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APPLICATION OF ZONE MODEL FOR FIRE HAZARD ASSESSMENT IN NON-INDUSTRIAL WORKPLACE – OFFICE

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ABSTRACT

This paper is going to introduce the use of the fire zone model (CFAST) for fire hazard assessment. The fire statistical records from the Fire Service Department (FSD) are discussed, which concern the numbers and the causes of the office fires occurred in Hong Kong. A detailed explanation for the steps of fire hazard assessment has been included. Finally, 10 cases with different building orientations were examined by using the CFAST zone model. As a result the relationship between the smoke layer temperature, the layer height and the building orientation were analyzed for the use of the fire hazard assessment. In addition the effect of the fire sizes and the compartment sizes were also analyzed.

(This is a final year student research project for BEng(Hons) in Building Services Engineering.)

1. INTRODUCTION

The role of the financial centre of Hong Kong becomes very important as Hong Kong is facing the economic transition. More and more foreign and mainland investors move their company to Hong Kong, therefore the demand of offices becomes very high. At the same time, the number of commercial staff is increasing as well. The larger numbers of people will stay in offices for a very long period in everyday therefore fire safety is a big concern and should be considered very carefully. However, there are not many studies reporting the fire environment in an office. In fact, there were more than five hundred fires occurred in offices and the major fire incidents (No. 3 Alarm or above) are the highest among all type of buildings. That is why it is necessary to carry out a fire study for the offices. By doing a fire hazard assessment for an office, it will be helpful to understand more about the fire characteristic of the offices.

This research studied the fire hazard in Hong Kong offices. The common design for the office and the past fire records were investigated to help find out the office's orientation, heat release rate and the time required to fill the office with smoke. Since smoke is the main factor affecting fire safety everywhere and evacuation of people, it has an important role in generating part of the essential parameters for the fire hazard assessment. In this project, the CFAST zone model was used to evaluate the fire environment of the office fire cases. In addition, the steps and the method of the fire hazard assessment were discussed. Finally, correlations were derived between the equivalent duration periods and predicted maximum hot gas temperature and the corresponding smoke layer interface height, so as to help accomplish the room modelling part of the fire hazard assessment.

2. FIRE SERVICES DEPARTMENT STATISTICAL DATA FOR OFFICE FIRE

According to the annual reports [2] from Fire Services Department (FSD) in the past seven years, it is recognized that, in every year there are more than 400 commercial fire cases occurred in Hong Kong. This number accounts for 5-6% of total fire cases in each year. As shown from the data on the right, in the 1990s, the commercial fire cases were even higher; it is almost a doubling of the cases after 2000. The reason why the commercial fire cases decreased is that, in 1996's Garley Building fire, a horrible fire led to 40 deaths, drew the concentration of the government to be concerned about fire safety of the commercial premises. Therefore, it brought up the enforcement of fire system inspection in Hong Kong.

Table 1: FSD office fire statistical record

Year	Number of Fires
1997	799
1998	678
1999	694
2000	587
2001	581
2002	476
2003	440

There are so many causes lead to a fire. For the offices fire, the common causes are shown on the following table.

Table 2: FSD cause of fire statistical record

Causes	1997	1998	1999	2000	2001	2002	2003
1. Over-heating of engines, motor and machinery	380	286	283	252	210	211	205
2. General electric fault	1529	1417	1344	1182	1112	1007	863
3. Careless handling or disposal of cigarette ends, matches and candles etc.	4411	4345	5489	3726	3749	2976	3160

