BRIEF REVIEW ON FORCED-VENTILATION REQUIREMENTS IN CHINA FIRE CODES

Qiao Kui
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

(Received 29 January 2003; Accepted 31 March 2003)

ABSTRACT

Smoke control systems are required in many buildings in China. Codes and requirements on forced ventilation installations related to smoke control system in China are reviewed in this paper. Key parameters are discussed and compared to those for codes in Hong Kong. Example cases on an underground carpark and a single room in a tall building are used for illustrating the requirements. Simulations with fire models FIREWIND will be carried out to justify the design following the codes.

1. INTRODUCTION

Consequent to joining the World Trade Organization, it is interesting to introduce the fire safety code system in China. In fact, research and development activities on fire were carried out actively in the past 50 years. This has become an important field in engineering for supporting fire codes system in China. The fire safety system itself is quite complicated and can be classified either by legal aspects or by technical specification issued by different government departments from National People's Congress to local governments. A summary chart is shown in Table 1.

Many fire codes are related to buildings, three commonly used are:

- Code for fire protection design of industrial buildings, stores and general apartments (GBJ-16-87, 1995) [5];
- Code for fire protection design of tall buildings (GB50045-95, 1997) [6]; and
- Design code for residential buildings (GB50096, 1999) [4].

There are far too many items to discuss on active fire protection system, and passive building construction. In this paper, only the forced ventilation systems in buildings are focused.

The objective of this research is to use fire models to evaluate the requirements of forced ventilation in China fire codes. Performance of smoke extraction system was studied to verify the necessary time for evacuation.

2. OBJECTIVES OF INSTALLING VENTILATION SYSTEM IN A BUILDING

Forced ventilation system installed in a building includes fans, ventilation pumps, pressurization systems, inlets and outlets of ventilation. Smoke extraction systems serve to prevent smoke spreading to some critical areas, reduce the smoke temperature and improve visibility by taking action such as diluting the smoke with fresh air [1-3].

One or more of the following objectives [1-3] must be satisfied by installing ventilation control system and smoke control system:

- Maintaining a tenable environment in the means of egress in large-volume building spaces during the evacuation time.
- Controlling and reducing the migration of smoke between the fire area and adjacent spaces.
- Providing conditions within and outside the fire zone that will assist emergency response personnel to conduct search and rescue operation, and to locate and control the fire.
- Contributing to the protection of life and reduction of property loss.
- Involving in smoke removal for a postflashover fire.

To achieve these objectives, smoke extraction systems and staircase pressurization systems are installed in most of the commercial buildings, residential buildings and industrial buildings in China Mainland [4-8].

Table 1: Classification of fire codes in China

Issued by	Legal aspects	Technical specification
National People's Congress	Legislative Fire Code	Administrative Fire Code
	• Fire Law of China • Penal Law of China • Punishment Regulation • Administrative Procedural Law • City Planning Law, etc.	
• State Council • Ministry of Public Security • Other Ministries (e.g. Ministry of Construction) • Local governments	Administrative Fire Code	Fire code of Management and Administration
	• Building Fire Administrative Regulation, etc.	
• Ministry of Public Security • Ministry of Construction • Local governments	Local Fire Code	Technical Law
	• City Planning Regulations • Design Code for Residential Buildings • Code for Fire Protection Design of Buildings, etc.	

There are two types of smoke extraction system:

- Dynamic smoke extraction system

  Dynamic system is a mechanical ventilation system capable of removing smoke including combustion products from the fire compartment, and also supplying in fresh air to maintain a specified smoke-free zone below the smoke layer.

- Static smoke extraction system

  Static system has been applied in natural ventilation, utilizing smoke reservoirs, located ducting and openings actuated by smoke detectors.

Dynamic smoke extraction system in residential buildings will be focused in this paper.

3. REQUIREMENTS ON FORCED VENTILATION SYSTEM IN CHINA FIRE CODES

Requirements of forced ventilation design for buildings in China are specified by four codes of practices:

- Code for fire protection design of industrial building, stores and general apartments (GBJ-16-87, 1995)[5]
- Code for fire protection design of tall buildings (GB50045-95, 1997)[6]
- Code for fire protection design of commercial buildings (JGJ48-88, 1989) [7]
- Code for fire protection design of garage, motor-repair-shop and parking-area (GB50067-97, 1998) [8]

Where GB codes are national standards. GBJ codes are national standards for construction. JBJ codes are standards for construction and civil engineering.

