FIRE RISK FACTORS IN SHOPPING MALLS

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ABSTRACT

In stage one project development, it was found that shops selling bedroom products such as curtains, blankets, pillows, and mattresses had the highest Fire Load Density (FLD) due to the combination of high calorific values, and hence the highest potential fire hazard. In addition, the results showed that season could affect the value of FLD, which means some shops would have high FLD in summer and lower FLD in winter, or vice versa. Moreover, it was also concluded that FLD is closely related to the shop floor area, it decreases with increasing floor area.

Fire Load Density (FLD) in shopping malls is further studied in this semester. Four field surveys were carried out on surveying 301 retail shops. It was found that 16% of the retail shops exceeded the limit of FLD under local code. And when using the survey results to compare with FLD for shops in New Zealand, it is observed that FLD for malls in Hong Kong is estimated to be higher. In addition to surveying FLD in shopping malls, two more themes were added: the Occupant Load Factor (OLF) and Heat Release Rate (HRR) of several retail shops. During the survey, occupant patterns in the shopping malls were studied. Such measurement can help in developing two analyses on occupant loading, that is the population density and the traffic flow of the shoppers.

Fire can spread to the adjoining stores within a short period. Therefore, heat release rate of a shop would be a valuable topic to study. In this report, HRR of a clothing shop, a toy shop, and a furniture store were estimated. Based on data from cone calorimeter, it is observed that under a higher radiative heat flux at 40 kWm^{-2}, the combustibles would be ignited within a much shorter time than under a heat flux at 20 kWm^{-2}.

1. INTRODUCTION

The Mainland's "facilitated individual travel" policy has been effective since July 2003, this encourages large number of mainland tourists to visit Hong Kong. As this scheme is further developed in the rest of Guangdong provinces, it will bring more visitors to our city. Shopping malls would become crowded not only during weekends but also in weekdays. This would create evacuation problems in case of fire. The aims of this project are to:

- Carry out survey on Fire Load Density (FLD) in shopping malls and make comparison with the values obtained in shopping centres in New Zealand.
- Study the Occupant Load Factor (OLF) and check with the requirements laid by the Buildings Department.
- Establish relationships between prices and quantities (storage) of goods with the fire services installations.
- Estimate the Heat Release Rate (HRR) of several retail shops and assess fire hazards.

Shop-keepers, security guards, and shoppers are the occupants found in shopping malls. The staff and the security guards, in general, are familiar with the building environment and its layout. On the contrary, the shoppers may not be familiar with the layout of the shopping mall, when there is a fire, they may not be able to locate the way to escape. Occupant density would then be an important parameter in the fire safety requirements.

Occupancy limits, or occupant load factors, are established to help ensure an area within a building can evacuate in a safe and efficient manner. It is determined by dividing the square footage of an area by the number of occupants at any given time. According to [1], the usable floor area that can be occupied by every occupant in a shopping centre (from basement to 2/F) is 3 m^2; while for 3/F and above, the usable floor area is 4.5 m^2 per person.

While for the heat release rate of a burning object, it is defined as the enthalpy change per unit time. It is typically reported in kilowatts or megawatts. Heat release rate is believed to be important for quantifying the growth and spread of a fire in a building. Understanding the heat release rate potential of an object is essential to eliminate the hazard such an object could pose if ignited. The reasons for its importance in describing fire hazard are:

- HRR is the driving force for a fire. In fact, heat generated would be feedback to the burning fuel to give more heat.

- Many variables are correlated to HRR. The generation of smoke, toxic gases, room temperature and other fire hazard variables tend to increase with increasing HRR.
- High HRR indicates high threat to life. This is because high HRR causes high temperatures and high heat flux conditions, which may be lethal to occupants.

