Fire hazard assessment of combustibles in big terminals

W.K. Chow

Department of Building Services Engineering,
The Hong Kong Polytechnic University, Hong Kong, ROC
E-mail: bewkchow@polyu.edu.hk

Abstract: It is observed that some big terminal buildings were functioning as more than just a passenger terminal, leading to the placing of combustibles in the big hall. For example, polyurethane sofas were put in areas providing catering services. A preliminary fire hazard assessment based on the identified scenario on burning those combustibles will be reported in this paper. Hazard assessment included studying the heat release rate, smoke filling in the hall and the air temperature distribution. Full-scale burning tests, empirical equations on key parameters and computational fluid dynamics are used. It is not good practice to close businesses in this economic climate. Therefore, remedial actions such as spraying fire retardant coatings which can stand higher radiative heat fluxes in case of accidental fire, and implementing appropriate fire safety management are recommended.

Keywords: fire hazard; transport terminal; heat release rate; fire model.

Reference to this paper should be made as follows: Chow, W.K. (2005) 'Fire hazard assessment of combustibles in big terminals', Int. J. Risk Assessment and Management, Vol. 5, No. 1, pp.66–75.

Biographical notes: W.K. Chow joined The Hong Kong Polytechnic (now The Hong Kong Polytechnic University) in 1981, and is now Chair Professor of Architectural Science and Fire Engineering and Director of the Research Centre for Fire Engineering in the Department of Building Services Engineering. He has been teaching and developing courses up to Master degree level and supervising PhD research projects on architectural science, fire and safety engineering for over 20 years. He is also the Founding President of the Society of Fire Protection Engineers (Hong Kong Chapter) set up in October 2002.

1 Introduction

There are many big terminal buildings in the Far East (including Hong Kong) such as, public terminal interchanges and airport terminals (Tsui and Chow, 2003). Because of the huge space and volume, it is not feasible to install dynamic smoke exhaust systems for the whole area, even though such a requirement is specified in the prescriptive codes on fire services installation (Fire Services Department, 1998). Protection against smoke is supposed to be covered by the ‘cabin’ concept (Law, 1990; Beever, 1991). This means, areas of higher fire risk such as retail areas would be covered by a roof. Those areas can be isolated under emergency by fire shutters, smoke curtains, smoke barriers or similar...
devices. Sprinkler and smoke extraction systems on a smaller scale are installed inside. It is targeted to ‘control’ the fire by operating the sprinkler. Smoke will then be extracted without spreading to the outside hall. The design itself has to be justified for further assessment (Chow, 1997). For example, sprinkler and smoke extraction systems have to be functioning properly as designed. The operating times of the sprinkler system and the smoke extraction system have to be determined carefully. All these will be addressed separately later under higher design fires, say above 2 MW. Further, effects of radiative heat flux on the heat release rate in these retail shops should be investigated carefully.

Use of alternative fire protection systems such as water mist fire suppression system (Chow and Yao, 2001; Chow, 2002) might be more appropriate in ‘extinguishing’ a fire, if the system is designed properly.

However, it is observed that combustibles such as polyurethane foam (PUF) sofa were placed in some terminal halls. There might be serious consequences when there is an accidental fire. PUF sofa would be ignited in a relatively short time if there is no appropriate protection with fire retardants (FRs) (Hao and Chow, 2003). Although the hall itself is big and the thermal effect due to an accidental fire might not be significant, the large quantity of smoke generated would spread to give psychological ill-effects to passengers staying inside. The problem can be quite serious when the terminal hall is densely populated with passengers. Crowd movement should be watched carefully as the consequence might be very serious if there is no good fire safety management (Malhotra, 1987).

Under the current investment climate since the Asian economic depression in 1998, it is not a good practice to stop those businesses. If adequate fire safety provisions on hardware including passive building construction and active fire protection system; and software on fire safety management are provided, there would not be serious consequences even when there is a fire. With the new fire protection technology, such a problem should not be difficult to solve.

Therefore, fire risk assessment is necessary and basically there are two parts (Forney and Jones, 1990; ASTM E1546-00, 2003). The first part is on scenarios analysis to get the expected severity such as deaths resulted from that scenario or cost of the incidence. This analysis is physical and relies on scientific understanding of the fire and the performance of protection systems. Assessment tools included empirical correlations on key parameters such as estimating the minimum heat release rate required for flashover, fire models or full-scale burning tests. The second part is on estimating the likelihood (or the fire probability) of that scenario. Past fire records and expert advices have to be considered. For a big public transport terminal as surveyed in this paper, there is not yet a database on fire records. The likelihood of the fire has to be proposed by experts, in consultation with the concerned authority, management and possibly the insurance company as well. Therefore, only fire hazard assessment will be carried out in this paper.