Following the building codes [5-8], forced ventilation system and smoke extract system should be installed in the following buildings, bearing in mind that buildings are classified in GB50045-95, 1997 [6] as in Table 2:

- Tall buildings of type I and type II (see Table 2) over 32 m high with ventilation or corridors over 60 m, basement over 200 m^2 in total or each single room over 50 m^2, atria of 12 m high and basement, refuge level;
- Underground carparks over 2000 m^2;
- Subways, individual department stores, hospitals and motels with usable area exceeding 500 m^2;
- Restaurants, exhibition centers, gymnasiums, ball halls, skating ranks with usable area exceeding 1000 m^3 and decorated by noncombustible materials. Or, the usable area exceeds 500 m^3 and decorated by combustible materials;
- Cinemas and auditoriums;

- Libraries, chanceries and workshops with usable area exceeding 1000 m^3;
- Underground buildings with smoke-proof staircases installed.

Minimum requirements of forced ventilation for residential buildings in the China code are shown in Table 3. Specification under the local codes [9-11] are shown as well. Requirements on the air change rates are similar except there is large difference in industrial buildings. The extraction rate of 15 to 20 air changes per hour (ACH) in the China code is much larger than that of 8 ACH in the Hong Kong code. A possible explanation is because most industrial buildings in Mainland China are for heavy industry. Therefore, higher air change rate is required to maintain the air quality inside the factory.

The requirements for smoke extraction system in the China fire codes are [6,12,13]:

- Smoke extraction rate is 4 to 8 ACH in general, over 15 ACH for industries, with minimum smoke extract sizing based on 7200 m^3, 60 m^3hr^{-1} for each smoke-proof zone.
- Smoke extraction rate is 6 ACH for atria less than 17000 m^3, or 4 ACH for atria larger than 17000 m^3.
- Minimum make up air rate is 50% to 80% of the extraction rate in general.
- Requirements on smoke detection system can be referred to The Building Standard Law of Japan [12] and British Standard 5839 [13].

Smoke spreading is limited by compartmentations or smoke barriers. The requirements on forced ventilation design is considered. The horizontal velocity of smoke spreading is 0.3 to 0.8 ms^{-1}, and the vertical velocity of smoke spreading is 3 to 4 ms^{-1} [3]. Referring to the requirements in Japanese building law [3,12], smoke extraction rate should be 4 m^3s^{-1} or 14400 m^3hr^{-1}. Wind speed at the inlet should be less than 7 ms^{-1} and wind speed at the outlet should be less than 10 ms^{-1} [3]. In Hong Kong fire codes, the requirements for wind speed at the outlet should be less than 6 ms^{-1} [9].

Table 2: Classification of buildings listed in Code for fire protection design of tall buildings (GB50045-95, 1997)

Classification	Type I	Type II
Residential buildings	High-grade residence, common residence with more than 19 floors	Common residence with 10 to 18 floors
Public buildings	Hospitals, motels, broadcasting and TV station buildings, post-office building, libraries, important office buildings, commercial buildings and multiple use buildings over 50 m high or over 1500 m^2 in each floor area.	Buildings except listed in Type I

Table 3: A comparison of minimum forced ventilation requirements for residential buildings in Hong Kong code [9-11] and China code [5-8]

<table>
<tr><th rowspan="2">Building uses</th><th colspan="3">Minimum extraction rate</th></tr>
<tr><th colspan="2">China Mainland Code</th><th>Hong Kong Code</th></tr>
<tr><td>Hotel</td><td>4-6 ACH</td><td rowspan="6">60 m^3hr^{-1} for each smoke proof zone</td><td>10 ACH</td></tr>
<tr><td>Industrial buildings</td><td>15-20 ACH</td><td>8 ACH</td></tr>
<tr><td>Basement</td><td>8 ACH</td><td>8 ACH</td></tr>
<tr><td>Commercial buildings</td><td>8.5 m^3hr^{-1} per person</td><td>8 ACH</td></tr>
<tr><td>Atria</td><td>4-6 ACH</td><td>8 ACH</td></tr>
<tr><td>Carparks</td><td>6 ACH</td><td>8 ACH</td></tr>
</table>

