JURNAL TEKNOLOGI, Edisi No. 4 Tahun XXI, Desember 2007, 247-255 ISSN 0215-1685

Fire Safety Improvement Of Rumah Toko Building By Smoke Shaft Systems

Adhi Saputra, Yulianto S Nugroho[1] and Bambang Sugiarto
Department of Mechanical Engineering, University of Indonesia
Kampus UI Depok 16424, INDONESIA
Ph. +62 (021) 7270032, Fax. +62 (021) 7270033, e-mail: yulianto.nugroho@ui.edu
[1]corresponding author

Abstrak

Makalah ini mengkaji bahaya asap kebakaran pada bangunan komersial multi-fungsi yang umumnya dikenal sebagai Rumah Toko atau "Ruko". Simulasi kebakaran dilakukan menggunakan model NIST Fire Dynamic Simulators (FDS). Input untuk model menggunakan rancangan dan ukuran tipikal bangunan Ruko yang banyak didapati di kota-kota besar di Indonesia. Berdasarkan suatu api rancangan tertentu, analisis telah dilakukan pada dua 2 skenario desain, yaitu desain Ruko tradisional dan desain Ruko yang telah dimodifikasi. Hasil penelitian ini memperlihatkan bahwa pada desain Ruko tradisional, saat mengalami kebakaran, dapat terjadi akumulasi asap dalam bangunan khususnya di lantai 2 dan 3 dalam waktu yang relatif singkat. Terkumpulnya asap dan produk kebakaran di dalam ruangan dapat meningkatkan potensi fatalitas penghuni. Modifikasi desain dengan menambahkan kalom asap dapat memperbaiki kapasitas ventilasi bangunan. Penggunaan sistem kolom asap dapat meningkatkan kapasitas pembuangan asap. Berdasarkan tingkat kepekatan asap yang terjadi, batas aman waktu evakuasi penghuni dapat diperpanjang dari 160 s menjadi lebih dari 400 s.

Kata kunci: *Teknik keselamatan kebakaran, rumah toko, simulasi FDS dan sistem pengendalian asap.*

Abstract

This paper examines the fire smoke hazards of commercial - multi-function buildings known as Rumah Toko or "Ruko". The fire simulation was carried out using the NIST Fire Dynamic Simulators (FDS) model. The input for the model was taken from a typical design and sizes of this building built in Indonesian cities. On the basis of a set fire, two (2) design scenarios have been analyzed, i.e. the traditional design and an improved design. The results of this work show that in the ordinary design of the Ruko building, smoke production during a fire can overcome the occupants in relatively short period of time. Meanwhile the improved design by means of installing smoke shaft systems can improve the venting capacity of the building. On the basis of smoke density level, the margin of safety for evacuation efforts is extended from 160 s to more than 400 s by the use of smoke shaft systems.

Keywords: *Fire safety engineering, multi-function building, FDS simulation and smoke control system.*

I. Introduction

Smoke and fire gases formed in most unwanted fires, are dangerous products of combustion that have critical influences on life safety, property protection, and fire suppression practices in building. In some fires, the volume of smoke is so great that it may fill an entire building and obscure visibility of the evacuates. In other incidents, the volume of smoke generated may be considerably less, although the danger to life is not necessarily diminished because of the presence of other airborne products of combustion [1]-[4].

In the event of a building fire, as smoke is transmitted from the area of fire origin, it is cooled by entrainment of air, and by heat transfer from the smoke body to building material such as the walls and ceiling. Once the smoke has cooled to a significant degree, it is transported in the same manner as any other pollutant, i.e. by the stack effect, the wind effect, and mechanical air movement systems. Therefore, building design and especially the size and location of the openings play great roles in managing the smoke movement [3].

In many big cities of Indonesia, such as Jakarta, Surabaya, Medan, Palembang, Makkasar etc., a particular type of commercial building which has combined function as shop and flat, the so called Rumah Toko or "Ruko" is very popular. A typical "Ruko" unit has 3-4 storey, 3,5 m wide and 9 m long, and a stairwell connecting all floors. The growth rate of "Ruko" development is phenomenal. However, the growth of "Ruko" is also shadowed by appalling records of fatalities in "Ruko" building fire accident.

