Pre-analysis of fire and smoke propagation in a multi-storied building by using FDS software

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***Abstract*: Most high-rise buildings are merely concentrating on structural design only. They do not give much importance to the area of fire prevention. This study emphasizes the importance of the simulation of fire growth and smoke propagation before building construction. This paper discusses the development of fire and propagation of smoke inside a multi-storied building by using a fire dynamic simulator (FDS) and user interphase software such as Pyrosim and 3D SketchUp. Based on the results obtained from the simulation, we can alter the building designs with a proper selection of materials and redesign structures. A 5-floor corporation building in Thrissur district, Kerala, is selected for study purposes. The main objective of this paper is to assess the fire growth and propagation of smoke in the building. Also, simulate the smoke spread from a compartment into an adjacent larger space. In this paper, we analyze the smoke propagation in structures at 60 seconds.**

***Keywords*: Smoke spread, FDS, SketchUp, Safety, Pyrosim**

1. Introduction

With the development of new cities, there will be a drastic decrease in the availability of free land. Also, modernization and urbanization will be a factor affecting the above problem. As a result, high-rise buildings have increased the chances of fire accidents. The main causes of death during a fire accident in a building are toxic gas inhalation from fire and problems caused by smoke. Also, the congested spaces and improper design in high-rise buildings are the major reasons for the smoke spread. FDS software is developed by building a fire research laboratory at NIST. FDS numerically solves the Naiver-Stokes equation for low spread fire and for incompressible flow; both the Continuity equation and Naiver-Stokes equation are used[1,2]. In the case of a large space, a large eddy simulation method is used (LES). It will help to resolve large-flow field solutions. It also gives better fidelity, and combustion is modeled using mass fractions (ratios of combustible gases originating in a given place corresponding to all main reactants and products). The Naiver-Stokes equation considers the conservation of mass, momentum and energy.

2. Related Works

According to the previous fire accidents, we can clearly understand that one of the major problems for fire accidents is improper structure and congested space in the building [3] [4]. Several experimental and numerical studies have been done on building and pool fires. Numerous building fire accidents caused a considerable loss of human life and property [5,6]. Mainly the introduction of high-rise buildings will be the reason for this increase in the death rate due to building fire accidents. There are some papers works conducted based on this area; they are as follows

2.1 In 2010 Zhen Xu et al.

They published a paper related to this topic. The main contents are the smoke hazards and its assessments using FDS and GIS, for that they calculate ASET (Available safety egress time) and RSET (Required safety egress time) and compare the two values. For a proper evacuation, RSET should be less than ASET. In that study, the mainly use three parameters such as toxicity, heat, visibility. Also, they use FDE (Fractional effective dose) and IHD (Integrated hazard dose), these are developed by NIST. In FED analysis toxicity, heat, visibility is considered whereas in IHD only toxicity and heat are considered and visibility will magnify the effect of toxicity. And FED proposed 6 gas models for the assessment. The first step in this process is obtaining the GIS model from the building information then it will be converted to FDS model by the interface given in the study. And the simulation is run in FDS. After running the FDS software spatial and temporal data are obtained. And the analysis and evacuation of smoke hazard and its assessment will be done and finally this result will be shown in GIS file.

2.3 In 2013, Jiiang Feng et al.

They published a paper based on performance-based fire protection design based on FDS. In the 1980s, they were using performance-based fire safety evacuation by using various properties, predictions, and numerical calculations. According to their findings danger due to fire is 3 ways, one is by toxic gases from synthetic leather fire, second is by oxygen usage for combustion process and also due to high temperature.

2.2 L. Chemg-Shing et al.

They published a paper based on ‘Computation prediction of propagation of smoke and fire in buildings'. Also, the paper discussed the smoke control and evacuation roots. This analysis is mainly done in areas such as big hotels, shopping centres…etc. They mainly use FDS codes for FDS simulation, the FDS codes will vary depends on the type of building. The validation of FDS will be done using the data from other CFD programs and standard codes. FDS uses the mixture fractional model for combustion models.