ACH = air changes per hour

4. CASE STUDIES

Two cases are considered for illustrating the forced ventilation requirements applied in different types of buildings under China fire codes:

- Case 1: underground carpark

  A 2000 m^2 underground carpark with smoke extraction rate of 6 ACH as required in Code for fire protection design of garage, automobiles workshops and parking-area (GB50067-97, 1998) [8]. The building height is 4 m, and there is a door opening of 6 m × 4 m.

- Case 2: single room

  A 50 m^2 single room with smoke extraction rate of 8 ACH as required in Code for fire protection design of tall buildings (GB50045-95, 1997) [6]. The room height is 3 m, and there is a door opening of 1 m × 2 m.

A 1 m by 1 m fire is located at the center with heat release rate following a NFPA t^2-fire [2] with cut-off value of 5 MW. All the four sets of slow, medium, fast, and ultra-fast t^2-fires are tested with the fire zone model in FIREWIND [14] taken as the simulation tool.

In such a zone model, a thermal plume is induced by the fire and a stable thermal stratified upper hot layer is formed. This gives two zones in both the carpark and the single room: an upper hot zone and a lower cool zone. When the fire started, the door is shut down immediately. The smoke extraction system is expected to operate at two different times t_{op}:

- $t_{0.45}$ is the time when the smoke layer thickness is 0.45 m, corresponding to a typical 'downstand' height in the China fire code [6] and the Hong Kong building fire code [16].

- t_{68} is the time when the smoke layer temperature is heated up to 68°C at ceiling. This is a common actuation temperature for sprinkler head. Note that a 68°C-rated sprinkler head might not be actuated when the smoke layer temperature reaches 68°C, depending on its response time index. Fast response type sprinkler head is assumed in this analysis so that the sprinkler head would be activated once the temperature reaches 68°C. This point is very important as the smoke extraction system might be operated first before a slower response type sprinkler head, if both systems are installed.

The initial temperature is taken to be 20°C. Flashover in the enclosure is assumed to occur when the upper layer gas temperature reaches 500°C as listed in the User's Manual of FIREWIND [14]. Forty cases were simulated.

5. RESULTS

Time to operate the smoke extraction system in the carpark and in the single room are shown in Table 4.

Typical results of the smoke layer temperature T_s (in ^{o}C) and smoke layer interface height h (in m) with the extraction system operated at the two operation times in the carpark are shown in Figs. 1 to 4. Results for the single room are shown in Figs. 5 to 8.

The time to operate the extraction system is important. For a slow fire in the carpark, smoke extraction system was operated when the smoke layer thickness was 0.45 m. 301 s was needed after the fire had started to make the extraction system operate, and another 76 s for the hot smoke layer temperature to reach 68 ^{o}C to activate the sprinkler. During this period, the smoke extraction system could keep the smoke layer at between 2.5 to 3.5 m high, which gave enough time and very safe environments for the evacuation of human and vehicles. After that, the smoke layer fell to below 1.5 m.

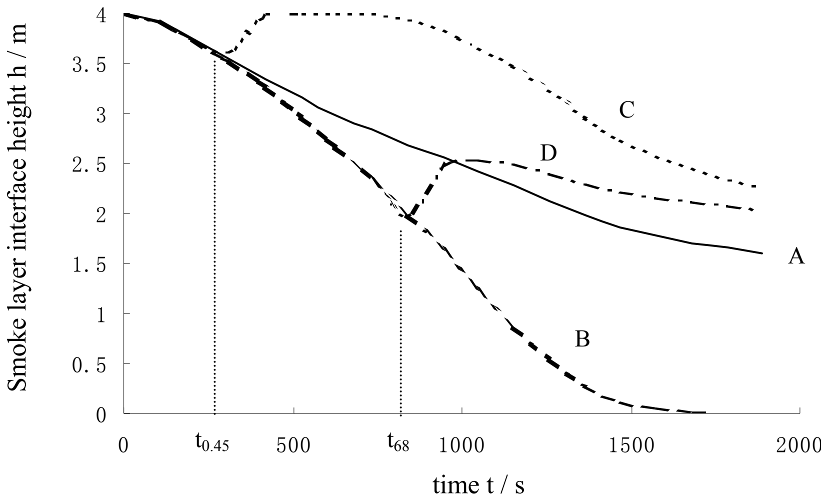
For a slow-t^2 fire in the single room, whether the door is closed or not has little effects on the time to operate the smoke extraction system. 34 s was needed after the fire had started to make the extraction system operate, and another 148 s for the hot smoke layer temperature to reach 68 ^{o}C to activate the sprinkler. Flashover occurred at 1027 s after the fire had started in the case of smoke extraction system operated at $t_{0.45}$. From the time the fire had been detected to the operation of sprinkler, occupants would have 148 s (nearly 2.5 mins) for evacuation, while the smoke layer height was kept at higher than 1.60 m.