This paper focuses in evaluating the smoke hazard of a "Ruko" unit fire using the Fire Dynamics Simulator (FDS) computer code. The load and arrangement of the building interior were deduced from typical design of the unit. The evaluation concerns on critical fire safety parameters such as heat release rate, smoke density parameter, and fire gases formed. This paper also proposes an improved smoke control for a "Ruko" unit by means of a smoke shaft system. Smoke shaft system is basically a stack (shaft) connecting each floor directly to the ambient atmosphere. In the event of a fire, smoke will be driven out from each floor of the building to the surrounding. A better understanding of the pattern of smoke production and yield will be one of the key parameter towards the implementation of performance-based fire protection system in building and plant designs.

2. Theory

The early fire behavior of building products is important for many aspects of fire safety engineering. The heat release rate is a fundamental variable of fire with which almost all other emission properties are highly correlated [1]-[3]. Another important descriptor of a fire is the smoke production rate. Smoke is produced in almost all fires and presents a major hazard to life. In an event of building fire, people die because they are unable to reach a place of safety before being overcome by conditions created by the fire [3]-[4].

In the early stages of a room fire, when burning is localized the combustion product will be progressively diluted in the buoyant plume, until deflected by the ceiling. The rate of layer thicken will depend on the rate of burning and the amount of entrained air. The mass flow rate of smoke at any height above a fire can be estimated by [3].

$$\dot{m}_s = 0{,}071\dot{Q}_c^{\;1/3} z^{5/3}\left[1 + 0{,}026\dot{Q}_c^{\;2/3} z^{-5/3}\right]$$

where $\dot{Q}_c$ is rate of heat release (kW), z is the height (m) above the virtual source. If z is the height of the smoke layer, then this equation gives the rate of addition of smoke to the layer.

Smoke will move under the influence of forces which will be apparent as pressure gradient within the bulk of the fluid. In a building fire, forces that create smoke movement can be [3]-[5]:

a. buoyancy created directly by the fire,
b. buoyancy arising from differences between internal and external ambient temperature ,
c. effects of external wind and air movement, and
d. mechanical forced convection system.

In order to prevent smoke accumulation in certain area of a building, smoke must be contained or extracted. The production and movement of smoke can be studied using experimental and modeling approaches. The use of computer models for simulating fires in enclosures has increased dramatically in recent years. This is due to many factors, including the increased complexity of building design, the recent emergence of performance-based regulations, the rapid progress made in the understanding of fire phenomena, and the advances made in computer technology [4]-[5].

The NIST Fire Dynamics Simulator is a computational fluid dynamics (CFD) model of fire-driven fluid flow. It solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flow with an emphasis on smoke and heat transport from fires [5]-[6].

A CFD model requires that the room or building of interest be divided into small three-dimensional rectangular control volumes or computational cells. The CFD model computes the density, velocity, temperature, pressure and species concentration of the gas in each cell as it steps through time. Based on the laws of conservation of mass, momentum, species, and energy, the model tracks the generation and movement of fire gases.

FDS approximates the governing equations on a rectilinear grid. This three-dimensional grid represents the volume modeled by FDS. The grid is isolated from the surroundings, that is, all the smoke and heat generated by the fire stays within the grid and the air does not enter the grid. The user may, however, prescribe vents that allow smoke and heat to leave and air to enter the grid area.

Building items such as walls, floors, windows, doors and furniture are described in FDS as rectilinear blocks. These blocks must have sides that are either horizontal or vertical and no sloped or curved surfaces are allowed. The blocks may be colored for identification and may be assigned material properties. The blocks may be entered into the simulation with exact measurements from the building. However FDS can only work with items that fall exactly on grid cell boundaries. FDS takes the input blocks and adjusts them to match the grid cell boundaries. As a result, items may either grow or shrink to match the grid. In most cases this does not have a major impact on the calculations, although it can result in walls with no thickness or walls with gaps at intersections. Usually these issues are resolved by adjusting the size of the blocks slightly to produce the desired geometry that matches the grid size [5]-[6].