3. Description about the building

Thrissur Corporation's multi-storied building is selected for the analysis of fire growth and Smoke propagation. The present model is a 5 storey building with overall plan area of about 18000 m^2 and the overall height is 15 meters. The different floors of the building are car parking, shopping centre, hotels, cinema theatre, and conventional hall. These areas have larger intensive density therefore the chance of catching fire will be high. By considering the chances of fire we chosen theatre (3rd floor) study purpose.

4. Chances of fire in the building

The main reasons for fire in a cinema theatre are carless smoking, electrical equipment failure, and malfunction on cooking equipment’s and also from inadequate wiring. Most of the theatres have less number of openings and the internal structure of this kind of buildings will accelerate the propagation of fire and smoke. Generally theatres are designed to be fire-safe. But, because of larger human density and tremendous size, emergency evacuation is challenging.

5. Designing procedure

The primary step of this research paper is to design the building structure. The main tools used for the design process are AutoCAD, Google SketchUp, and Pyrosim. The 2D drawings are completed using Auto CAD, Fig: 1.a., which is imported to SketchUp for making a 3D design, fig.0. Next, the designed 3D structure is exported to STL format; STL is a 3D printing format. For simulation purpose, the STL file is imported to pyrosim.

(a) (b)

Fig:-1.(a) Plan of top floor (b) Sketchup designed view of top floor

There are mainly three types of meshes. They are course, moderate and fine. The accuracy of calculation is inversely proportional to area of cells. Size of mesh cell is calculated by using the equation given below [7].

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

Whereas,

D^*= fire diameter in cm

$\dot{Q}$ = Heat Release rate in kW

ρ_∞=Density in kg/m^3

C_p = Specific heat in kJ/Kg-K

T_∞ =Ambient temperature in k

g = Gravity in m/s^2

We are using fine meshes to get the most accurate results and to capture the features of both the flow and thermal fields. We use a computational rectilinear mesh of cells 720×216×27 to get almost cubic cells with dimensions 0.1× 0.1. × 0.1 m^3

6 Major input data and Boundary conditions

The major input data for the simulation are material data, surface data, ignition source, and simulation parameters.

6.1. Material Data

Material data mainly contains data such as material ID, material type (solid/liquid fuel), density, specific heat, conductivity, emissivity, absorption coefficient, and heat of combustion. Surface material, thermal properties of the materials, and material type such as or solid…etc. Also, data's such as heat release rate, specific heat, conductivity, emissivity, and absorption coefficient come under material data. In this paper, we use materials such as foam, gypsum, and concrete.

6.2 Surface Data

Surface data is derived from material data. Which mainly contains surface ID, color and appearance, and surface type (whether adiabatic, inert, burner, hearer/cooler, supply, exhaust, layered or air leak). We chose the theatre chair as the initial ignition source for that we have to define upholstery in surface data. Upholstery is layered surface with foam material. Wall is also layered with gypsum material.

6.3 Ignition source

The first ignition source is defined by giving Heat Release Rate per Unit Area (HRRPUA), Ramp-Up time (Tanh or t^2) and surface type. The surface type used in the ignition source is the burner. In this paper HRRPUA of the ignition source is taken as 5000kW/m^2.

6.4 Simulation parameters

In simulation parameters we define simulation starting time as 0 seconds and ending time as 60 seconds. And boundary conditions as ambient temperature-32ºC, ambient pressure-1.01325E5 Pa, relative humidity-44%, and specific gravity-9.8 m/s^2 and wall as default surface type of mesh.