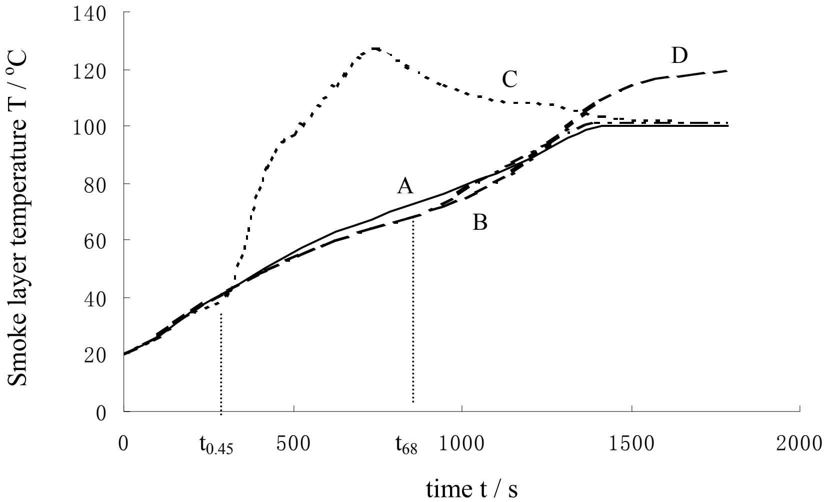
It is also observed that requirements of smoke extraction system for carpark are effective, the smoke layer can be kept at a higher position. But small extraction rates would not have any effect in the small single room.

The same results are found in all the four sets of slow, medium, fast, and ultra-fast t^2-fires.

Table 4: Time to operate the smoke extraction system in the carpark and single room

NFPA t^2-fires	Car park		Single room			
			Door closed		Door open	
	t_{op} at $t_{0.45}$	t_{op} at t_{68}	t_{op} at $t_{0.45}$	t_{op} at t_{68}	t_{op} at $t_{0.45}$	t_{op} at t_{68}
Slow	301 s	842 s	34 s	116 s	34 s	116 s
Medium	224 s	345 s	26 s	106 s	28 s	107 s
Fast	156 s	165 s	18 s	50 s	21 s	51 s
Ultra-fast	112 s	77 s	16 s	15 s	17 s	17 s