When a wall, ceiling, floor, piece of furniture, or any other material is defined for use in the FDS model, it is given a set of physical and thermal properties that are used by the model. Some of these properties such as thermal diffusivity, thermal conductivity, density and thickness impact the heat transfer in the material. For materials that burn, additional parameters such as ignition temperature, heat of combustion, heat of vaporization and maximum burning rate are specified.

The combustion process is handled in two ways within FDS. In one version, the fuel gasification rate is related to the radiant heat flux imposed from the fire onto the material. The mass burning rates of these same materials are measured in a cone calorimeter (or similar) apparatus.

Vents in FDS are openings from the model to ambient conditions outside the computational domain. Vents allow smoke and heat to leave the grid area and air to enter. Vents may be either simple openings that allow natural flow to occur based on the buoyancy of the hot gases, or vents may use a specified or forced flow rate such as the flow from a fan. Vents can also be used to introduce heat into the modeling domain. In both the mock-up and the incident simulations, vents are used to represent the areas of the foam which were initially ignited.

Smokeview allows the viewing of FDS results in three-dimensional snapshots or animations. Smokeview can display contours of temperature, velocity and gas concentration in planar slices. It can also display properties with iso-surfaces that are three-dimensional versions of a constant value of the property [5].

3. FDS Simulation

All of the input parameters required by FDS to describe a particular scenario are conveyed via one or two text files created by the user. These files contain information about the numerical grid, ambient environment, building geometry, material properties, combustion kinetics, and desired output quantities. The numerical grid is one or more rectilinear meshes with (usually) uniform cells. All geometric features of the scenario have to conform to this numerical grid. Objects smaller than a single grid cell is either approximated as a single cell, or rejected [5]-[6].

The building geometry is input as a series of rectangular blocks. Boundary conditions are applied to solid surfaces as rectangular patches. Building and content materials are defined by their physical properties, thermal conductivity, density, thickness, and burning behavior properties.

Table 1.
Material Properties of The Building Contents [1],[3],[5]

Floor	Item's name	Material	Density (kg/m^3)	T_{ign} (^{0}C)	Burn Rate Max (kg/m^2/s)	Heat Vap (kJ/kg))	Heat Comb (kJ/kg)	Thermal Conductivity (W/mK)
3rd	Mattress	Foam	40	280	0,03	1700	30000	n.a.
3rd	Bed	Wood	450	360	0,008	500	16100	n.a.
3rd	Chair	Wood	450	360	0,008	500	16100	n.a.
3rd	Table	Wood	450	360	0,008	500	16100	n.a.
3rd	Cupboard	Wood	450	360	0,008	500	16100	n.a.
3rd	Sofa	Foam	40	280	0,03	1500	30000	n.a.
3rd	Floor	Carpet	750	290	0,05	2000	22300	n.a.
2nd & 1st	Curtain	Rayon	1520	420	0,05	2000	16329	0.289
2nd & 1st	Curtain	Cotton	1500	400	0,049	2000	18850	0.461
2nd & 1st	Curtain	Wool	1300	600	0,051	2000	20515	0.193

