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Fire Safety Design of a Five Storey Office Building: Fire Design and Smoke Control

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ABSTRACT

Over 75 % of fatalities recorded from fire incidents are attributed to the effects of smoke rather than the direct burning from the fire. A study on fire safety design and smoke control was conducted in a 5 storey Asha Office Building. A restaurant is considered to be the worst-case scenario. Hence, appropriate fire protection measures such as smoke detectors, heat detectors and sprinklers are to be installed. Using a fire load density of 570 MJ/m^2 for an office building, an ignition will take place at 388 seconds. The heat release required at the growth stage of the fire is 1,460 kW and the time required for the smoke detector to respond is 353 seconds. A heat release rate of 10.7 MW at a temperature of 596^{o}C at 956 seconds would be reached before a flashover occurs. At a fully developed fire stage, the heat release rate is almost twice (20 MW) that of flashover stage which is 10.7 MW. The type of smoke control system to be adopted in Asha office building is smoke and heat exhaust ventilation system (SHEVS). For an effective operation of SHEVS at any time, both natural and mechanical ventilators should be installed but not to operate simultaneously in the same smoke reservoir. With a convective heat flux of 5,993 kW, the mass flow rate of smoke in the restaurant is 32 kg/s. A minimum number of three exhaust points will be required based on a volumetric flow rate of 43 m^3/s.

Keywords: Fire safety, Fire design, Story building, Smoke control.

INTRODUCTION

Fire serves as a source of power and heat for both industrial and domestic uses. Although, it still serves as a threat to life loss, property damage, environmental degradation and loss of reputation if carelessly handled. In fires, smoke occurs when there is incomplete combustion (when fuel is not completely burnt). Smoke is an airborne product of combustion that is made up of solid and liquid particles within a gaseous mass from a fire which is normally together with large volumes of air that become entrained into them as a result of their motion (PD 7974-2; 2002). The common combustion products are carbondioxide, hydrogen cyanide, carbon monoxide and hydrogen chloride amongst others. The main cause of deaths in indoor fires could be attributed to inhalation of smoke where about 75% of the victims die due to the effects of the smoke rather than the direct burning from the fire itself (Smoke Learning Hub, 2023). The smoke generated could be exceedingly irritating or toxic dependent on the house contents. For instance, burning plastics could frequently generate soot and poisonous gases like hydrogen chloride and carbon monoxide. The presence of flammable compound is another danger associated with smoke. Thus with enhanced oxygen, these could lead to a backdraught or flashover effect by igniting either via open flames or by their own temperature. Smoke is also associated with obscuration of visibility hence leading to difficult evacuation of fire victims. Consequently, bulk of the victims including

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firefighters become dazed in smoke and hence could not find their way out of a building.

In this paper, a fire safety design and smoke control were conducted in Asha Office Building which is prone to fire outbreak due to the presence of the combustible fuels, oxygen availability and ignition sources.

MATERIALS AND METHODS

Asha Building is a projected 5 storey administrative building to be sited in Federal Polytechnic Kaura Namoda, Zamfara State Nigeria. The building has a length of 47 m, width of 65 m, and height 17 m. The ground floor has a ceiling height of 4 m and the remainder of the floors have a ceiling height of 3 m each. Additionally, the ground floor is made up of 39 offices, a studio, stores, garage, toilets and a restaurant (comprising service, shanks, kitchen and store). Also, the ground floor has 3 dead-end corridors of 10.7 m each. A council chamber, rest room and toilets as well as 36 offices situated on the first floor of the building. The Second to fourth floors have 44 offices and toilets each. The length of the corridors at each floor is 46.8 m and 27 m along the width and depth of the building respectively. The offices in the entire building are of various sizes dependent on the number of persons expected to stay in such offices. The door sizes designed for main entrance and garage are 3.6 m x 2.1 m and 2.4 m x 2.1 m respectively. For offices, stores and toilets, the respective door sizes are 0.9 m x 2.1 m, 0.75 m x 2.1 m and 0.75 m x 2.1 m. Also, the windows scheduled for the offices, main entrance, restaurant, and toilets are 1.8 m x 1.2 m, 0.9 m x 1.600 m, 0.9 m x 1.2 m and 0.6 m x 0.6 m in that order as shown in Figure 1.