2. FIELD SURVEY PROCEDURE

Four shopping malls were selected for the analysis. FLD was weighted by estimating the numbers and types of combustibles within a retail shop. According to the local code [2], FLD is computed by the formula:

Weight of contents (kg) × Calorific value of contents (MJ/kg) / Floor area (m^2) (1)

Such value (FLD) is composed of two parts: fixed fire load and movable fire load. Basically, items like storage rack, furniture owned by the shop owner, lighting fittings, or partitions are classified as fixed fire loads. While commodities sold are the movable loads found inside a shop.

For occupant pattern of a shopping mall, there are two ways to carry out the survey. The first method is to select a particular usable floor area in m^2 (without any obstructions) and count the number of persons occupying that area at 15 minutes time interval. This was done between 12:00 at noon until 20:15 at night. And the second method is to check the traffic flows of the shopping malls. It was executed by choosing one of the exits from a shopping mall, and counted the number of persons entering and leaving the mall at one hour interval.

Finally, for the estimation of heat release rate of retail shops, it was studied by referring to the cone calorimeter test results from ref. [3]. Curves of heat release rate versus time for each of the materials tested at two incident fluxes were constructed (that is under incident radiative heat fluxes for flashover of 20 kWm^{-2} and another high value at 40 kWm^{-2}). The way to estimate the HRR of a shop is done by:

- Determining the possible type of material that could be found inside a retail shop.
- Examining the HRR performance of the material from ref. [3] so that HRR per unit area (kWm^{-2}) at a particular minute could be obtained. For example, at 30 s, the HRR per unit area for wood at heat flux 20 kWm^{-2} is 135 kWm^{-2}; while at heat flux 40 kWm^{-2}, the HRR per unit area obtained is 150 kWm^{-2}.
- The HRR per unit area (kWm^{-2}) obtained is then multiplied by the total surface area (m^2) of the combustible, which would get Kilo Watt (kW) in final outcome using equation (2) below.
- Summarizing the HRR of all combustibles to get a resultant curve (on the upper limit of the total heat release rate) that both incident fluxes for comparison.

$$Q_{total} = \sum_i Q_i \text{ cone calorimeter} \times A_i \quad (2)$$

where Q_i cone calorimeter is the heat release rate per unit area of the i^{th} combustible in kWm^{-2}, i is the type of combustibles being studied, and A_i is the total surface area of i^{th} combustibles in m^2.

In this report, HRR of a clothing shop, a toy shop, and a furniture store were chosen to be estimated. The type of combustibles for each shop category and the burning duration period are summarized in Table 1 and further analysis would be shown in Section 4.4.

Table 1: Key data for thermal analysis

Retail shop	Combustible items (i)			Burning duration
Clothing Shop (Shop Area = 45 m^2)	- Textile - PVC - Polystyrene	- ABS - Wood - PMMA	- Polycarbonate	26 minutes
Toy Shop (Shop Area = 18 m^2)	- PVC - Polystyrene - Polyethylene	- Polypropylene - ABS - Wood	- PMMA - Polycarbonate - Cardboard	26 minutes
Furniture Store (Shop Area = 75 m^2)	- Polystyrene - ABS	- Wood - Nylon	- PMMA - Polycarbonate	38 minutes

Table 2: Shopping malls surveyed

Shopping mall	District	Year of construction (Class)	Target customers	No. of retail shops inside	Estimated total floor area (m^2)
Mall A	Mong Kok	1996 (2)	Students	123	4,500
Mall B	Ho Man Tin	1975 (3)	Residents/ Students	57	12,300
Mall C	Sham Shui Po	2002 (1)	Residents	58	6,100
Mall D	Central & Western	1997 (2)	Tourists	63	12,500

3. FIELD SURVEY OBSERVATIONS

In last semester, the shopping mall's period of construction has been divided into four classes: before 1972 (Class 4); during 1972-1987 (Class 3); during 1987-1998 (Class 2); and after 1998 (Class 1). The field survey was started in mid-January. Initially, it was expected to carry out surveys on all classes. However, due to refurbishment of old buildings, it is difficult to find Class 4 constructions, while the existence of Class 3 buildings is still common in Hong Kong.