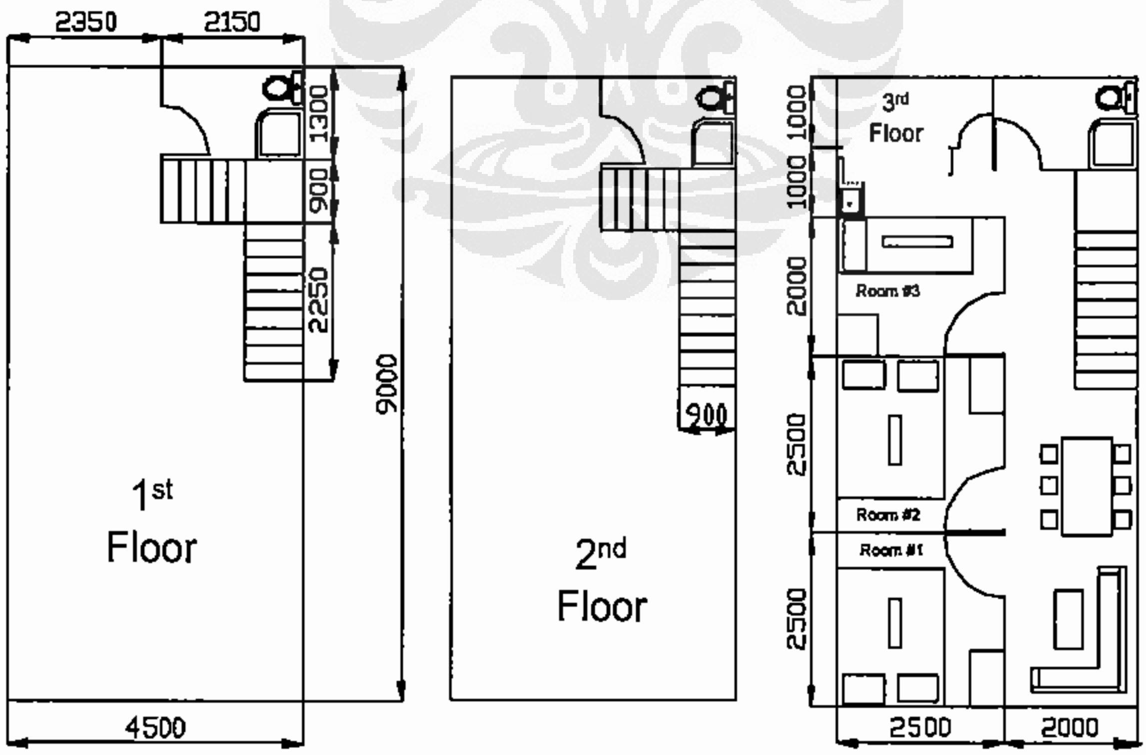


Figure. 1.
Layout and Sizes of The Building.

The typical layout and size of the "Ruko" building studied is based on the result of survey work in several cities in Jakarta. As shown on Figure 1 the typical geometry of the object, i.e. a typical "Ruko" unit has 3 storey; 3,5 m wide, 9 m long, and 9 m high. In this study, the "Ruko" is used as general commercial building for fabric trading. In this scenario, the first floor is a display area, the second floor is storage area, and the third floor is functioned an accommodation. A stairwell connecting all the floors. The 3 dimensional (3D) layout input for FDS simulation is presented in Figure 2. Table 1 provides the material properties of items in each floors.

Vents in FDS are openings from the model to ambient conditions outside the computational domain. Vents allow smoke and heat to leave the grid area and air to enter. Vents may be either simple openings that allow natural flow to occur based on the buoyancy of the hot gases, or vents may use a specified or forced flow rate such as the flow from a fan.

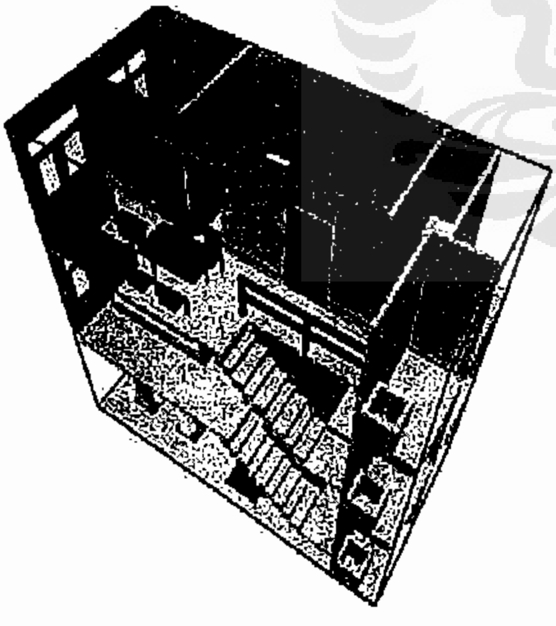


Figure 2.
The 3D Layout Input for FDS Simulation of Scenario #1.