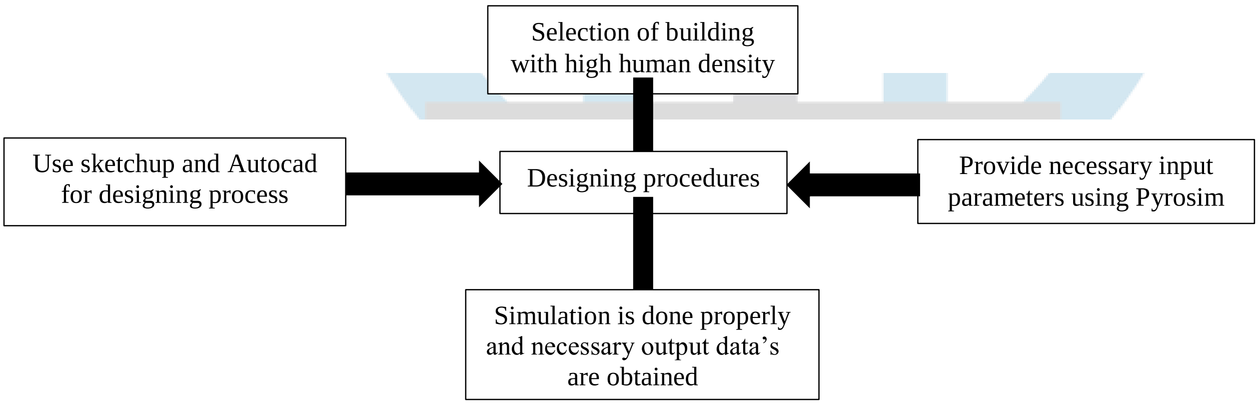
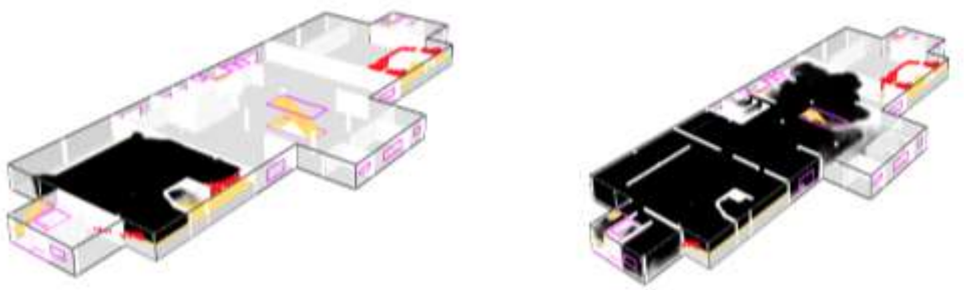