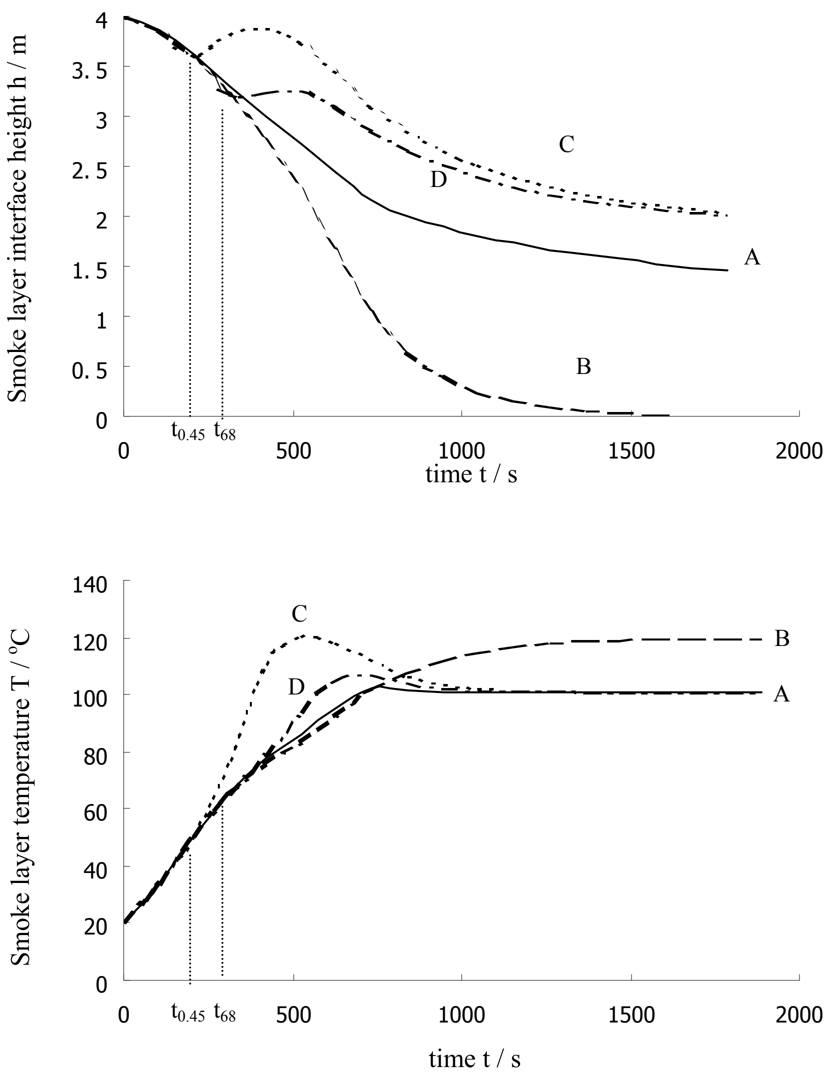


A Natural ventilation
B No ventilation
C Smoke extraction system operated at smoke layer thickness of 0.45 m
D Smoke extraction system operated at smoke layer temperature of 68°C

Fig. 1: Smoke layer interface height and temperature in the carpark under an NFPA slow t^2-fire

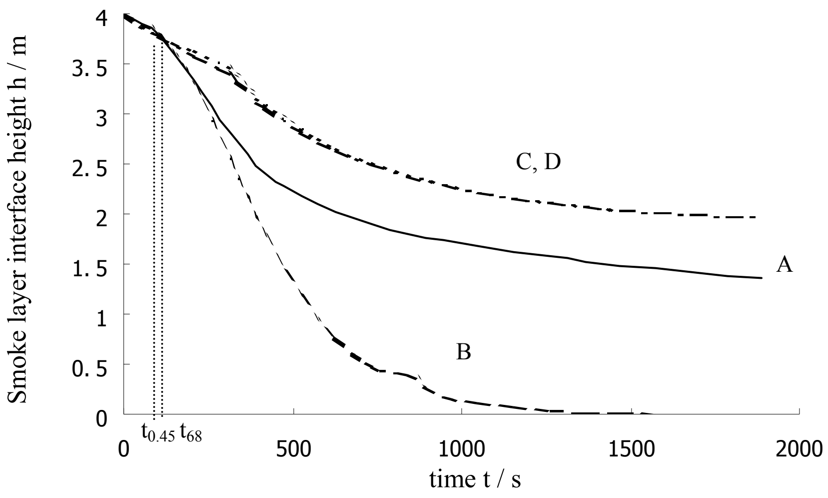
It is observed that the smoke layer would fall to low level quickly in the single room. Even if the extraction system was operated at an earlier time, the smoke layer could not be kept at higher positions. Therefore, it can be concluded from the simulated results that the extraction system has no effect on the fire environment in the small single room, apart from reducing the temperature slightly, say by 10%.