In modeling the "Ruko" fire, the ventilations were provided by window openings. It is assumed that the wind speed was very low, with negligible affect to the vents. The hydrodynamics calculations performed by FDS allow air, hot gases, smoke and flames to move through the building. Thermal radiation, like light, travels by line-of sight and may be intercepted by obstacles within the grid. In this model the opening within the grid was provided by the stairwell connecting all floors.

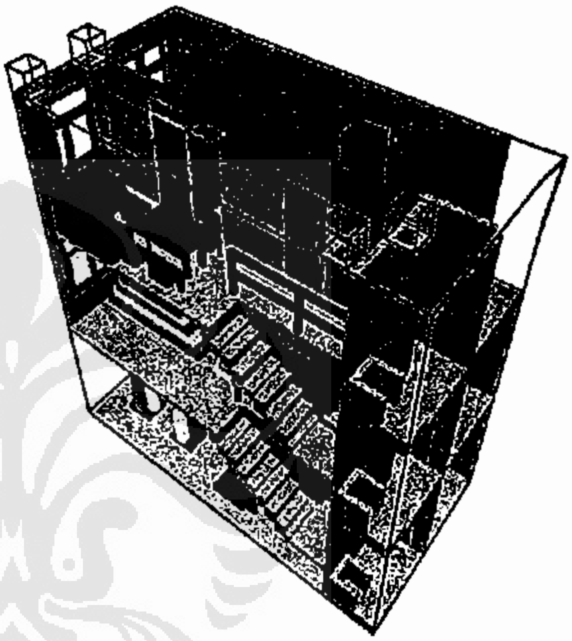


Figure 3.
The 3D Layout Input for FDS Simulation of Scenario #2 – with Smoke Shaft Systems.

The input data for materials of the building structure and contents are defined according to the function of each floor. The physical and thermal properties such as thermal diffusivity, thermal conductivity, density and thickness, ignition temperature, heat of combustion, heat of vaporization and maximum burning rate are specified based on the FDS databases. The "Ruko" fire was initiated by a ramp fire with a rate of heat release of 700 kW/m^2. The initial fire was situated in the second floor. Fire which is started in the second floor is considered to have the worse impact on fire and smoke spreads due to its function as storage area. The FDS input for the initial fire is written as follows:

```
Fires & SURF
ID='FIRE',HRRPUA=700,RAMP_Q='RAMP_FIR
E',/
&RAMP ID = 'RAMP_FIRE', T = 0., F = 0
/
&RAMP ID = 'RAMP_FIRE', T = 15., F =
1 /
&VENT XB=0,1.5,0.7,2.9,4,4
SURF_ID='FIRE', XYZ=0,0.7,4,
SPREAD_RATE=0.01  /
```

As shown on Figure 3, this paper also proposes an improved smoke control for a "Ruko" unit by means of a smoke shaft system. Smoke shaft system is basically a stack (shaft) connecting each floor directly to the ambient atmosphere. In the event of a fire, smoke will be driven out from each floor of the building to the surrounding by vent. The design capacity of each shaft is 1 m^3/s. The results of both designs are presented and discussed in the following section.

4. Results And Discussion

Simulation results on the evolution of smoke development and spread at time equals to 95s, 128s and 160s are provided in both columns in Figure 4. The first column is for scenario #1, and the second column for the improved design with smoke shaft system.

Smoke spread to the nearest room through openings between rooms. In these simulations, smoke can spreads to other areas through the stairwell, and the connecting doors within the same floors.