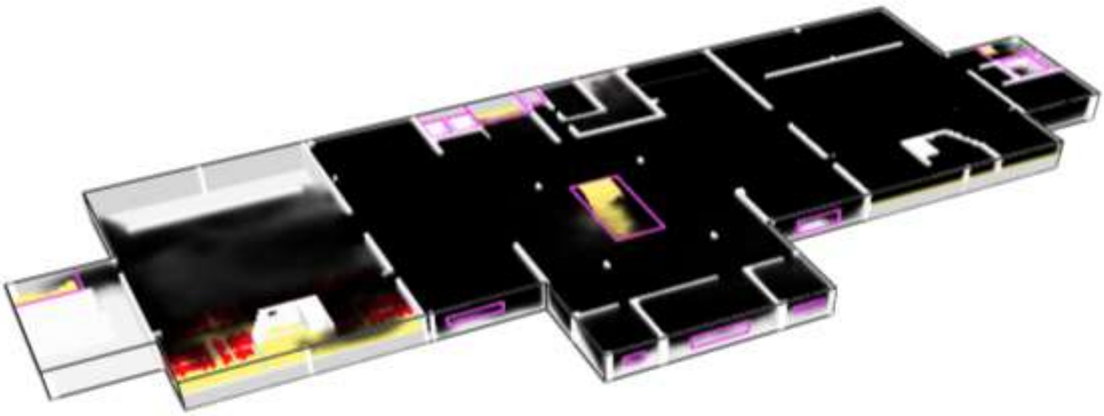
Fig 3.0:- Procedure for simulation

9. Result and Discussion

The main output results of simulation works are as follows

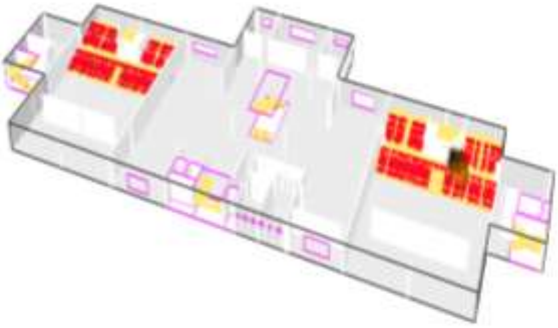


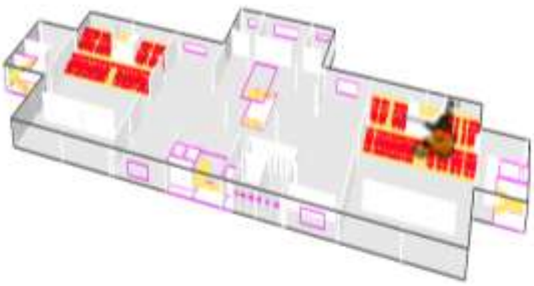
(a) (b)



(c)

Fig:2 (a) - Smoke propagation at 16 sec(b) Smoke propagation at 30 sec(c) Smoke propagation at 60 sec

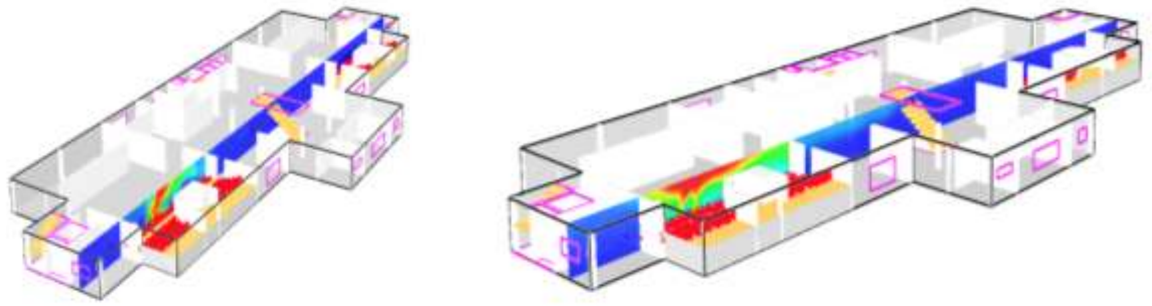




(a) (b)

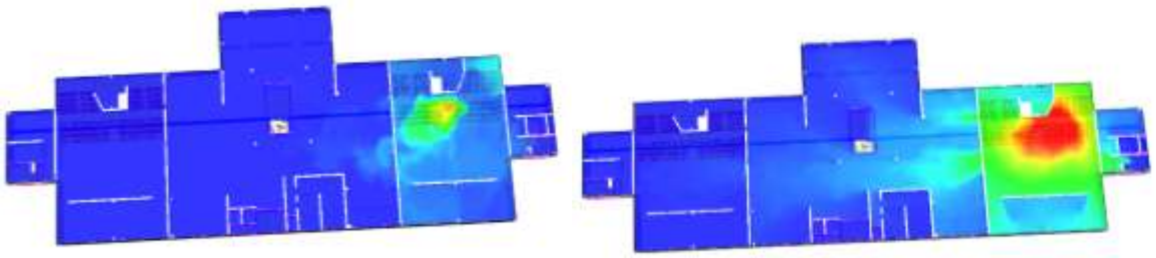
(c)

Fig: 3 (a) - Smoke propagation at 16 sec (b) Smoke propagation at 30 sec(c) Smoke propagation at 60 sec