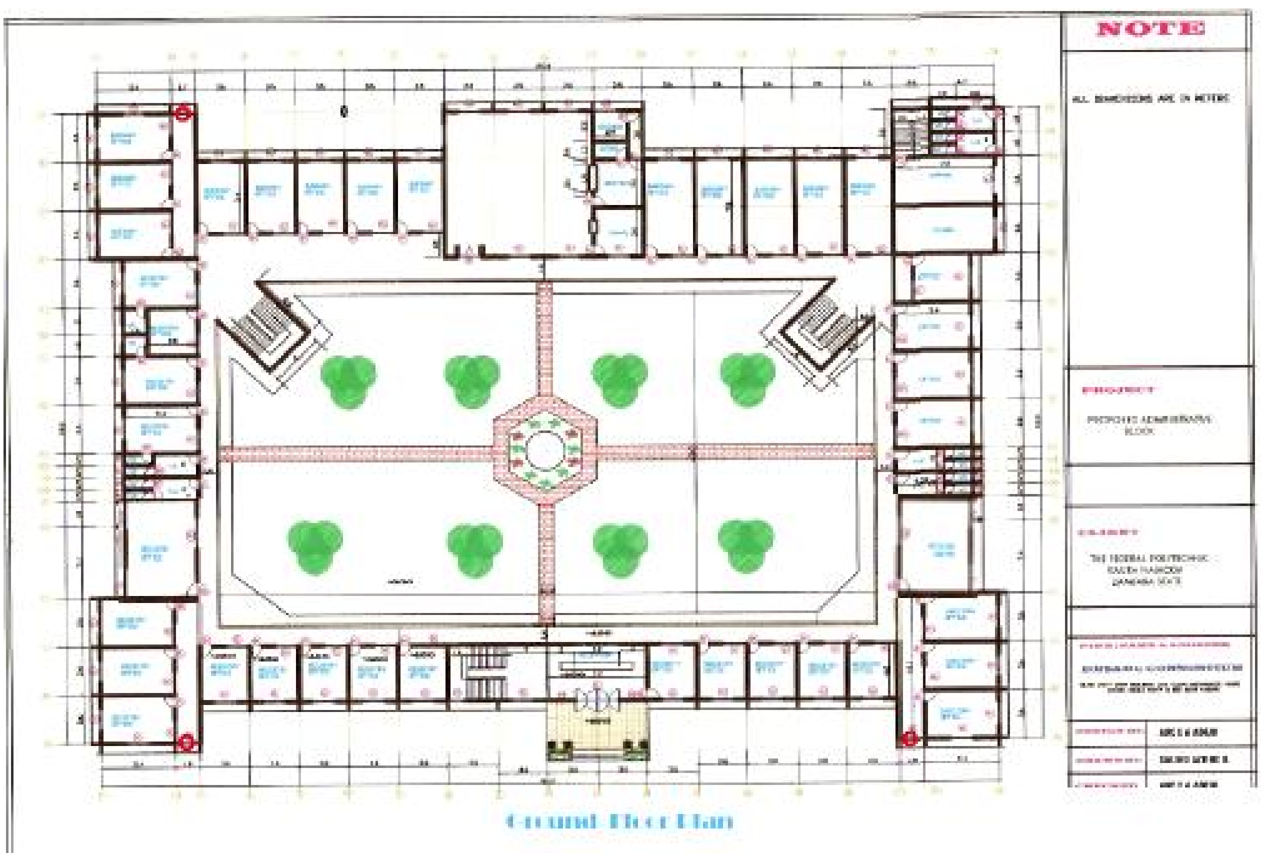

Figure 1: Overview of a layout of a ground floor of Asha Office.