The simulation results shows that smoke can be seen at the early stage of fire. As shown in the first column of Figure 4, at the first 95s, smoke was quickly developed and filled in the upper zone of second floor and moved upward to the third floor. The smoke density increase significantly by the time following heat significant of heat release rate at fire origin. Thirty three second later (at 128s) the third and second floors have been overcome by the smoke. At 160s, smoke filled the stairwell area of the second floor and spread to the first floor. It is believed that the visibilities of the occupants were reduced significantly as smoke reach the first floor.

The effectiveness of the smoke shaft system compared to the ordinary design is shown in the second column of Fig. 4. It is shown that the smoke shaft system can reduces the accumulation rate of smoke within the building. Since smoke shafts are installed separately for each floor, they provide ways for the smoke to move upwards directly to the surrounding atmosphere. As a result the rate of smoke accumulation which directly correlates with the deterioration of visibility can be reduced significantly. Using the propose system, even after 160s, the smoke can not fill up the second floor. Smoke is prevented from spreading to the first floor.

The comparison of both scenarios are clearly presented in Figures. 5-8 for each floor. In the ordinary design (Figure 5), the safety limits [7] in terms of smoke density reach at 160s for the upper floors. Meanwhile, the improved design using the smoke shaft system provide better smoke venting. After 400 s, the density of smoke in the upper layers of the second scenario is still below the safety limit. In the view of fire safety engineering, the use of effective venting system can maintain the visibility for the occupants in the event of "Ruko" fires.

Figures 7 and 8 present the visibility within the building for each floor. The untenable conditions are reached at 27s for 2nd floor (Figure 7). Meanwhile, the improved design using smoke shaft system Figure 8 has better visibility.

Although the result of this simulation looks promising, nevertheless, further experimental works still need to be done, especially in ensuring the consistency and effectiveness of the propose smoke shaft systems.

