for both evacuation simulation and pedestrian dynamics/circulation analysis.[5]
STEPS	STEPS has good visualization and support for complex geometry and evacuation scenarios. Also, it can import data from CFD and zone models. (Fluent, FDS)

A. Fire Scenarios And Smoke Control Modeling Software

1) FDS (Fire Dynamic Simulator)

Fire Dynamics Simulator User's Guide noted that the FDS is a computer program that solves equations that describe the evolution of fire. Since it needs some theoretical knowledge when working with FDS. And also, there is no Graphical User Interface (GUI) for model development, and it is not very user-friendly. However, various programs have been developed to generate the text file containing the input parameters that are required for FDS.

2) Pyrosim

According to PyroSim User Manual, some highlights are listed as follows,

- Can import CAD files (.dwg) and 3D files (fbx) to create and manage complex models.
- High-level 2D and 3D geometry drawing tools.
- Flexible unit system that supports working in either metric or English units.
- Tools to manage multiple meshes.
- HVAC systems integrated into the CFD simulation.[2]

The objectives of the study include performing a fire scenario simulation in faculty buildings with evacuation and identifying a safer place to evacuate. Therefore, selecting an optimum fire scenario simulation software and evacuation modelling software is quite important. Many evacuation software exist, but few allow direct coupling with the FDS. When coupling two different software the compatibility of these two software should be very clear.

FDS+Evac is one of the acceptable combinations to allow simultaneous simulation of fire and evacuation processes. FDS and the Evac are both developed by NIST (National Institute of Standards and Technology) and, there are no coupling issues. But, according to Blixt, there are some limitations to using FDS. Poor visualisation compared to commercial software packages, lack Of GUI for model development, and limited support for complex environments[6] are some limitations.

Pyrosim+Pathfinder is another suitable software couple that can use to simulate fire and evacuation processes. Pyrosim and pathfinder have a lot of advantages when comparing FDS+Evac. Since pathfinder has good visualization, support for complex geometries, and evacuation scenarios it was selected for further simulations. Both softwares developed by Thunderhead Engineering and it is commercial software. Also there are Students license available for Undergraduates.

B. Stages of Fire Growth

When consider a fire in a compartment or a room, Fire development will go through the following stages,

- Growth stage (Pres flashover) - Ceiling Jet
  - Smoke Layer
- Flashover
- Post-flashover

C. Fire Growth

Once the fuel starts to burn, the fire plume will create a smoke layer. During the fire, it produced hot combustion products, and due to the elevated temperature, these products will buoyant above the fuel. This fire plume is important in the early stage of fire growth because this plume will act as a transport mechanism of the fire. As a result, it transports all combustion products from the fire's origin to the upper levels of the building.

After the plume reaches the room ceiling, it cannot go higher and fire smoke will spread laterally. In the initial stage, the ceiling jet spread as a thin layer. Also ceiling jet is another transport mechanism of fire. It is very important in fire protection engineering to identify the places that need safety devices.

The ceiling jet flows laterally, and once it hits a wall or other obstacles, the room will begin to fill with smoke. During the smoke-filling process, the higher portion of the room will get heated, and energy may be radiated back down to the other fuels on the room's floor level. Then begin to warm the other fuels, and when the increased temperature reaches the ignition point, all of the materials in the room will begin to burn at the same time. Usually, it is called the flashover.