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Fire risk assessment was conducted in accordance with Regulatory Fire Reforms (2005) in order to determine the area with the highest possibility of fire occurrence. The risk assessment was based on two considerations namely the presence of high number of people especially visitors who are not familiar with the building and lastly the possibility of high fire growth from restaurant. A detailed fire risk assessment on Asha Office Building was conducted by Na'inna and Bature (2023). The outcome of the risk assessment revealed certain challenges on the design building which include insufficient number of escape routes and exits, absence of fire resistance structure in the architectural building plan and lack of early warning and detection systems. Others are kitchen as an inner room passes through more than one room via a corridor, with a longer travel distance as well as restaurant as an ancillary to the main building has only one escape route. The restaurant (comprising kitchen, store, service and shanks) is considered to be the worst case scenario. As a result of this, appropriate fire protection measures such as smoke detectors, heat detectors and sprinklers are to be installed.

The purposes of smoke control system in Asha Office building are to protect means of escape by ensuring a smoke - free clear air layer below a thermally buoyant smoke layer and to control gases temperature in the buoyant smoke layer. The smoke control system will also assist fire fighting operations by creating good visibility conditions below the hot buoyant smoke layer and finally to assist in protecting properties by ensuring that the thermal stability of building structures is maintained. The standards to be used for smoke control in Asha Office building are BS 7346 - 4 (2003) Components for Smoke Control System, PD 7974 - 2 (2003) Spread of Smoke and Toxic within an Enclosure of Fire Origin and CIBSE Guide E (1997) Fire Engineering.

RESULTS AND DISCUSSION

Fires Design

The objective of fire design in Asha Office is to determine how often a material is expected to burn and how fast this burning will occur. This is to provide the possible consequences and set up a basis for appraising the risk of fire and to compare the effectiveness of different safety measures. This objective can be achieved by determining the location of fire, fire load density, stages of fire development having considered the influence of building size, potential ignition sources and location, types of combustibles and ventilation conditions (Karlsson and Quintiere, 1999). A steady - state design is to be assumed in order to enable smoke control system to cater for all fires up to design fire size and ignoring the growth phase of the fire (CIBSE Guide E, 1997).

Fire Load Density for a Restaurant

The fire load density for a restaurant is a measure of the total energy released by combustion of all combustible materials present per unit area of the restaurant. According to PD 7974-1 (2003), this can be expressed mathematically as:

$$q_k = \sum \frac{m_c H_c}{A_f} \quad (1)$$

where $q_k =$ Fire load density for the restaurant (MJ/m^3)
$m_c =$ Total mass of each combustible material in the restaurant (kg)
$H_c =$ Effective calorific value of each combustible material (MJ/kg)
$A_f =$ Total internal area of the restaurant which is 156 m^2

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The types of combustible materials in the restaurant are cooking oil, chairs, tables, cookers, plastics amongst others. However, as a result of the absence of the actual mass of the combustibles, the fire load density is taken to be 570 MJ/m^2 for an office building at the 80% value for UK (DD 240 -1; 1997).

Stages of Fire Development in an Enclosure

There are four stages of fire development in an enclosure fire namely initiation (ignition), growth stage (pre-flashover), fully developed stage (post flashover) and decay stage. Initiation (ignition) is an exothermic reaction which leads to an increase in temperature above the ambient. The fire in this stage grows slowly as a result of the spread of flame over the item first ignited. In growth stage (pre-Flashover), the fire grows more quickly and tends to spread to neighbouring items, but remains effectively local. Fire at this stage is also called fuel – controlled fire. At fully developed stage, all the combustibles will be fully involved in a fire and flame tends to fill the whole compartment. Very high temperature is normally associated at this stage. It is also termed ventilation control. At the final stage (decay stage), the flame temperature drops by 80% of its maximum value. The above stages of fire development can be shown in Figure 2.