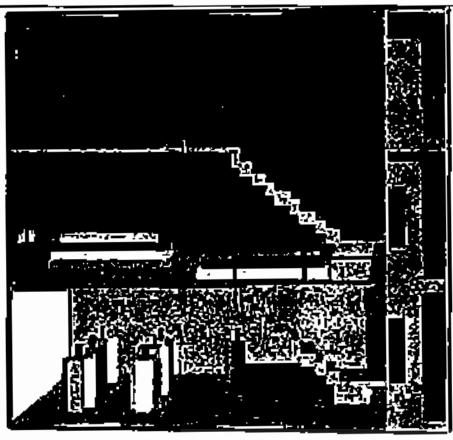
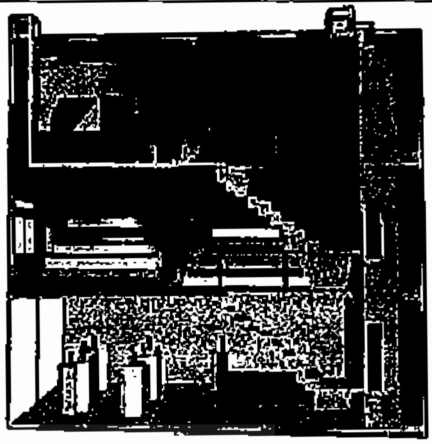
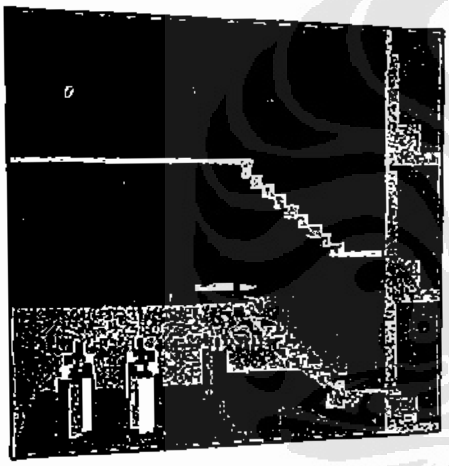
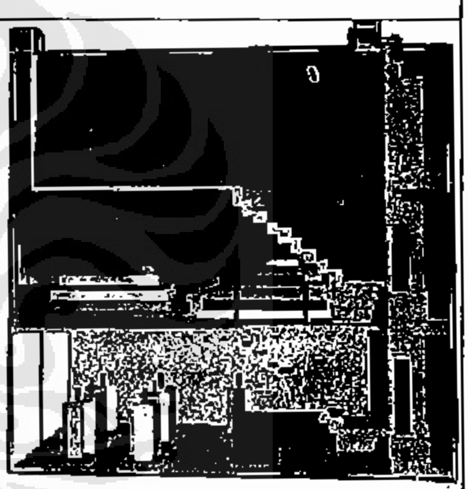
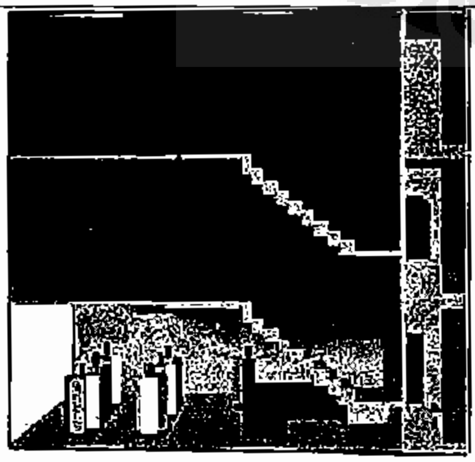
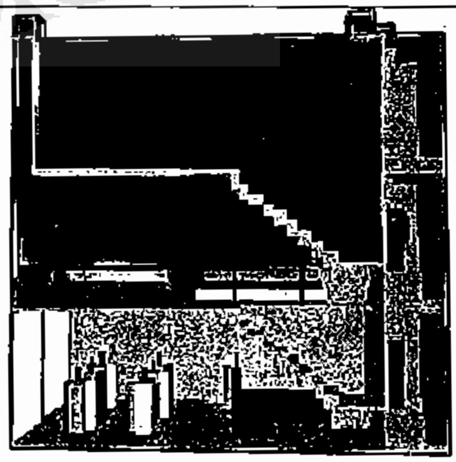
Time (s)	Scenario #1 Ordinary design	Scenario #2 Improved design – with smoke shaft system
95		
128		
160		

Figure 4.
Comparison of Smoke Development and Spread Against Time Within the "Ruko" Building, Scenario#1 The Ordinary Design, and Scenario#2 – with Smoke shaft System.

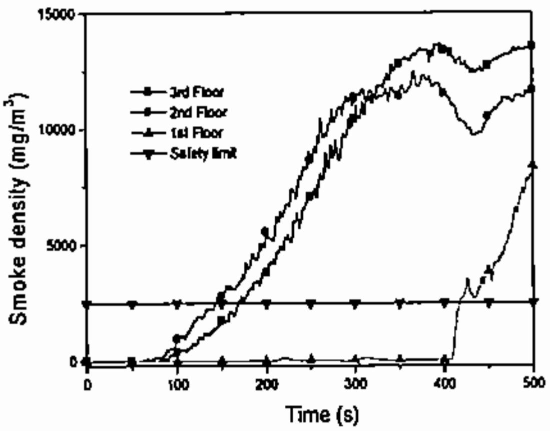


Figure 5.
Smoke Density Against Time for The Scenario #1.

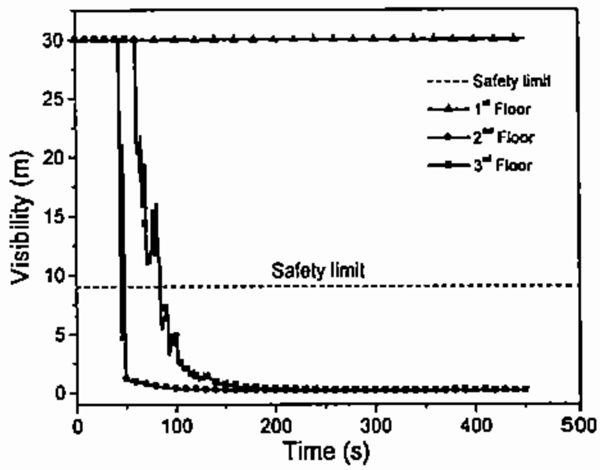


Figure 8.
Visibility Against Time for The Scenario #2 (with Smoke Shaft System).