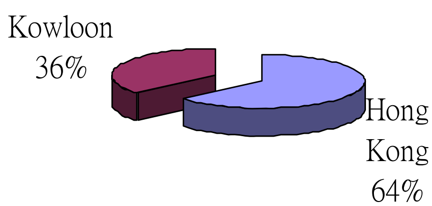

Fig. 1: Office fires distribution

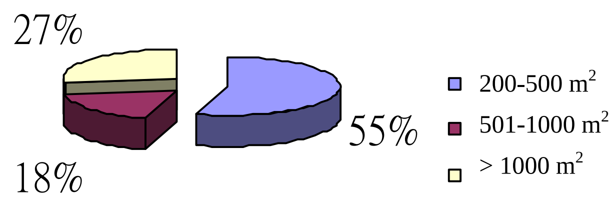

Fig. 2: Burnt office area

The careless handling or disposal of cigarette butts is the major reason. In an office there are lots of combustible materials (e.g. paper). When the burning cigarette butts is thrown to the rubbish bin. The contents can be burnt and will lead to a fire. In addition, the electric faults also are the main reason leading to a fire as most of the electric cables in old commercial buildings are deteriorated. The large short-circuit current can heat up and burn the cable. And the spread of fire from the cable can lead to a whole sale burning of the premise.

In regard to the FSD statistic data [1] in 2004, totally 11 major office fires occurred in Hong Kong. Most of them occurred in Central. It is easy to understand that, as Central is the commercial centre all of the high and modern buildings are located at this location. That is why the chance of office fire is the highest. The following charts show the office fires location and the offices burning area.

3. ZONE MODEL

The zone models [3] are types of software that are developed to help us understand the compartment fire. It emphasizes that fire in a room is divided into an upper and a lower zone, each having a unique measurable temperature, concentration of by-products of combustion, and intersection height. In general, there are 11 equations set up for 11 variables including the mass, volume, density, enthalpy, temperature and pressure of the compartment. But there are seven equations derived from physics, therefore only four variables need to be solved from the remaining four equations. By using a zone model, it can help us solve the 11 variables easily and directly. Besides, the zone model is very useful to help simulating and predicting the fire scenario and there are lots of research proving that, the zone model can predict the correct trend of accumulated smoke layer height and temperature distributions in a multi-compartment structure and can give a reasonable prediction for pre-flashover.

4. THE USE OF THE 2 LAYERS ZONE MODEL

In real fire situation, we can observe that the smoke generated from a fire tends to move upwards; therefore the space of the room is clearly divided into two layers, the upper layer with hot smoke and the lower layer with cooler air. Due to this scenario, if we want to find out the fire environment in this room, a two layers zone model is recommended to use as it can help us save a lot of calculations and time.

5. THE MODEL CFAST

CFAST [3] is a model capable of predicting the environment in a multi-compartment structure subjected to a fire. It calculates the time evolving distribution of smoke and fire gases and the temperature throughout a building during a user-specified fire. It can be referred to as zone or finite element models. This means that each room is divided into a small number of volumes (called layers), each of which is assumed to be internally uniform. That is, the temperature, smoke and gas concentrations within each layer are assumed to be exactly the same at every point. In CFAST, each room is divided into two layers. Since these layers represent the upper and lower parts of the room, conditions within a room can only vary from floor to ceiling, and not horizontally. This assumption is based on experimental observations that in a fire, room conditions are divided into two distinct layers. While we can measure variations in conditions within a layer, these are generally small compared to differences between the layers. CFAST is based on solving a set of equations that predict stated variables (pressure, temperature and so on) based on the enthalpy and mass flux over small increments of time. These equations are derived from the conservation equations for energy mass, momentum, and the ideal gas law.

6. FIRE HAZARD ASSESSMENT

Fire hazard assessment [11] is a process that results in an estimate of the potential severity of the fires that can develop under defined scenarios while the defined incidents have occurred. Fire hazard assessment cannot predict the likelihood of a fire occurring. Hazard assessment is based on the premise that when an ignition has occurred, consistent with a specified scenario and these potential outcomes of the scenario can be reliably estimated.

The goal of a fire hazard assessment is to determine the most likely outcome of a specific set of conditions called a “scenario”. The scenario includes details of the room dimensions, contents, and materials of construction, arrangement of rooms in the building, sources of combustion air, position of doors, number, locations and characteristics of occupants, and any other details which will have an effect on the outcome of interest. This outcome determination can be made by expert judgment, by probabilistic methods using data on past incidents, or by deterministic means such as fire models. Nowadays using a fire model is becoming a trend for determination, supplemented where necessary by expert judgment. While probabilistic methods are widely used in risk assessment, they find little overt application in modern hazard assessments.