The scenario identified is, ignition of the PUF sofa in a big terminal hall. The first step is on understanding the heat release rates and smoke spreading upon ignition of those combustible items. The objective of this paper is to report such a study on preliminary fire hazard assessment. Results would be useful for recommending appropriate remedial actions such as applying FRs and introducing proper fire safety management.
2 Heat release rate

With the knowledge of heat release rate (Huggett, 1980; Babrauskas and Grayson, 1992; Peacock, et al. 1994), the following can be understood:

- an indication of the size of the fire
- the rate of fire growth, and consequently, the release of smoke and toxic gases
- the time available for escape or fire suppression
- the type of suppressive action that is likely to be effective
- other attributes that define the fire hazard
- possibility of having a flashover fire.

The heat release rate when burning an object, is now commonly measured by the oxygen consumption method (Huggett, 1980). As shown in the literature, 13.1 MJ of heat would be given out in burning polymer with 1 kg of oxygen. This is regarded as a universal constant for most fuels in a fire involving similar reactions in breaking the carbon-carbon, carbon-hydrogen and carbon-oxygen bonds. In an oxygen consumption calorimeter, combustion products generated in burning an item together with the entrained air, are collected by a canopy hood connected to an exhaust ‘fan-duct’ system. A ‘duct section’ with gas sampling tubes and sensors properly aligned, is installed in the exhaust duct. These gas samplers and sensors are connected to an instrument station for data analysis with a computer. This arrangement (Babrauskas and Grayson, 1992) is used in the cone calorimeter, the furniture calorimeter, the ISO9705 room-corner fire test (ISO 9705:1993(E), 1993), the ‘industry calorimeter’ (Månsson, Dahlberg, Blomqvist and Ryderman, 1994) and the single burning item test (Smith and Shaw, 1999).

3 Full-scale burning tests

It is difficult to select a site for full-scale burning tests in urban areas like Hong Kong. The land costs are far too expensive and there are tight environmental protection regulations. Real fire tests cannot be performed frequently. A site far from those urban areas should be selected for carrying out such studies. In this way, environmental impact of the burning tests can be minimised. Further, there should be water, electricity and heating supply in remote areas which are cold, like Sweden.

A facility, known as the PolyU/HEU Assembly Calorimeter (Chow, 2001; Chow et al., 2003), has now been developed. This is a joint project between the Harbin Engineering University (HEU) and The Hong Kong Polytechnic University (PolyU). A full-scale burning hall is designated in a small town Lanxi in a remote area of Northern China, which is about 200 km away from Harbin, Heilongjiang, China. An ‘exhaust hood’ and a ‘fan-duct system’ were installed successfully. The ‘duct section’ and the associated instrument including the oxygen analyser, laser system, carbon monoxide analyser and carbon dioxide analyser, flow and temperature measuring systems were installed for measuring heat release rate up to 5 MW at the moment. All the instruments were calibrated properly, using a small standard gas burner fire by following the user’s manual.
A chamber of the same size as specified in the ISO Room-Corner fire test (ISO 9705:1993(E), 1993) was built for studying the heat release rate of PUF sofa (Dong, Zou and Gao, 2002). A selected PUF sofa of length 2 m as shown in Figure 1a was studied. The sample was put in the room calorimeter and burnt under an accidental fire of 100 kW, in following the ISO 9705:1993(E) (1993). Two sets of tests were carried out with the heat release rate curves shown in Figure 1b. It is observed that the peak heat release rate went up to 860 kW, with the total burning time over 1800 seconds (or 30 minutes). The time of having heat release rate higher than 500 kW is about 700 seconds. Note that burning an item will not liberate too high the heat release rate. However, such a long burning time of 30 minutes might lead to serious consequences, in igniting other combustibles.