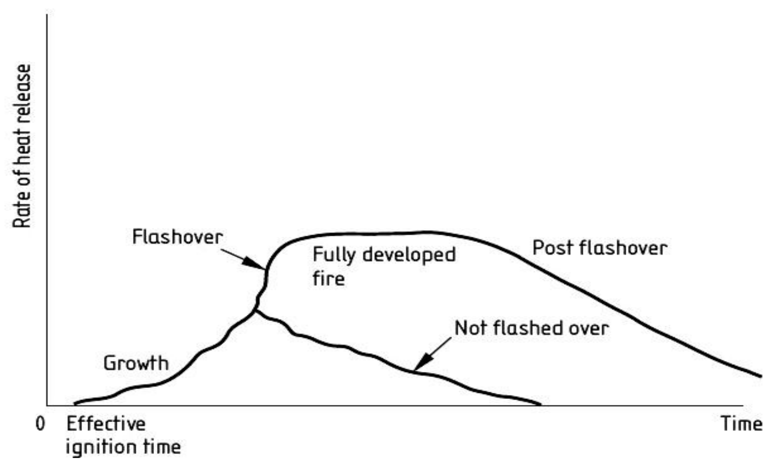

Figure 2: Stages of fire development in a compartment.

Design Fire Calculation for Ignition Time

The time that is required to ignite the first material in the restaurant assuming to be hardboard of 3.175 mm thick can be calculated using a formula given by Phylakhtou (2008) as:

$$t_{ig} = C(k\rho c)\left[\frac{(T_{ig} - T_\infty)}{q}\right]^2 \quad (2)$$

where t_{ig} = Ignition time in seconds

C = Thermal conductivity of the material with heat losses which is 0.667
$k\rho c$ = Thermal properties of the material which is 0.88 *(kW/m^{2}K)^2 s*
T_{ig} = Ignition temperature which is 365^{o}C (638K)
T_∞ = Ambient temperature (Nigeria) which is 30^{o}C (303K)
q = Minimum ignition heat flux which is 14 kW/m^2
Therefore, the ignition time, t_{ig} = 388 seconds

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Design Fire Calculation for Growth Stage (Pre – Flashover)

The fire at this stage is nearly always accelerating and it can be represented mathematically using a t - squared fire which shows that the rate of energy release Q (kW) increases as the square of the time assuming a steady state fire design (Karlsson and Quintiere, 1999). Equation 3 shows the relationship between the Q and t - squared fire:

$$Q = \propto t^2 \qquad (3)$$

where Q = heat release rate in kW.

α = growth factor in kW/s^2

t = time from established ignition in seconds

According to Drysdale,(1999) the classification of fire growth factor for different types of occupancies is presented in Table 1.

Table 1: Growth factor for different types of occupancies

Classification	Slow	Medium	Fast	Ultrafast
Growth Factor (kW/s^2)	0.0029	0.0117	0.0469	0.1876
Occupancy	Picture gallery	Dwelling, Office, Hotel reception, Hotel	Shop	Industrial storage, plant room
Characteristics time (sec)	600	300	150	75

The amount of heat output, Q, to be produced taking α and t for an office building to be 0.0117 kW/s^2 and 300 sec is 1053 kW. Growth stage (pre-flashover) is relevant to life safety in the sense that it is the stage at which smoke detectors, evacuation of occupants, sprinklers and first aid firefighting begin to operate. The distance, r, from the centre of the fire plume for the restaurant can be obtained from the Figure 3.

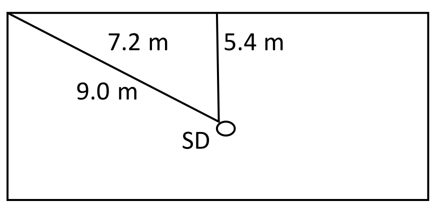

Figure 3: Determination of the distance from the centre of fire plume for restaurant.

The radial distance from the plume axis is obtained using a Pythagorean Theorem, $r = (7.2^2+5.4^2)^{0.5} = 9.0$ m

In order to determine the heat release rate required to activate a smoke detector for *$r \geq 0.18H$,* the Equation 4 from Drysdale (1999) would be used as:

$$T_{max} - T_{amb} = \frac{5.38(Q/r)^{2/3}}{H} \qquad (4)$$

where T_{max} = maximum rated temperature for smoke detector which is 70°C (Drysdale, 1999)
T_{amb} = Nigerian ambient temperature which is 30°C.
Q = size of fire (heat release rate) required to activate smoke detectors in kW
r = radial distance from the plume axis which is 9 m.
H = ceiling height which is 4.0 m.