Hazard assessment can be regarded as a subset of risk assessment. That is, a risk assessment is a series of hazard assessments which have been weighted for their likelihood of occurrence.

Fire hazard assessments performed in support of regulatory actions generally look at hazards to life, although other outcomes can be examined as long as the condition can be quantified. For example, in a museum or historical structure, the purpose of a fire hazard assessment might be to avoid damage to valuable or irreplaceable objects or to the structure itself. It would then be necessary to determine the maximum exposure to heat and combustion products which can be tolerated by these items before unacceptable damage occurs.

7. METHOD AND PROCEDURE

7.1 Performing a Fire Hazard Assessment

Performing a fire hazard assessment is a fairly straightforward, engineering analysis. The steps include:

1) selecting a target outcome;
2) determining the scenario of concern that could result in that outcome;
3) selecting an appropriate method for prediction;
4) evaluating the results; and
5) examining the uncertainty.

The following sections describe these steps.

7.2 Selecting a Target Outcome

The target outcome most often specified is to avoid fatalities of the occupants of a building. Another might be to assure that fire-fighters are provided with protected areas from which to fight fires in high rise buildings.

7.3 Determining the Scenario of Concern

Once the outcomes to be avoided are established, the task is to identify any scenarios which may result in these undesirable outcomes. Here, the best guide is experience. Records of past fires, either for the specific building or for similar buildings or class of occupancy can be of substantial help in identifying conditions leading to the outcome to be avoided. Statistical data from the local Fire Services Department on ignition sources, first items ignited, rooms of origin, etc., can provide valuable insight into the important factors contributing to fires in the occupancy of interest. Anecdotal accounts of individual incidents are interesting but may not represent the major part of the problem to be analyzed.

7.4 Selecting an Appropriate Method for Prediction

7.4.1 Fire Models

A recent survey stated that there are 62 models and calculation methods that could be applied to fire hazard assessment. Thus the need is to determine which one is the most appropriate to a given situation and which is not. The key to this decision is a thorough understanding of the assumptions and limitations of the individual model or calculation and how these relate to the situation being assessed.

7.5 Accounting for Uncertainty

This refers to dealing with the uncertainty which is inherent in any prediction. In the calculations this uncertainty derives from assumptions in the models and from the representativeness of the input data. In evacuation calculations there is the added variability of any population of real people. In building design and codes, the common method of treating uncertainty is adding a safety factor. A sufficient safety factor is applied such that, if all of the uncertainty resulted in error in the same direction the result would still provide an acceptable solution.

In the prediction of fire development and filling time the intent is to select the design fires which provide a *worst likely* scenario. Thus, a safety factor is not needed here unless assumptions or data are used to which the predicted result is very sensitive.

The fire hazard assessment report should include a discussion of uncertainty. This discussion should address the representativeness of the data used and the sensitivity of the results to data and assumptions made. If the sensitivity is not readily apparent, a sensitivity analysis (vary the data to the limits and see whether the conclusions change) should be performed. This is also a good section in which to justify the appropriateness of the model or calculation method in the manner discussed previously.

8. CFAST SIMULATION FOR 10 OFFICE CASES

In order to understand how the room dimensions, contents, materials of construction, arrangement of rooms in the building, sources of combustion air and position of doors affect the fire scenario, totally 10 offices in Hong Kong with different location, arrangement and size were investigated. Afterward, by using CFAST to perform the simulation for these 10 fire environments, the maximum upper layer temperature, lowest layer height, the maximum heat flux and the other corresponding parameters such as time and heat release rate were obtained.