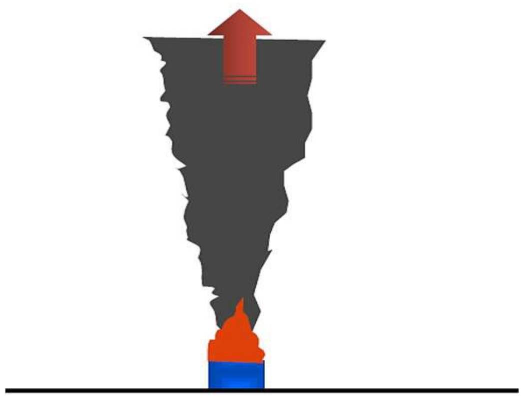

Fig. 1. Fire Plume

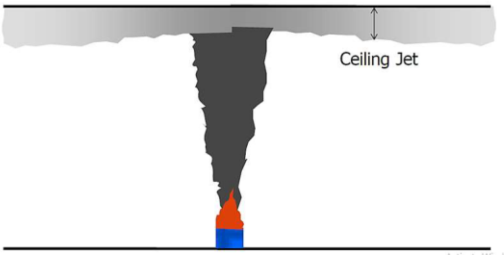

Fig. 2. Celling Jet

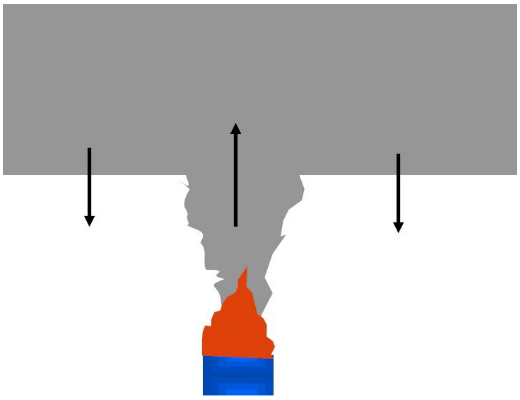

Fig. 3. Increased Celling Jet

III. METHODOLOGY

To demonstrate the use of pyrosim, have constructed the 3D model of the manufacturing Laboratory (92 X 30 X 13 feet) by using Google SketchUp. The building consists of Lathe Machines, Arc welding machines, Grinding machines, Milling machines, Tool stores, etc. The below figures show the 3D model of that laboratory.

A. Scenario Selection

For simulation purposes, the considered fire scenario is an oxy-acetylene gas welding accident. Because in the fire risk assessment, it has the highest risk rating. There can be many accidents like oxygen and acetylene cutting hose bursts, Gas leakages, damage the gas cylinders, and unexpected accidents. The fire can start when a spark from welding operations lands at the top of the cylinder. A leak at the gas regulator's threading and the cylinder's valve outlet is the immediate cause of the incident.

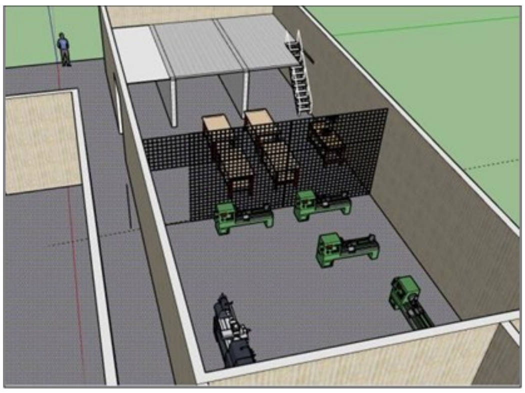

Fig. 4: 3D Model of Manufacturing Lab

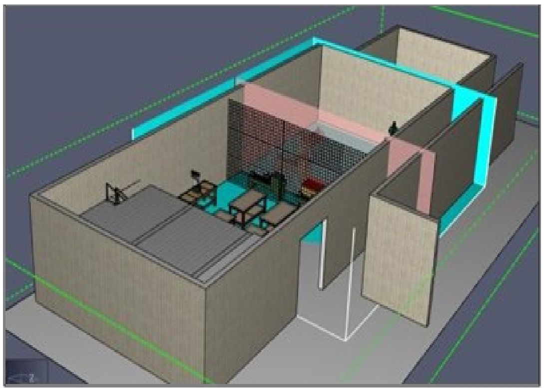

Fig. 5: Imported 3D model

B. Turbulent Jet Modeling

The considered fire phenomenon is acetylene gas leakage fire. Therefore, it can be considered as a turbulence jet modelling and this method is based on the equivalent diameter and velocity profile. In the simulation, the Mathematical background is discussed, and to determine the jet exit condition, the calculations are done according to Fig. 5.