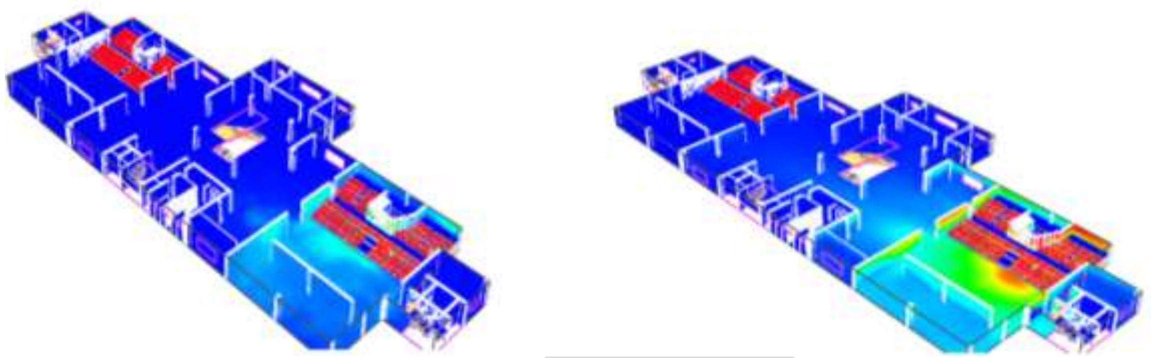
(a) (b)

Fig: 4(a) - Smoke propagation at 16 sec (b) Smoke propagation at 45 sec



(a) (b)

Fig: 4(a) - Smoke propagation at 16 sec(b) Smoke propagation at 45 se



(a) (b)

Fig: 4(a) - Smoke propagation at 16 sec (b) Smoke propagation at 45 sec

HRR

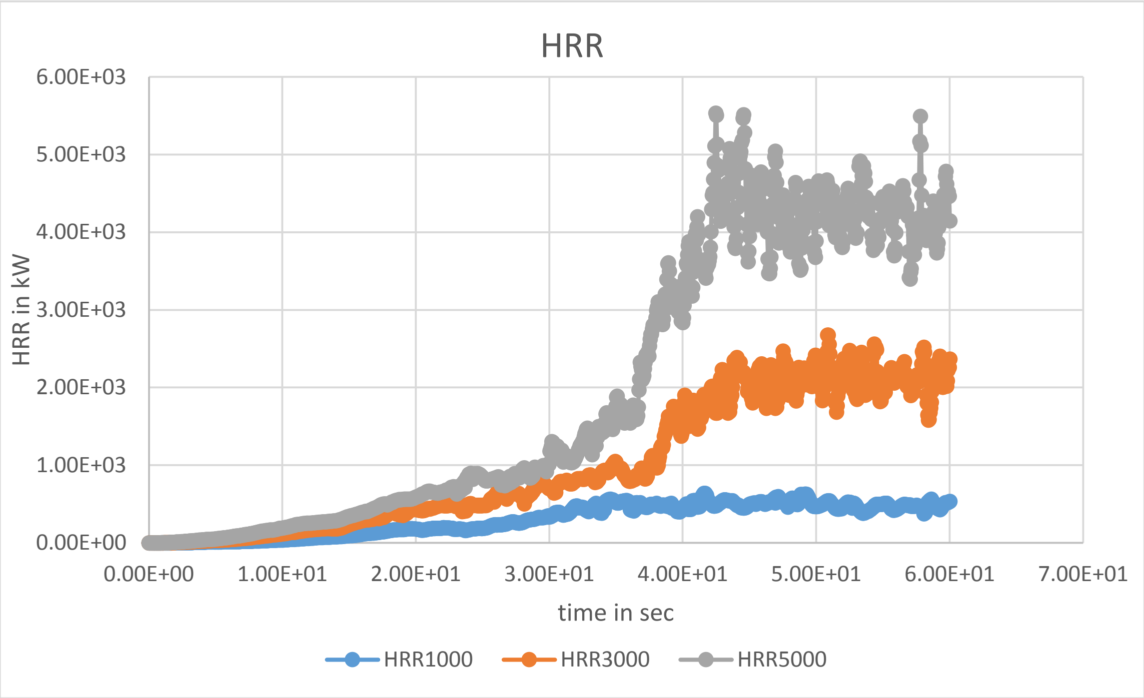


Fig 5:- Heat release rate for 60 sec

Heat release rate (HRR) is a primary fire hazard indicator. It is a critical parameter to characterise a fire and it is generally measured in kW and MW. Especially the peak amount is the primary characteristic determining the size, growth and suppression requirements of a fire environment. The above graph shows that at 0-1 sec the materials ignites so the amount of heat released is less. From 1-3 sec there is a sudden hike in the graph, this shows flash over of the material. Then from 3-60 sec is the burning phase.