In the simulations, four different fire sizes were adopted; they are 1 MW, 3 MW, 5 MW and 10 MW respectively. It is because in the real case we cannot predict what the first ignited item is and we cannot know how big the fire size is; as a result the level of damage cannot be determined. Therefore, by using these four fire sizes, we can find out how critical the burning result is when they have different levels of destructive power.

In order to perform the worst scenario for the offices and make the simulations simpler, these 10 simulations used the same assumption and setting. The assumptions are as follows:

1) The interior room height of all offices are 4 m;
2) The fire source will only be located at the largest and the smallest room;
3) No fire source will be located at the corridor;
4) All windows within the offices are closed;
5) All interconnection doors between different compartments are opened;
6) The simulation time of all cases are 2000 s;
7) The Ultra Fast growth fire curve is adopted; and
8) No detection and sprinkler system installed.

9. SIMULATION RESULTS

Due to the large amount of data, it is not efficient to show all data with different fire sizes, that is why the smallest and largest fire size in the largest compartment will be extracted to have further discussion. The following table shows the generated results of 10 cases with 1 MW and 10 MW fire sizes. They are related to the offices area, maximum temperature, lowest layer height and the heat flux.

9.1 Effect of Fire Size

From the table, it can be seen that the fire size is the major component affecting the fire environment. As the fire size increases, the whole environment parameters tend to change to the extreme level. Take office 5 as an example, when 1 MW fire size is used the maximum temperature is just 472°C, however, when 10 MW fire size is used the maximum temperature of the compartment is almost a doubling of the 1 MW which is 864°C, and this fire size can even lead to the flashover of the room when the temperature is higher than 600°C [12]. In addition, the lowest layer height is also affected by fire sizes. The higher the fire size is, the lower the layer height is. Similarly, the heat flux generated is also proportional to the fire size.

9.2 Effect of Compartment Size

Not only is the fire size affecting the fire environment, the compartment size is also a major factor affecting the result.

Table 3: Generated results from CFAST

Office	Area(m²)	Tmax(°C) 1MW/10MW	Corresponding Time(s) 1MW/10MW	Corresponding Layer Height(m) 1MW/10MW	Corresponding Flux(W/m²) 1MW/10MW	Lowest Layer Height(m) 1MW/10MW	Corresponding Time(s) 1MW/10MW	Corresponding Temperature(°C) 1MW/10MW	Corresponding Flux(W/m²) 1MW/10MW
1	166.4	436 / 667	110 / 230	2.6 / 0.7	810 / 6548	0.8 / 0.3	670 / 460	404 / 532	1056 / 3357
2	77.4	453 / 856	670 / 670	1.2 / 0.2	1392 / 21490	1 / 0.2	110 / 220	424/ 780	1145 / 14097
3	59.1	477 / 822	670 / 470	0.5 / 0.1	1871 / 17637	0.5 / 0.1	280 / 150	472 / 693	1838 / 8809
4	149.3	407 / 727	670 / 660	1.2 / 0.3	1009 / 10690	1.2 / 0.2	180 / 230	404 / 682	952 / 8170
5	30.5	472 / 864	670 / 440	0.8 / 0.2	1749 / 21653	0.7 / 0.2	110 / 170	445 / 759	1460 / 12486
6	161.9	397 / 672	210 / 670	1.5 / 0.6	867 / 7323	1.4 / 0.5	230 / 230	397 / 627	870 / 5467
7	142	417 / 725	220 / 320	1.1 / 0.2	1091 / 10339	0.2 / 0	680 / 450	404 / 532	1126 / 3265
8	159.3	402 / 702	180 / 670	1.4 / 0.4	911 / 9005	1.2 / 0.4	410 / 210	399 / 616	930 / 5187
9	87.4	441 / 698	650 / 680	0.6 / 0.2	1548 / 9630	1 / 0.1	200 / 150	436 / 591	1406 / 4943
10	123.5	409 / 754	180 / 670	1.2 / 0.3	1007 / 12651	1 / 0.2	300 / 210	408 / 664	1039 / 7503

As shown in the graph when the same fire size is used, the maximum temperature of the compartment will gradually decrease with compartment size. However, the small fire size 1 MW does not have deep fall with it. Taking 10 MW fire size for example, the smallest compartment size 30.5 m² has the highest upper layer temperature, which is almost 200°C higher than the largest compartment size 166.4 m². Similarly, for the other fire size, the same temperature distribution will also occur. By looking at this graph, the minimum upper temperature can still be up to about 450°C. Therefore, the temperature inside is quite high and may lead to burning of the whole premise.