Four shopping malls were surveyed between January and March. Their main features are summarized in Table 2.

3.1 Popularity of Individual Travel

As "individual travel" is getting popular, many entertaining activities are now changing to suit those mainland tourists who are on individual travel. The occupant type within a shopping mall now includes not only local shoppers and tourists from other Asian and European countries, but also tourists from the Mainland China. During the field survey, it was observed that the shopping malls were crowded not only in weekends, but also in weekdays.

3.2 Other Variables Correlated to FLD

Survey on Malls A and B were carried out during the Chinese New Year. The shopping centres were decorated with plants, lanterns, poetic couplets, happy wishes written on red papers, or other movable Chinese New Year backdrops. These are expected to increase the fire load within a shopping mall. Moreover, in case of fire, these would become obstacles to occupants.

3.3 Relationship between Price of the Goods and Fire Services Installations

Among the four shopping centres visited, Mall A generally sells watches, toys, stationeries, sportswear and clothing. The prices are ranging from HK$10 to HK$2,000 and Fire Services Installations (FSI) such as fire shutter, fire detection and sprinkler system have been provided. While for Malls B and C, their target customers are residents living nearby, they are selling daily necessities with price ranging from several dollars to several thousands and basic FSI were provided for fire fighting. And for Mall D, it is located in a popular tourist district selling special souvenirs, golden accessories, and other brand-named clothing at relatively high prices (up to HK$80,000) aiming to attract the tourists to purchase. To protect the high-priced produces, the shops, in general, even provide potable extinguishers for property protection.

3.4 Layout of Combustibles

Combustible items commonly stored in the retail shops are PVC (polyvinyl chloride), PS (polystyrene), ABS (acrylonitrile butadiene styrene), PC (polycarbonate) or wood, etc. These might be ignited easily by the incident heat flux if there is an accidental fire, while these combustibles are almost placing on the floors or racks adhered to the walls. So the analysis on the survey results would be based on the heat flux of 20 kWm^{-2} at floor level and 40 kWm^{-2} at vertical wall [6].

4. RESULTS AND ANALYSIS

The survey results could be used to study the fire hazard, evacuation strategy, and also the smoke management system of a shopping mall.

4.1 FLD Analysis for the Shopping Malls

The FLD for the four shopping malls are estimated and summarized in Table 3.

Table 3: Fire load densities for the shopping malls

Shopping Mall	FLD Range
Mall A	320 – 1670 MJm^{-2}
Mall B	190 – 10340 MJm^{-2}
Mall C	100 – 2530 MJm^{-2}
Mall D	75 – 1730 MJm^{-2}

The upper limit of FLD under the local code [2] is 1135 MJm^{-2}. The reason for the high value of 10,340 MJm^{-2} in a retail shop (Mall B) is because

of its compact display of bedding products. Blanket (wool), pillow (polyester), and mattress (polypropylene) which have calorific values of 20.67 $MJkg^{-1}$, 23.25 $MJkg^{-1}$, and 51.15 $MJkg^{-1}$ respectively cause the high value of FLD in estimation. This eventually concludes that the higher value of FLD, the higher fire risk the shop possesses.

After estimation of FLD for the retail shops, the cumulative frequency of the FLD of 301 retail shops is further calculated and shown in Fig. 1. The limit for the cumulative frequency is set at FLD above 1,135 MJm^{-2}. Fig. 1 shows that 84% of the shops are below the upper limit while the rest are over the value of 1,135 MJm^{-2}. Shop-keepers should consider reducing the number of combustible items in order to lower the FLD of the shop.

4.2 Comparison of FLD between Malls in Hong Kong and in New Zealand

A comparison of FLD in the two regions is presented in Fig. 2. It is observed that FLD of malls in HK have higher values. This is because shops in Hong Kong are compacted and the shop owners have a common habit of piling up the stocks, while malls in New Zealand do not, as they have spacious shop area [4].