The heat release required, Q, is 1,460 kW. Assuming that the fire starts from the corner, the value of Q will be 1/4th of the centre Q, 1,460 kW therefore, the fire at the corner is 365 kW. The time required for the smoke detector to respond obtained using Eq. 3 is 353 seconds. This is based on a given fire size of 1460 kW (heat released required to activate smoke detector) and a growth factor for medium fire which is 0.0117 kW/s^2. According to Drysdale (1999), the ceiling jet velocity, u_{max}, can be calculated to measure the plume properties at a ceiling level using Eq. 5 as:

$$u_{max} = \frac{0.195Q^{1/3}H^{1/2}}{r^{5/6}} \quad (5)$$

Therefore, the ceiling jet velocity, u_{max} = 0.71 m/s

Design Fire Calculation for Flashover Stage

If the sprinkler does not operate, the increased heat release rate would lead to an undesirable event known as flashover which is a transition between a growth period and a fully developed fire. Flashover is a rapid transition to a state at which all the combustibles in the enclosure are fully involved in a fire. Flashover is normally influenced by factors such as fuel, ventilation, heat release rate and temperature. Sudden change of fire from fuel-controlled fire to ventilation control fire is also called flashover. Considering the mass entrainment of air into the restaurant with a vent opening area A_V and height H_V, the maximum burning rate, m (in kg/s) for a stoichiometric mixture according to Phylakhtou, (2008) is given in Equation 6 as:

$$m = 0.09A_v\sqrt{H_v} \quad (6)$$

However, the limiting mass burning rate for flashover is given in Equation 7 as:

$$m_{lim} = \left(50 + 33.3A_v\sqrt{H_v}\right) \text{x } 10^{-3}\ kg/s \quad (7)$$

According to Phylaktou, (2008), a flashover will occur if $m \geq m_{lim}$.
The restaurant has seven windows of 0.9 m x 1.2 m each and a door of 1.6 m x 2.1 m.
A total area of vents (windows and door), $A_V = A_1 + A_2 + A_3 + A_4 +$ --------A_n = 10.92 m^2
The total height of the vent $H_V = (A_1H_1 + A_2H_2 + A_3H_3 +$ ------$)/A_V$ = 1.477 m
Substituting these values into Equations 6 and 7, m is 1.19 kg/s and m_{lim} is 0.49 kg/s.
Therefore, flashover will occur since $m \geq m_{lim}$.

According to PD 7974-1 (2003), for flashover to occur, it is assumed that a temperature of about 600^{o}C most be reached. The rate at which heat is released considering the influence of thermal properties of the internal linings can be obtained in Equation 8 as:

$$Q_{FO} = 750\left(h_k A_T A_v H_v^{1/2}\right)^{1/2} \quad (8)$$

Q_{FO} = the rate of heat release at flashover (kW)
h_k =the effective heat transfer coefficient (kW/m^2/K)
A_T = the total surface area of the restaurant (m^2)
A_V = the area of the ventilation opening (10.92 m^2)
H_V = height of the ventilation opening (1.477 m)

The dimensions of the restaurant are 10.8 m x 14.4 m x 4 m with a wall and ceiling of a gypsum plaster and a concrete floor. The area of floor and ceiling (A_f and A_C) is 156 m^2 each while the area of the wall, A_w is 202 m^2 minus the vent area, A_V (10.92 m^2) which makes A_w to be 191 m^2.

The total surface area, A_T is the summation of A_f, A_C and A_w which is 502 m^2. The value of h_K can be obtained using Equation 9 as:

$$h_k = \frac{A_w}{A_T}\left(\frac{(k\rho c)_w}{t_c}\right)^{1/2} + \frac{A_c}{A_T}\left(\frac{(k\rho c)_c}{t_c}\right)^{1/2} + \frac{A_f}{A_T}\left(\frac{(k\rho c)_f}{t_c}\right)^{1/2} \quad (9)$$

t_c= characteristics time of the fire which is 1,000 seconds (Phylakhtou, 2008)
$(k\rho c)_w$ = thermal properties of gypsum plaster for wall is 5.8 x10^5 W^{2}s/m^{2}K^2
$(k\rho c)_c$ = thermal properties of gypsum plaster for ceiling is 5.8 x10^5 W^{2}s/m^{2}K^2
$(k\rho c)_f$ = thermal properties of gypsum plaster for floor is 2.0 x10^6 W^{2}s/m^{2}K^2
Substituting the above values into Equation 9, the value of h_k is 0.0305 kW/m^2/K.