For the lowest layer height graph, it is obvious that the smoke generated by whatever size of fire can still fill up the smallest room 30.5 m² to make the lowest layer height down to 0 m, it can prove that the size is much affecting the smoke and time for depression. Moreover the largest fire size 10 MW can also lead to the smoke filling up the relatively large compartment. But for the largest compartment, due to the large volume of the compartment, the smoke has sufficient space to spread, so that all the smoke will stay at the upper level of the compartment and it will not be down to the lower layer because it is due to the buoyancy theory.

For the heat flux, the flux in the smaller compartment has the highest value it is because the flux generated in the smaller compartment has more chance to heat the surface of the surroundings as a result more items are heated up and they give out the radiant energy as well, so it would increase the volatilization rate. As a result, higher flux will be generated in the small compartment but not in the large compartment.

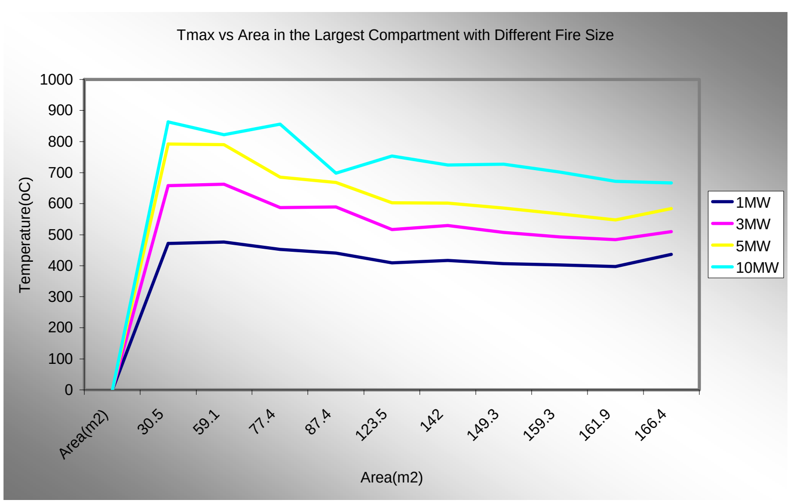

Fig. 3: T_{max} with area graph

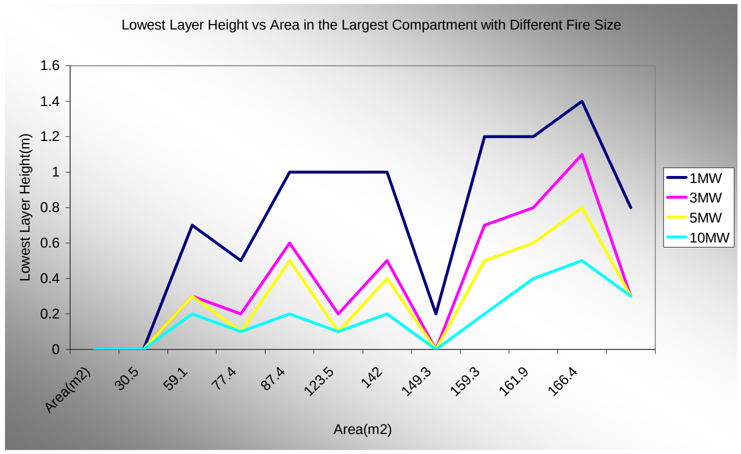

Fig. 4: Lowest layer height with area graph

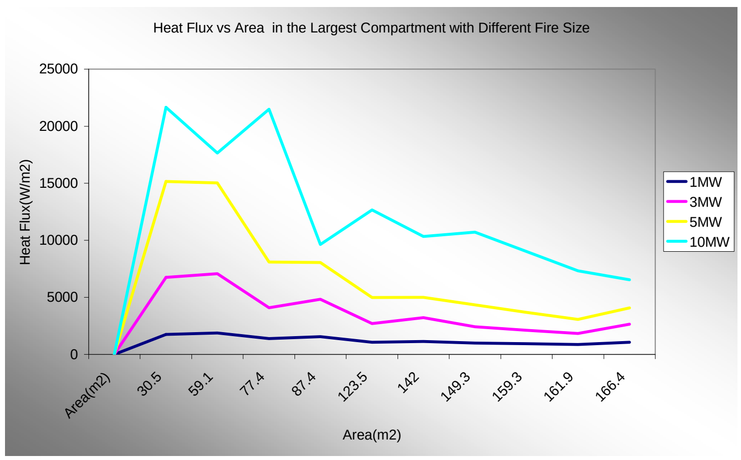

Fig. 5: Heat flux with area graph

10. APPLICATION OF THE SIMULATION RESULTS FOR HAZARD ASSESSMENT

By using the results obtained from the simulations, we can predict the probability of flashover, the time taken for the smoke depress to the lowest level and the heat flux generated so as to act as part of analysis for the fire hazard assessment.

10.1 Flashover

According to [12], when the burning temperature is higher than 600°C flashover will occur. Fire spread on or to an object is driven by radiant energy from its surroundings (flames and hot gases and room surfaces) which heat the surface and increase the volatilization rate. The higher the upper layer temperature, the higher the imposed flux and the more objects ignite and burn, thereby spreading the fire. As a result all material inside the compartment will burn. This fatally increases the danger level for the occupants. Therefore, the maximum temperature obtained from the model is very useful for finding the possibility of flashover. In addition, the time taken for the temperature rise is also important for the evacuation of the occupants.

10.2 Smoke Depression