BURN RATE

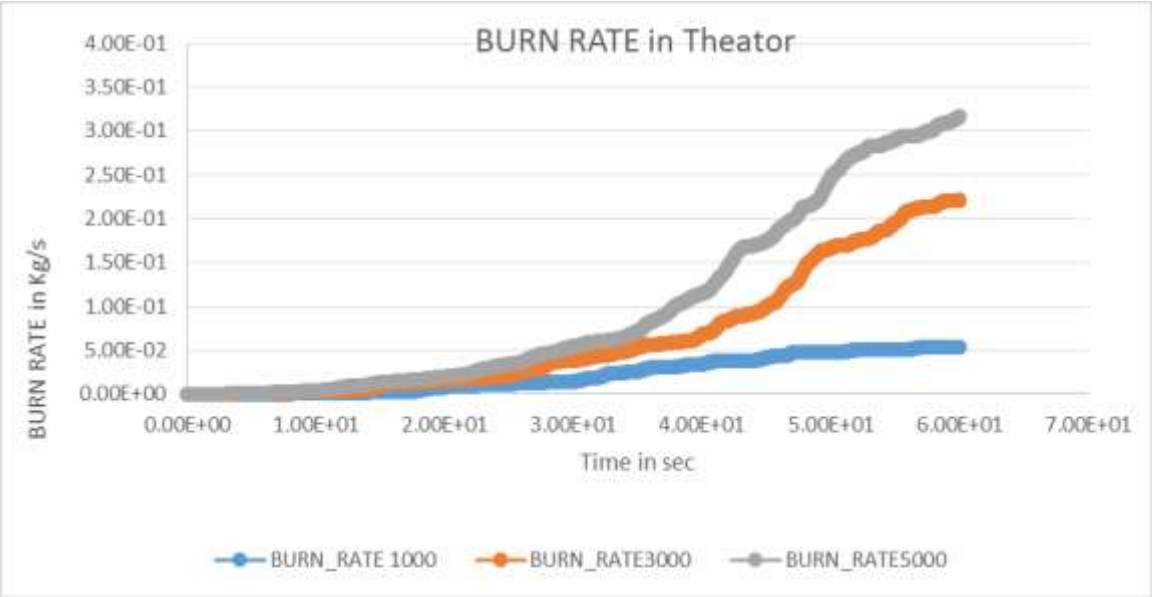


Fig 6:- Burn Rate for 60 sec

Burn rate is defined as the rate of burning of a substance. In the above graph there is a sudden increase from 0 to 3 sec and then the burn rate became constant. The main factors that affects the burn rate are length of the combustion zone, average mass flow rate of the fluid, type of fuel used.

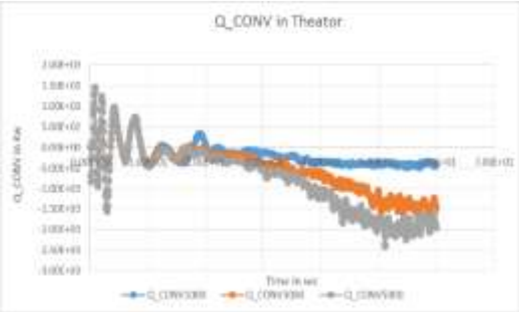


Fig 7.a

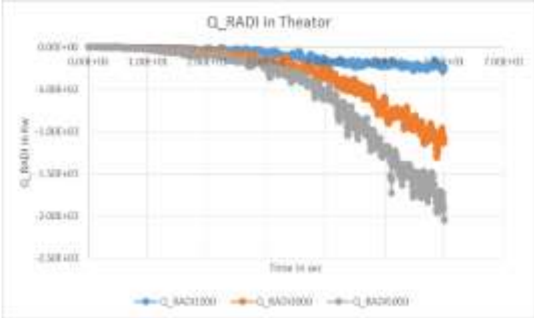


Fig 7.b

Fig 7. (a) Convective heat transfer for 60 sec (b) Radiative heat tranfes for 60 sec

Both conduction and convection are discribed on the basis of heat flux. The above two graphs is in negative reagion. Since heat flux is a vector quantity, neagative sign indicates that flow of heat is in the opposite direction.