The heat release rate prior to flashover, Q_{FO} using the Equation 8 is 10,686 kW. This shows that a fire size of 10.7 MW would be reached before a flashover would occur. Also, the time, t, prior to flashover for a growth factor for medium fire (α = 0.0117 kW/s^2) obtained using Equation 3 is 956 seconds. This shows that the restaurant will be fully involved in a fire at about 16 minutes from the time of ignition.

The temperature of the restaurant at the flashover stage can be determined using a formula in Equation 10 sourced from PD 7974 -1 (2003) as:

$$\Delta T = 6.85\left[\frac{Q^2}{h_k\, A_T\, A_V\, H_V^{1/2}}\right]^{1/3} \quad (10)$$

where ΔT = temperature rise in ^{o}C;

Q^2 = heat release rate at flashover stage which is 10,686 kW;
h_K = effective heat transfer coefficient which is 0.0305 kW/m^2/K;
A_T = total surface area of the restaurant which is 502 m^2;
A_V =area of the ventilation openings which is 10.92 m^2;
H_V =height of the ventilation openings which is 1.477 m;

Therefore, ΔT = 565.5^{o}C. Adding the ambient temperature (30^{o}C) to ΔT will give the value of the temperature in the restaurant prior to flashover as 596^{o}C.

The total energy released during the flashover stage in the restaurant can be obtained by integrating Equation 3 with respect to time and this can be expressed mathematically as indicated in Equation 11:

$$Q_{total} = \int \alpha t^2 dt = \frac{1}{3}\,\alpha t^3 \quad (11)$$

Using a growth factor for a medium fire, α which is 0.0117 kW/s^2 and time prior to flashover, t which is 956 seconds, the total energy, Q_{total} released is 3,407 MJ.

Therefore, the mass of fuel burnt (kg) at this flashover stage can be calculated using Equation 12 as given by Phylakhtou, (2008) as:

$$m = Q_{total}/\Delta H_c \quad (12)$$

Q_{total} is the total energy released which is 3,407 MJ and ΔH is the calorific value of wood which is 18 MJ/kg (DD 240-1, 1997). The mass of fuel, m is 189 kg. Therefore, the quantity of fuel (wood) to be burnt at flashover is 189 kg.

The length of the flame prior to flashover in the restaurant can be obtained using Equation 13 sourced from Drysdale (1999) as:

$$L = 0.23\, Q^{2/5} - 1.02D \qquad (13)$$

where Q = rate of heat release prior to flashover which is 10,686 kW

D = diameter of the fire which can be obtained using a formula given in Equation 14 as

$$A = Q_{total} / FLD \qquad (14)$$

where A = flame area in m^2;

Q_{total} = total energy released which is 3407 MJ;

FLD = fire load density for an office building at 80% fractile value is 570 MJ/m^2. The flame area, A, is 6.0 m^2 and using $A = \pi D^2/4$, the diameter of the fire, D is 2.76 m. By substituting the values for D and Q in Equation 13, the flame length, L, at flashover stage is 6.6 m.

Design Fire Calculation for Post Flashover

A transition of fire from its growth stage to fully developed stage occurs once flashover is reached. This leads to the production of high heat release rate of energy and temperature of about 1,100^{o}C. At this stage, collapse of load bearing element and a fire spread within the compartment will occur as a result of high thermal stress imposed on the structural elements (Drysdale, 1999). The rate of heat release, Q, at this stage can be determined using an Equation 15 sourced from Drysdale, (1999) as:

$$Q = m_{air} \Delta H_{cair} \qquad (15)$$

ΔH_{cair} is heat of combustion of air which is 3MJ/kg, and m_{air} is the mass flow rate which can be calculated using Equation 16 as:

$$m_{air} = 0.5 A_v H_v^{1/2} \qquad (16)$$

A_V is the area of ventilation opening which is 10.92 m^2 and H_V is the height of the ventilation opening which is 1.477 m. The rate of heat release, Q, from Eq.15 is 20 MJ. This shows that, the size of the fire at this stage is almost twice to that of flashover stage which is 10.7 MW. Decay stage is the final stage of fire development where 80% of the fuel is burnt and the fire changes from ventilation controlled to fuel controlled.