It is obvious that the deaths in the fire case are always caused by smothering. Therefore, it is important to know how fast the smoke depressed to the alert level. As a result, the time for the occupant's evacuation can be determined. On the other hand, the lowest height of smoke generated by the model can also act an index for the fire expert to determine how dangerous the compartment is. It is because, if the lowest height of smoke is not lower than the acceptable level, then the compartment can still be safe for the evacuation as people will not smother by the smoke. However, if the smoke is lower than the acceptable level, the occupants inside the compartment should evacuate as fast as possible;

otherwise they will be dangerous in getting smothering.

10.3 Heat Flux

Heat is assessed as an incapacitation measure in the analysis; it is not differentiated from lethality. When convective heat is predicted to the cause, the death may ultimately be from toxicity or oxygen deprivation, but only because the victims were prevented from escape by convected heat.

11. CONCLUSION

In conclusion, the fire size is the major factor affecting the fire environment of the burning office. The larger the fire size is, the higher the possibility of the flashover is. On the other hand, the compartment is also another issue affecting the office fire. As it was found when a fire burn in the smaller compartment, the dangerous level can up to a horrible level. It is because the temperature can even higher may reach to flashover and the smoke layer height can down to the unacceptable level which may lead to getting smothering. Due to the time limitation, only 10 cases have been done, the data from these 10 cases may not be enough to represent all fire scenarios. As a result, the generated data maybe have some deviation from the real case. However, as all of the cases used the worst situation in the simulation therefore the assessment result is still acceptable while the worst case will not come out. Furthermore, in order to have more realistic data to analyze how the common Hong Kong office's orientation affect the fire environment, more fire studies in different orientation, size, and categories should be carried out. Finally, due to the capability of the CFAST, only part of the fire hazard assessment could be achieved. So more data such as the occupant-set probabilities for offices, reaction time for the detection system and etc, should be collected to complete the full hazard assessment.

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