Figure 1  The tested polyurethane foam sofa

![Polyurethane foam sofa tested](image)

(b) Heat release rate

Test 1  Test 2
4 Estimation of smoke filling time

Upon ignition of such a sofa, the smoke generation rate can be estimated by the air entrainment rate (CIBSE, 1997; Morgan and Gardner, 1999). In burning that sofa, there is a burning time of 700 s with heat release rate higher than 500 kW. The peak heat release rate is up to 1000 kW. In addition to testing those two cases, higher heat release rates of 2000 kW (commonly used in terminal hall design) and 5000 kW (commonly used in shopping malls) were also assessed. The flame height $z_1$ (in m) of a fire of convective heat release rate $\dot{Q}_p$ (in kW) and longest length $d_s$ (in m) is (CIBSE, 1997):

$$
z_1 = \frac{0.035 \dot{Q}_p^{2/3}}{(d_s + 0.074 \dot{Q}_p^{2/3})^{2/3}}
$$

For height $z$ (in m) higher than $z_1$, the smoke production rate $\dot{M}$ (in kgs⁻¹), when taken to be the air entrainment rate, is (CIBSE, 1997):

$$
\dot{M} = 0.071 \dot{Q}_p^{1/3} z^{5/3}
$$

Values of $\dot{M}$ are plotted against $z$ in Figure 2 for $\dot{Q}_p$ of 500 kW, 1000 kW, 2000 kW and 5000 kW by taking $d_s$ as 2 m. Values of $z_1$ are 1.08 m, 1.62 m, 2.39 m and 3.91 m respectively for those values of $\dot{Q}_p$.

Figure 2 Smoke production rate
It is observed from the figures that, if the clear height is kept at 4 m, smoke production rates for 500 kW, 1000 kW, 2000 kW and 5000 kW fires are 5.7 kgs⁻¹, 7.2 kgs⁻¹, 9 kgs⁻¹ and 12.2 kgs⁻¹ respectively. For such a low smoke production rate, it would take a long time to fill up the terminal hall.

To understand the smoke filling process, an example of terminal hall as in Figure 3 is considered. Suppose the floor area of the region of interest is \(A_f\) (in m²), ceiling height \(H\) is 9.5 m and specific heat capacity of air at constant pressure \(C_p\) is about 1100 Jkg⁻¹K⁻¹, neglecting thermal effect due to the huge space volume, mass balancing gives:

\[
\frac{d}{dt} \left[ C_p A_f (H - z) \right] = 0.071Q_p^{1/3} z^{5/3}
\]  

Integrating would give the time \(t_4\) (in s) to fill the hall with smoke of interface height 4 m (a value to be agreed by the owner and the Authority) as 520 \(A_f\), 413 \(A_f\), 329 \(A_f\) and 243 \(A_f\) respectively for 500 kW, 1000 kW, 2000 kW and 5000 kW fires.

Even if the region of interest is small, say taking \(A_f\) as only 100 m² by isolating with smoke curtains, \(t_4\) would be quite long of 867 min, 688 min, 548 min and 405 min for 500 kW, 1000 kW, 2000 kW and 5000 kW fires respectively.

5 Simulation of smoke movement by computational fluid dynamics

A better estimation of the smoke filling process can be achieved by applying Computational Fluid Dynamics (CFD) (Chow, 1998) to study the thermal-induced air flow. The example of terminal of geometry as shown in Figure 3a, is considered. As shown above that if the space volume is very huge, burning the sofa would give a fire of very small burning area with respect to the hall area. The peak heat release rate in burning a PUF sofa as in Figure 1a, would be up to 1000 kW. It is not practical to calculate the entire space volume, and so a ‘slice’ of width 33 m was cut out to estimate the probable environment under a 1 MW fire. The CFD simulation tool PHOENICS was selected with the software executed in a pentium with details reported before on studying terminal fire (Chow, 1998; Li and Chow, 2004).
The region of interest as shown in Figure 3 is divided into 21, 20 and 20 parts along the x-, y- and z-directions respectively. All the four vertical sides are taken as free boundaries with the fire placed at the centre of the region.

Consequence of having a 1000 kW fire can be understood by the CFD calculations. Steady-state results of velocity vectors and air temperature predicted from PHOENICS, are shown in Figures 4a and 4b. Basically, there is very little thermal effect to the big hall as the air temperature in most part of the region of interest is less than 500°C. However, smoke spreading out of it as indicated by the velocity vectors, might cause problems if the terminal hall is overcrowded with passengers. Much longer time might be required for total evacuation as human behaviour under crowded conditions was very different.