4.3 Occupant Patterns in the Shopping Malls

The occupant pattern in a mall is evaluated as usable floor area per person which was measured between 12:00 to 20:15. Fig. 3 presents the relationship between occupants and usable floor area. When there is an increasing number of occupants occupying a specified area, the floor area for each occupant possessed would be reduced. Therefore, the higher value of usable floor area per person, the lower risk of evacuation problem that a mall might have. From Fig. 3, it is observed that:

- Population density in Mall B is quite high. There are six time intervals having OLF below 3 m^2 per person.

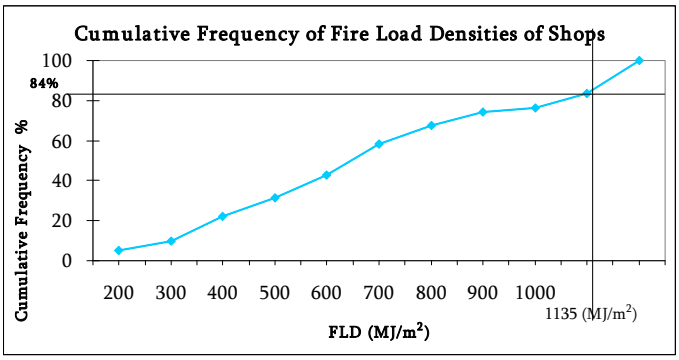

Fig. 1: Cumulative frequency of the FLD of 301 retail shops

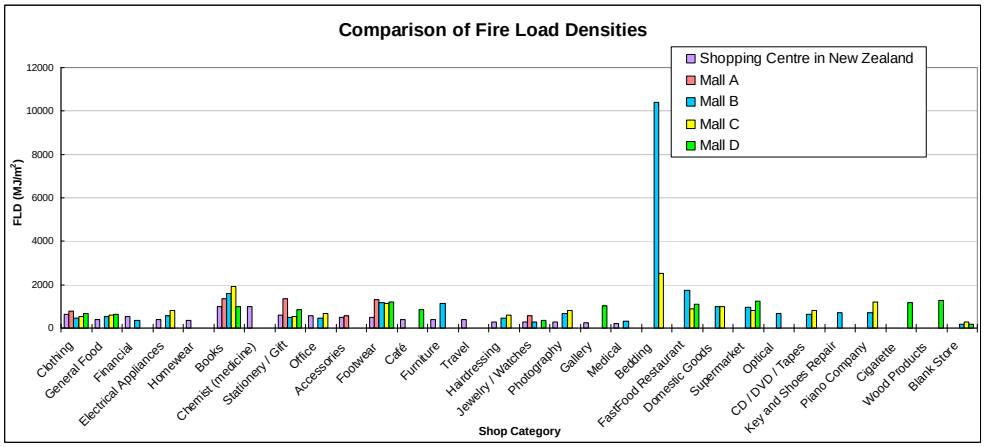

Fig. 2: FLD comparisons between shopping malls in Hong Kong and in New Zealand

- The result showed that Mall C provides more spaces to occupants when compared to Malls B and D. The peak occurred at 18:30 in which every occupant could occupy 90 m^2.
- Population density in Mall D is high. There are 11 time intervals having OLF below 3 m^2 per person. Between 18:00 to 20:15, the OLF was kept under 3 m^2 per person. Each occupant even occupied only 1.3 m^2 at 18:45.

Apart from studying the population densities of the shopping malls, the traffic flow of shoppers were also studied. Fig. 4 shows the occupant inflow and outflow of the Malls B, C and D. The results recorded are actually referring to the number of occupants going into and leaving the shopping mall, recorded in every hour.