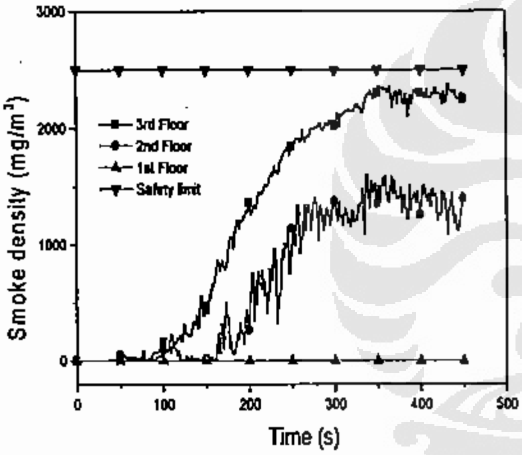


Figure 6.
Smoke Density against Time for The Scenario #2 (With Smoke Shaft System).

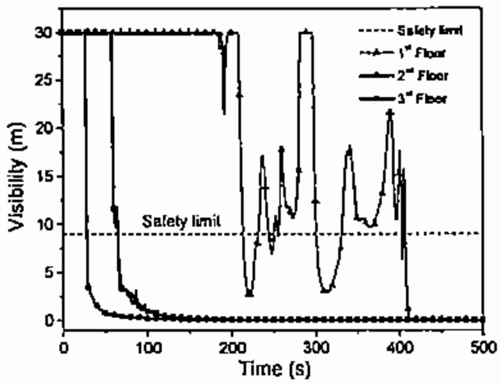


Figure 7.
Visibility Against Time for The Scenario #1.

5. Conclusion

The growth of fire and smoke production rate in buildings that combine accommodation and commercial functions (Rumah Toko or Ruko building) are the key parameters in assessing the fire safety of the occupants. The results of this study show that in the ordinary design of the Ruko building, smoke production during a fire can overcome the occupants in relatively short period of time. On the basis of this simulation, the application of smoke shaft systems can improve the venting capacity of the building. On the basis of the smoke density level, margin of safety for evacuation efforts is extended from 160 s to more than 400 s by the use of smoke shaft systems.

Acknowledgment

The authors acknowledge the FDS developers at NIST for their help and communication during the course of this work.

References

[1]. Quintiere, J. G., A Theoretical Basis for Flammability Properties, Fire and Materials, 30 (2006), 175-214,.

[2]. Nugroho, Y.S., Junaedi, A., and Kiswanto, G., Pengembangan Kalorimeter Api untuk Karakterisasi

Sifat Bakar Material, Jurnal Teknologi, 4 (2005), 294-301.
[3]. Drysdale, D., An Introduction to Fire Dynamics, 2nd Edition, John Wiley & Sons, John Wiley & Sons, 2003.
[4]. Mulholland, GW, Smoke Production and Properties, Chapter 13, The SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2006, pp. 2-258 – 2-268.
[5]. Kevin McGrattan, Fire Dynamics Simulator (Version 4) Technical Reference Guide, National Institute of Standards and Technology, USA, March 2006.
[6]. Pope, N.D., and Bailey, C.G., Quantitative Comparison of FDS and Parametric Fire Curves with Post-flashover Compartment Fire Test Data, Fire Safety Journal, 41(2006), 99-110.
[7] Surat Edaran Mentri Tenaga Kerja #SE-01/MEN/1997, Nilai Ambang Batas Faktor Kimia Di Udara Lingkungan Kerja, Ministry of Manpower Republic of Indonesia, 1997.