**Figure 4** Steady-state results of CFD simulations

Again, higher heat release rate of 2000 kW which is commonly used in terminal hall design; and 5000 kW for shopping malls, are also tested with steady-state results shown in Figures 4c and 4d. As illustrated in the figures, thermal environment for a 2000 kW fire would not be too different from that of a 1000 kW fire. However, the thermal effects under a 5000 kW fire would be quite severe. Most part of the region of interest has temperature above 200°C.

### 6 Fire hazard assessment

As observed by visual inspection while touring round an airport terminal, PUF sofa was found in the passengers’ terminal. Therefore, igniting the PUF sofa by accident can be taken as a typical fire scenario. In this paper, only the consequence of the identified scenario of burning a PUF foam sofa is estimated. Results achieved in the above on the heat release rate, smoke production rate and temperature distribution data, are applied for a preliminary fire hazard assessment. This is not a consultancy studying report from a safety auditor appointed to carry out a fire hazard assessment, but pointing out how those results complied from the above can be applied.

As defined in ASTM 1546 (2003), fire hazard is the potential for harm associated with fire. Fire hazard assessment is a process for measuring or calculating the potential
Fire hazard assessment of combustibles in big terminals

for harm created by the presence of a material, product, or assembly in the relevant fire scenarios. It was further proposed (ASTM E1546-00, 2003) that procedures for fire hazard assessment should include seven steps:

- defining the scope
- identifying the measure of harm to be assessed
- identifying and describing the scenarios of concern
- identifying the test methods or calculation procedures needed to produce the measures of fire hazard
- using the scenarios to define key parameters of the test method or calculation procedures
- identifying the types and sources of data required to support the test methods or calculation procedures
- identifying the criteria or procedures for evaluating the fire hazard measures relative to the degree of harm.

In following this procedure, the scenario identified is burning a PUF sofa in the terminal hall by accident. The hazard measures will be the consequence due to the heat release, smoke filling and temperature distribution. Studies in the above would provide the relevant data by the full-scale burning tests on heat release rate, time required for the smoke layer interface height falls down to a certain height, and the smoke temperature distribution.

In view of the heat release rate curve of the PUF sofa as shown in Figure 1b, generating 500 kW of thermal power for 700 s, is quite dangerous. It is possible to ignite adjacent items such as luggage carried by the passengers. Much higher heat release rate can then be resulted. Note that in testing surface partition or lining materials in the room calorimeter following ISO 9705, the maximum heat release rate for an accidental fire applied to assess the material is only 300 kW. The fire resulting from burning a PUF sofa placed in the terminal would give heat release rate much higher than this standard gas burner. Whether PUF can be placed in a terminal without sprinkler protection, is recommended to be reviewed carefully.

Results on the smoke filling process induced by burning the PUF sofa, are useful in assessing the time required to fill up the terminal hall. The designed total evacuation time should be shorter than the filling time for keeping the smoke layer above a certain height, or known as the clear height. In this example, the average smoke layer temperature in the terminal hall should not be higher than 60°C even for a 1000 kW fire. The total evacuation time can be extended to a longer value under this scenario. For example, if it is agreed to keep smoke layer above 4 m, the smoke filling time is 867 min. Basically, all occupants should be evacuated within this long smoke filling time under normal condition. However, psychological effect under fires should be watched. Further, as the evacuation pattern depends on the number and locations of the exits, a more detailed analysis on evacuation pattern should be carried out to understand the evacuation time distribution.
7 Conclusions

A preliminary fire hazard assessment in an airport terminal was carried out. The hazard scenario identified is burning a PUF sofa. Consequences denoted by the heat release rate, smoke filling time and air temperature distribution were, then analysed. Results of the hazard assessment suggested that placing PUF sofa in big terminal halls without sprinkler protection might not give serious thermal problems. The maximum heat release rate of the sample tested might go up to 860 kW. A steady heat release rate higher than 500 kW would be resulted within a burning duration of 700 s. The smoke production rate would be very low, taking a long time to fill up the large space of big terminal halls. This point is also supported by CFD simulations.

However, that does not imply that it is unnecessary to take appropriate actions. Crowd movement under emergency conditions with smoke might be a concern. Fire safety management (Malhotra, 1987) should be worked out carefully. A fire safety plan containing at least the following four parts is recommended:

- maintenance plan
- staff training plan
- fire prevention plan
- fire action plan.

In the fire prevention plan, applying fire retardant coatings onto the PUF sofa (Hao and Chow, 2003) would help to delay the ignition time. However, the materials should be assessed properly. Testing the samples with a cone calorimeter is suggested to be the minimum requirement.

References