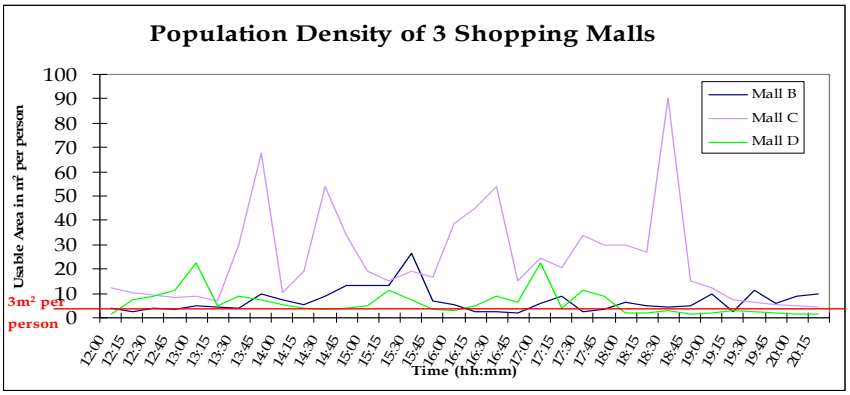

Fig. 3: Population density of the shopping malls between 12:00 to 20:15

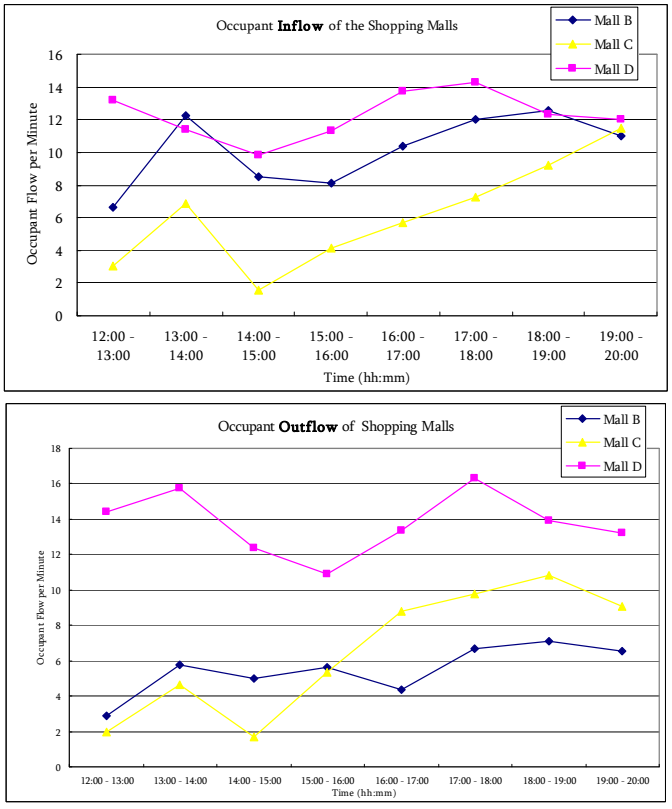

Fig. 4: Occupant traffic flow per minute of the shopping malls

The occupant traffic flows showed that:

- Occupant inflow and outflow for Mall C is the lowest among the three malls. The lowest traffic flows were recorded between 14:00 – 15:00. During this period, residents were expected to return home after lunch, and students were still having lessons, so the traffic flows were lower.
- Occupant inflow and outflow for Mall D is the highest among the three malls. The traffic flow was kept above 10 persons per minute for the whole day. The mall was rather crowded as compared to other Malls being surveyed. This is because Mall D is a popular tourist spot. It attracts not only tourists, but also local citizens. Recently, mainland tourists on individual travel have become the major occupants of the malls, not only in weekends, but also in weekdays.
- For Mall B, it had an intermediate traffic flow, not too high or too low. The mall actually has four exits (only one of the exits was chosen for measurement). By observation, occupants just made use of the mall (as a shortcut) to go to other places.

4.4 Heat Release Rate of Some Specialty Shops

HRR is a critical factor in predicting the contribution of a burning material to the growth of a fire. Figs. 6, 7 and 8 are three types of retail shops commonly found in a shopping mall, and the resultant HRR of each shop is to be estimated according to the cone calorimeter test in ref. [3].