Smoke Control Design

The type of smoke control system to be adopted in Asha office building is Smoke and Heat Exhaust Ventilation System (SHEVS). In this system a separation between a smoke at an upper layer and a lower layer of fresh air occurs via venting from the buoyant smoke layer using either natural or mechanical ventilators and substituting it with a clean air entering the space beneath the layer. Natural ventilators are commonly used due to its low cost and easy maintenance. This is in addition to the complexity of the building and wind effect on natural ventilators. Consequently, mechanical ventilators are to be employed in order to cancel the effects of wind and pressure differential via the use of fans. The fans are to operate automatically once automatic alarm and detection systems are activated so as to provide at least 10 air changes per hour which is able to handle gas temperature of 300^{o}C for not less than an hour (Building Regulations, 2006). For an effective operation of SHEVS at any time, both ventilators (natural and mechanical) should be installed in Asha Office building but not to operate simultaneously in the same smoke reservoir (BS 5588-7, 1997).

The space in Asha office building through which smoke is exhausted at upper level and supplying cool air at lower level is the atrium which is to be covered with a glass roof. The entire storey in the Asha office building are to open directly to the atrium so that, smoke will flow from the ceiling layer into the atrium void via the corridor vents where it will begin to rise upwards as a result of buoyancy. In order for SHEVS to serve its purpose, adequate calculations are to be carried out so that smoke's properties likely to be encountered are determined.

Fire Area and Fire Perimeter

The location of interest with possible impact of smoke spread based on the risk assessment conducted is the restaurant. Based on BS 7346-4 (2003), the fire area, A_f, and fire perimeter, P, assuming a fuel-bed controlled fire in non-sprinklered office building are 47 m^2 and 24 m respectively. The design fire is assumed to be a steady- state fire.

Convective Heat Flux at the Opening

According to BS 7346-4 (2003), the convective heat flux Q_W can be obtained using Equation 17 as:

$$Q_W = 0.5 q_f A_f \quad (17)$$

where q_f is heat release rate per unit area which is 255 kW/m^2 (Table 3 of 7346-4; 2003), A_f is the fire area which is 47 m^2. Therefore, the convective heat flux is 5,993 kW.

Rate of Smoke Flow in the Restaurant

The rate of air entrainment into a plume of smoke rising above a fire in kg/s is calculated using Equation 18 sourced from BS 7346 - 4 (2003) as:

$$m_{smoke} = C_e P Y^{3/2} \quad (18)$$

where m_{smoke} is the mass flow rate of smoke in kg/s,

C_e = constant of proportionality which is 0.337 for an office building (BS 7346-4),

P = Perimeter of fire which is 24 m,

Y = Clear layer height for an office building which is 2.5 m (BS 7346 - 4 Table 2),

Therefore, the mass flow rate of smoke in the restaurant is 32 kg/s.

Temperature of the Hot Gases

The hot gases temperature above the burning region of a fire can be obtained using Equation 19 as:

$$\theta = \frac{Q_w}{c m_{smoke}} \quad (19)$$

Where θ = temperature of the hot gases,
Q_w = convective heat flux at the opening which is 5,993 kW,
c = specific heat capacity of air which is 1.0 KJ/kg/K,
m_{smoke}= mass flow rate of smoke which is 32 kg/s,
Therefore, the temperature of the hot gases is 187^{o}C. The total smoke temperature, T, is obtained by adding the hot gases temperature to ambient temperature, T_o, (30^{o}C) to give 217^{o}C. This shows that the restaurant will not be fully involved in a fire since the total smoke temperature is less than flashover temperature (550^{o}C).