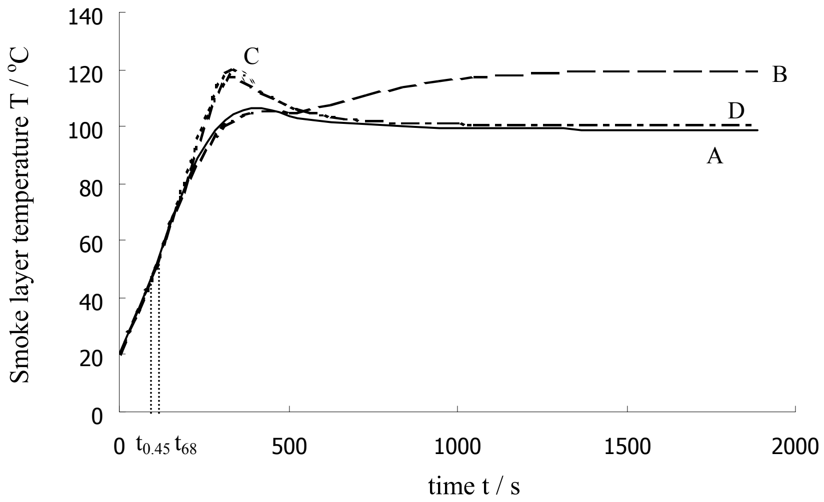
No flashover occurred in the carpark simulation. Results on the time to flashover t_f in the single room for the two operating times t_{op} of the smoke extraction system under a slow, medium, fast, and ultra-fast t^2-fire are shown in Table 5. It is observed that time to flashover t_f would be longer when the smoke extraction rate was increased.



A Natural ventilation
B No ventilation
C Smoke extraction system operated at smoke layer thickness of 0.45 m
D Smoke extraction system operated at smoke layer temperature of 68°C

Fig. 2: Smoke layer interface height and temperature in the carpark under an NFPA medium t^2-fire



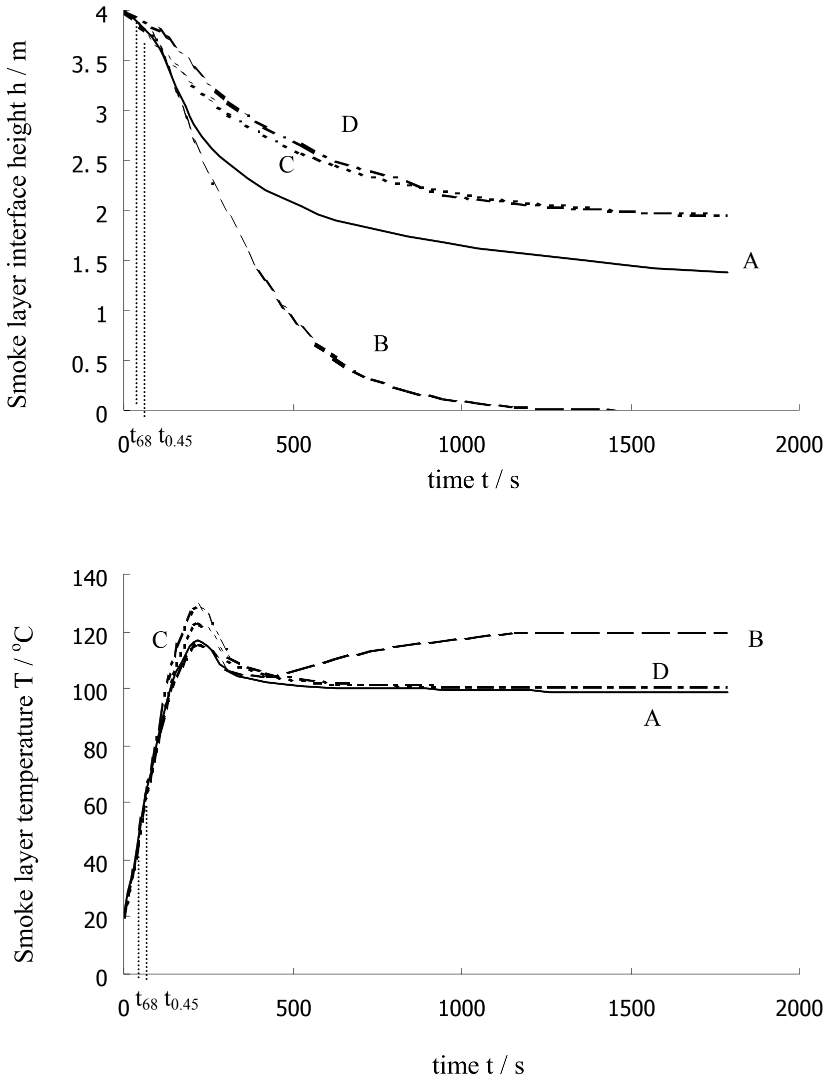


A Natural ventilation
B No ventilation
C Smoke extraction system operated at smoke layer thickness of 0.45 m
D Smoke extraction system operated at smoke layer temperature of 68°C