The resultant HRR is generated using equation (2) in Section 2 above. HRR of a clothing shop may be composed of different combustibles. However, these materials may not be ignited at the same time. In Fig. 5, it can be seen that, for example, the ignition time for Textile is 30 s, while PMMA took about 4 mins to be ignited.

Moreover, the highest HRR was obtained with PC (5,760 kW). The initial peak HRR for PC (at 6.5 mins) was also among the seven highest. After recording the value of Q_i cone calorimeter for each sample, the total surface area A_i of the materials exposed is estimated. And finally, the resultant HRR Q total can be obtained.

The resultant HRR curve for a clothing shop with floor area 45 m^2 was estimated in Fig. 6. For flashover heat flux recorded at floor level of 20 kWm^{-2}, the peak HRR of 10.8 MW would be found after 6.5 mins. But for a higher radiative heat flux at 40 kWm^{-2} (recorded at vertical wall), the peak HRR of 9.3 MW would be found after 3 mins.

Fig. 7 shows the estimated resultant HRR curve for a toy shop with floor area 18 m^2. For a flashover heat flux of 20 kWm-^{2}, the peak HRR of 10.9 MW would be found after 6.5 mins. But for a higher radiative heat flux, the peak HRR of 19.2 MW would be found after 4 mins. The combustibles would be ignited within a much shorter time.

The resultant HRR curve for a furniture store with floor area 75 m^2 was estimated in Fig. 8. For a flashover heat flux of 20 kWm^{-2}, the peak HRR of 14.1 MW would be found after 6.5 mins. However, for a higher radiative heat flux at 40 kWm^{-2}, the peak HRR of 14.3 MW would be found after 5 mins. The combustibles would be ignited within a much shorter time.