Smoke Volumetric Flow Rate

The overall exhaust capacity of the mechanical smoke exhaust ventilators can be obtained using Equation 20 obtained from PD 7974-2 (2003) as:

$$V = \frac{m_{smoke} T}{\rho_o T_o} \quad (20)$$

Where V = volumetric flow rate in m^3/s,
m_{smoke} = mass flow rate of smoke which is 32 kg/s,
T = total smoke temperature which is 490 K (217^{o}C),
ρ_0 = ambient air density which is 1.2 kg/m^3,
T_0 = ambient temperature which is 303 K (30^{o}C),
Therefore, the volumetric flow rate is 43 m^3/s

Minimum Number of Exhaust Points

It is necessary to determine the minimum number of exhaust points for any particular layer depth as a result of the maximum flow rate of smoky gases that will enter at any individual exhaust point. This is to ensure that no air is drawn up in order to achieve an efficient exhaust (PD 7974 – 2). The required number of extract vents (N) according to PD 7974-2 (2002) is obtained using an Equation 21 as.

$$N \geq \frac{m_{smoke}}{m_{crit}} \quad (21)$$

where N is the required number of exhaust points and m_{smoke} is the mass flow rate of smoke which is 32 kg/s. m_{crit} is the critical exhaust rate at an exhaust point prior to the onset of plug-holing in kg/s which can be obtained using Equation 22 as:

$$m_{crit} = \frac{2.05\rho_o(gT_o\theta)^{0.5}d^2w_v^{0.5}}{T} \quad (22)$$

Where ρ_0 = ambient air density which is 1.2 kg/m^3

T = total smoke temperature which is 490 K (217^{o}C)

ρ_0 = ambient air density which is 1.2 kg/m^3

T_0 = ambient temperature which is 303 K (30^{o}C)

θ = maximum temperature rise which is 460 K (187^{o}C)

g = acceleration due to gravity which is 9.81 m/s^2

d = depth of smoke layer which is 1.0 m

w_v = diameter of a circular duct (assuming an area of 12 m^2) which is 4.0 m

Therefore, m_{crit} = 11.74 kg/s. However, the minimum number of exhaust points (N) required using the Eq. 22 is 3.

CONCLUSION

In most indoor fire incidents, over 75 % of fatalities recorded could be attributed to the inhalation of smoke rather than the direct burning from the fire itself. The smoke is also associated with the presence of flammable compound and obscuration of vision which make evacuation efforts compounded. A fire safety design and smoke control were conducted in Asha Office Building. Based on a fire risk assessment, a restaurant (comprising kitchen, store, service and shanks) is considered to be the worst-case scenario. As a result of this, appropriate fire protection measures such as smoke detectors, heat detectors and sprinklers are to be installed. Using a fire load density is taken to be 570 MJ/m^2 for an office building, an ignition will take place at 388 seconds. The heat release required at the growth stage of the fire (pre-flashover) is 1,460 kW and the time required for the smoke detector to respond is 353 seconds. A flashover will occur since m (1.19 kg/s) is higher than m_{lim} is (0.49 kg/s). Additionally, a fire size (heat release rate) of 10.7 MW at a temperature of 596^{o}C would be reached before a flashover would occur. Also, the time prior to flashover will be 956 seconds. This shows that, the restaurant will be fully involved in a fire at about 16 minutes from the time of ignition. At fully developed fire stage, the size of the fire at this stage is almost twice (20 MW) to that of flashover stage which is 10.7 MW. Decay stage is the final stage of fire development where 80% of the fuel is burnt and the fire changes from ventilation controlled to fuel controlled. The type of smoke control system to be adopted in Asha office building is Smoke and Heat Exhaust Ventilation System (SHEVS). For an effective operation of SHEVS at any time, both ventilators (natural and mechanical) should be installed in Asha Office building but not to operate simultaneously in the same smoke reservoir. With a convective heat flux of 5,993 kW, the mass flow rate of smoke in the restaurant is 32 kg/s. A minimum number of three mechanical smoke exhaust points will be required based on a volumetric flow rate of 43 m^3/s.

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