C. Selecting the optimal mesh size for the simulation

It is important to define the number of mesh divisions in the simulation. This cell size can be determined by using characteristic fire diameter and the cell size ratio. Characteristic fire diameter is given by the following equation,

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{\frac{2}{5}}$$

Where,

$\dot{Q}$ − Heat Release Rate
ρ_∞ − Density
c_p − Specific Heat
T_∞ − Ambient temperature
g − Gravity
dx − Cell size

D. Define the Reaction

To simulate combustion, the user needs to define a reaction. For that on the Model menu, click Edit Reactions. After we can define a custom reaction or we can import a defined reaction from the library. If the user creates a custom model, have to define the fuel composition by specifying the number of C, H, O, and N atoms.[2] The fuel compositions are included in the SFPE handbook.

E. Create Fire Surface

Here the user needs to define the properties such as Heat Releasing rate and surface Temperature of objects in the FDS mode. For that on the Model menu, click Edit Surfaces. Then the Edit surface window will be open.

F. Create the fire

To create the fire, define the fire location in our model create an obstruction and assign the fire surface to the top of the obstruction. The geometry of the obstruction needs to be included.

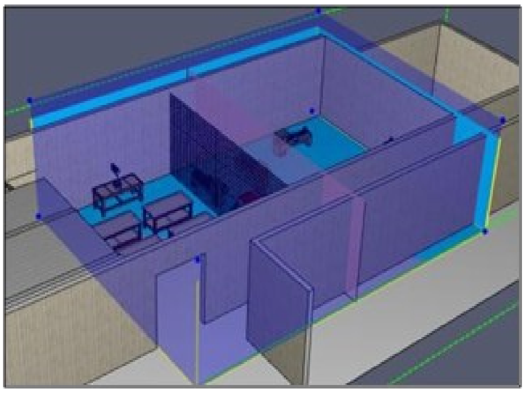

Fig. 6: Created Mesh

G. Add 2D/3D slice plane

Slice planes visualise the gas-phase data like temperature and pressure velocity.

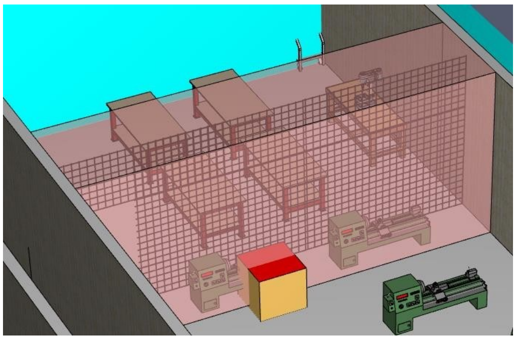

Fig. 1. 3D slice plane

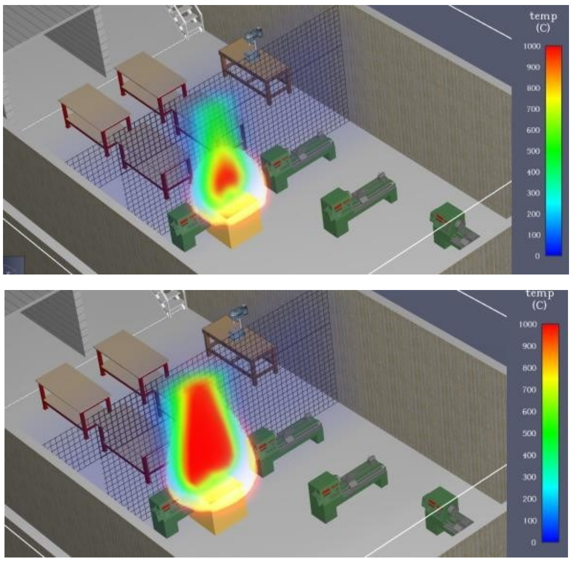

Fig. 7: Fire viewed on the slice plane

H. Set the solution time and Run the simulation

On the analysis menu, we can set the simulation time. Then run the FDS and the results can be visualised as follows.