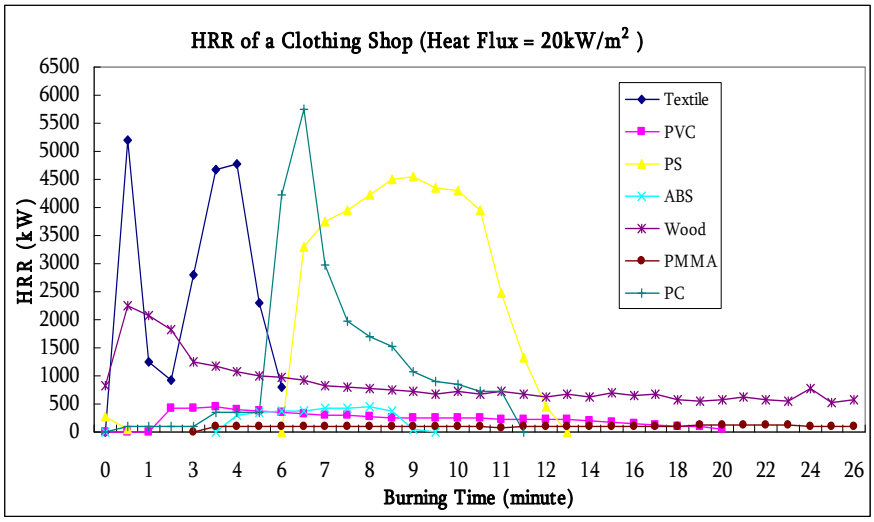

Fig. 5: Heat release rate of a clothing shop at 20 kWm^{-2} heat flux

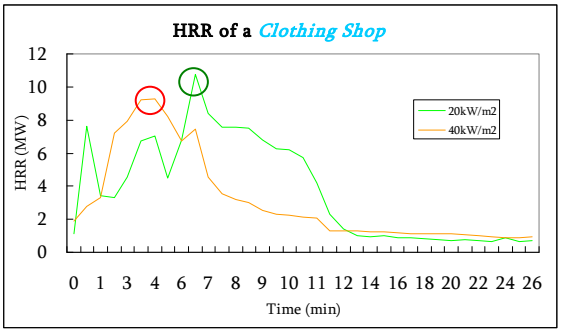

Fig. 6: Resultant heat release rate of a clothing shop

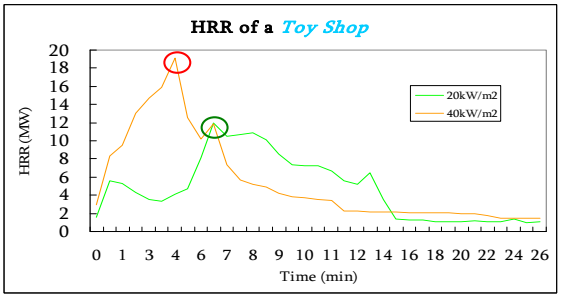

Fig. 7: Resultant heat release rate of a toy shop

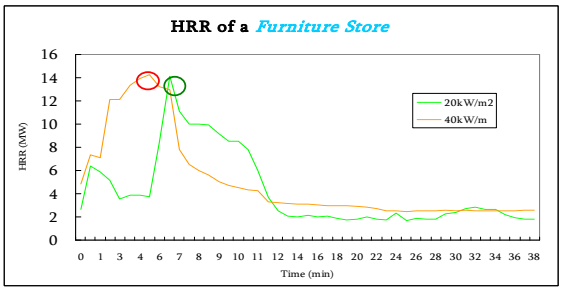

Fig. 8: Resultant heat release rate of a furniture store

5. REDUCING FIRE HAZARDS

From the survey on FLD, OLF, and HRR of shopping malls, the following fire prevention measures can be considered in order to reduce fire hazards of a mall:

- Checking of stock height inside the retail shops and not to pile up too much stock. This could help to reduce movable loads of a retail shop.
- Reducing the use of combustible furnishings could help to reduce the fixed fire load of a shop.
- Training and educating retailers and security staff in fire fighting yearly or half-yearly.
- The presence of evacuation schemes may not be enough, especially for mainland tourists on individual travel who are unfamiliar with the Hong Kong environment. Therefore, mandarin announcement is required (where it is suggested to be a clear and simple one).
- To prevent the spreading of smoke, smoke management in the form of extract, ventilation or reservoirs is required to provide adequate time for the occupants to escape.

6. CONCLUSION

This research surveyed the fire load densities of three different classes of shopping malls in Hong Kong. The field survey results were analyzed by establishing the relationship between the fire loads, occupant's density, and HRR of different shop categories. The results are summarized as follows:

- One retail shop selling bedding products in Shopping Mall B has got the highest FLD due to its compacted display and high calorific values contained.
- 84% of the retails are below the upper limit of FLD of 1,135MJm^{-2} under the local code. This indicates there are still 16% of the shops possessing high fire risk in which their FLD has exceeded the limit.
- Relationship can be further established between the price, quantity of goods, shop area, insurance, and also the fire services provision inside a retail shop. During the field survey, it is observed that for shops selling fundamental commodities at relatively low price, stocks are piled up while the shop itself is not spacious. Moreover, only minimum fire services installations are provided. Some sprinklers are even blocked by the goods. The major reasons for piling up the stock are because of convenient and high stock turnover. In addition, shops selling fundamental commodities may not cover high insurance as compared to those shops selling gold or jewelry, which means fire safety and security are being underestimated.
- The population densities of shopping malls are getting higher as there is an increasing number of mainland tourists on individual travel to Hong Kong. This would lead to evacuation problems in case of fire. It is suggested that the present evacuation strategy and crowd movement should be modified to cope with the growing number of occupants in malls.

- High HRR indicates high threat to life. Peak HRR are always generated within several minutes. Shop-keepers should be trained to extinguish the fire and help to evacuate shoppers to a safe place as soon as possible.

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