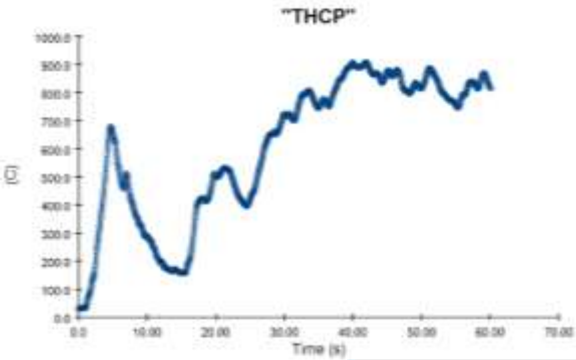


Fig 8.a

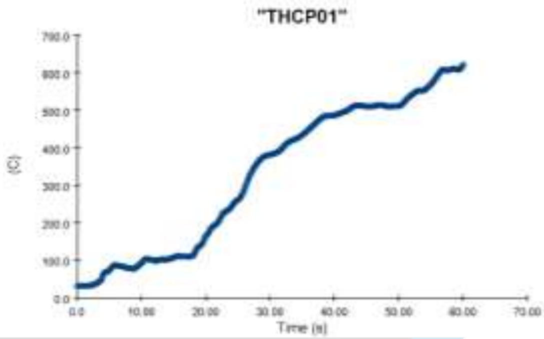


Fig 8.b

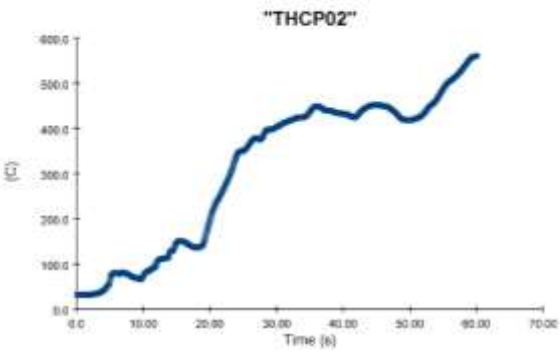


Fig 8.c

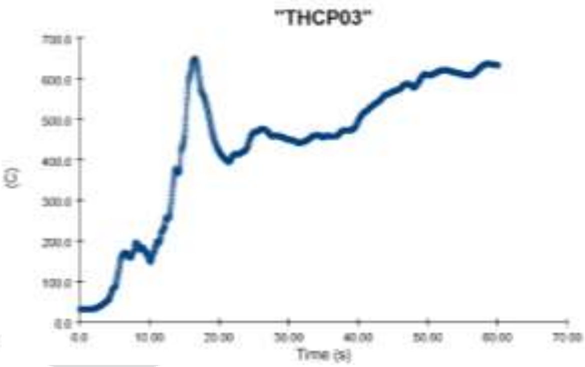


Fig 8.d

1. Fig 8.:- Thermocouple readings at different locations

Thermo couple is a temperature measuring device. In the simulation themocouples are placed at different locations to find out variation in temperature. The above graphs rising of temperature is directly propotional to time. There is a sudden increse of temperature between 20 and 50 sec in the above graphs, that is the peak temperature limit.

10. Conclusion

The following conclusions can be stated based on the above results

- Since the doors and windows are in the closed position, the temperature rise very high in a short period of time. Which leads to the occurrence of flash over, that results in the structural burning and collapse.
- To avoid the above problem we can place an automatic door opening system which operates at the time of smoke detection. Thus flash over occurrence can be prevented.

11. Acknowledgement

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