IV. Analysis Procedure

Before performing a complete fire scenario, identifying the different types of ignition sources is significant. According to Syphard, Alexandra and Vertus, ignition sources of the manufacturing laboratory are grouped as follows: [7]

TABLE III. IDENTIFIED IGNITION SOURCES IN THE MANUFACTURING LABORATORY

Natural	Lightning – Largely related to local topography, with strikes occurring more frequently in higher elevation sites. If a lightning protection system is not available,it is possible to tend a lightning fire.
Accidents	Electrical fires - Sparks due to failure of power (electrical) lines, short-circuits due to contact between two lines, Faulty Sockets/ Appliances, Light Fixtures & Fittings, Outdated Wiring Systems, soldering During work - Arc welding, Gas welding, grinding, Milling, Metal Cutting Diesel, Kerosene, HCL and Cutting fluids arestored in the tools store. Accidents involving Fluid store
Negligence	Irregular dumping Near the machines

Fire risk assessment plays a starting point for developing fire safety design and modelling. Risk assessment is the process of identifying hazards and evaluating the level of risk (including whom and how many are affected) arising from the hazards, taking into account any existing risk control measures.[8]

"Introduction to Fire Safety Management" Suggested the following steps to perform Risk Assessment.

- Preparing an inventory of activities - Identify all the buildings and areas (including the activities and tasks undertaken) that will need to be assessed.
- Identifying the significant hazards – Have to consider Reviewing Records/Documents, Location Inspection & Activity Observations.
- Identifying who is at risk - Who is directly involved with work Students, employees other people
- Evaluating residual risk - Evaluate the level of residual risk.
- Record the significant findings.[8]

When evaluating residual risk, there are several ways to perform it. The method applied for any particular risk will depend on some factors, such as the complexity of the activities and the type and nature of the workplace. The risk evaluation methods are as follows.

A. Qualitative analysis

Qualitative analysis describes the quality of the risk using words. The Probability and Impact Matrix is one of the most commonly used methods in qualitative assessment. It is based on the two components of risk, probability of occurrence, and the impact on the objective if it occurs. All Risks can be categorised under four divisions,

1) *High Probability + High Impact*
2) *Low Probability + High Impact*
3) *High Probability + Low Impact*
4) *Low Probability + Low Impact*

There is a high risk when a high probability of occurrence and a high impact are involved. And it is the most considerable thing. When performing fire safety design. We can prioritize or rank risk for further analysis and actions. The top priority is given to the risk which has high probability and high risk.

TABLE IV. PROBABILITY IMPACT MATRIX CHART

	High Impact	***Medium Impact***	***Low Impact***
High chance of an event	High Risk	Medium Risk	Low Risk
Medium chance of an event	Medium Risk	Medium Risk	Low Risk
Low chance of an event	Low Risk	Low Risk	Insignificant Risk

B. Quantitative analysis

Quantitative risk analysis is a numeric estimate of the overall effect of risk on the project objectives such as cost and schedule objectives.

1) Semi-quantitative analysis

Semi-quantitative risk assessment provides an intermediary level between the textual evaluation of qualitative risk evaluating the residual risk.

V. CONCLUSION

This study investigated what are the different modelling methods for the fire and evacuation process. Then identify different fire sources in the manufacturing laboratory of the faculty. Identified suitable software to simulate as pyrosim and pathfinder. Then the theoretical basis of the FDS was discussed under major components of FDS. The theoretical basis discussed related governing equations for the fire phenomena simulation and discussed the theoretical background of human egress. Then identified the different fire sources of the manufacturing laboratory with the risk rating. Also, determined how to perform a fire risk assessment. Acetylene gas leak fire accident was simulated in pyrosim. The theoretical background was discussed for Turbulence jet modelling to determine the heat release rate calculation. Then simulate human egress in Pathfinder. From pyrosim results, the visibility slice results show that at the 20th-second smoke visibility will be almost zero. Also, determine that for safer evacuation, the occupants should evacuate from the welding room at least within 16 seconds. Pathfinder simulation results show that all the occupants in the welding room will evacuate within 10 seconds. For this simulation, it is assumed that the only vent in the welding room is the door. Finally, there will be some suggestions to improve the fire safety of the faculty manufacturing laboratory.

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