Fig. 3: Smoke layer interface height and temperature in the carpark under an NFPA fast t^2-fire

Table 5: Time to flashover in the single room

NFPA t^2-fires	Natural ventilation	Door closed	System operated t_{op} at $t_{0.45}$ and t_{68}	System operated with door open
Slow	1136 s	916 s	1027 s	1154 s
Medium	572 s	479 s	515 s	581 s
Fast	288 s	255 s	258 s	293 s
Ultra-fast	178 s	161 s	161 s	182 s

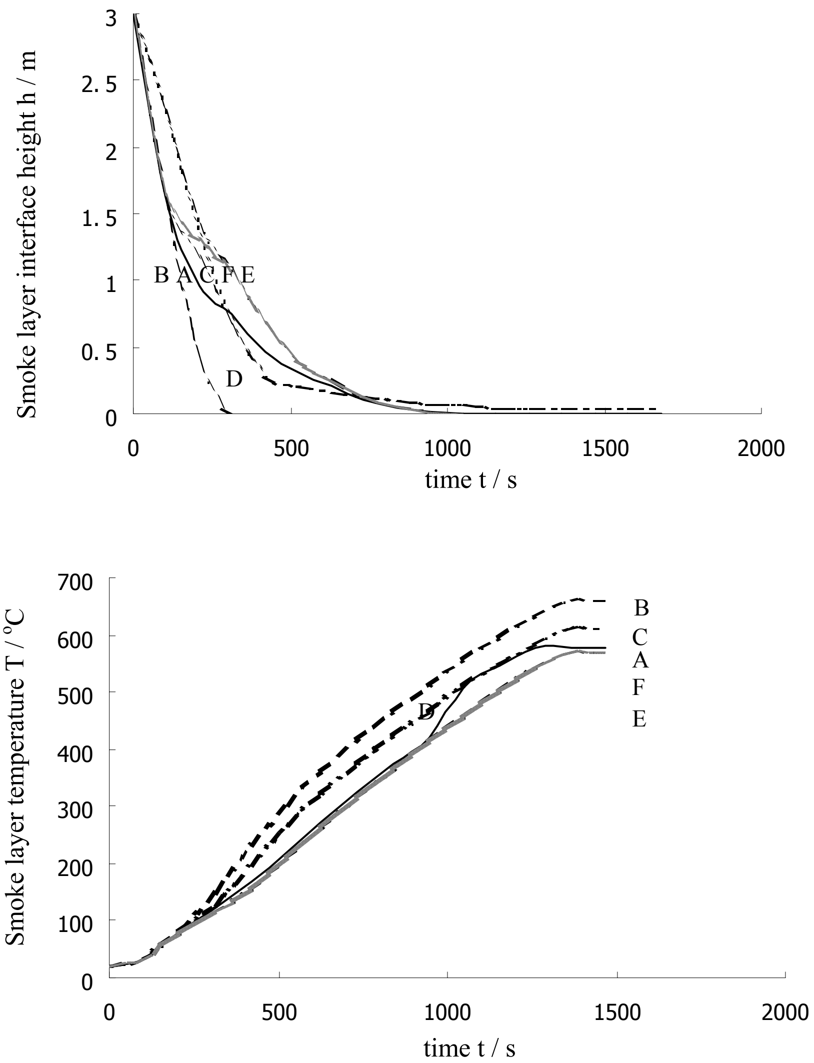


A Natural ventilation
B No ventilation
C Smoke extraction system operated at smoke layer thickness of 0.45 m
D Smoke extraction system operated at smoke layer temperature of 68°C

Fig. 4: Smoke layer interface height and temperature in the carpark under an NFPA ultra-fast t^2-fire

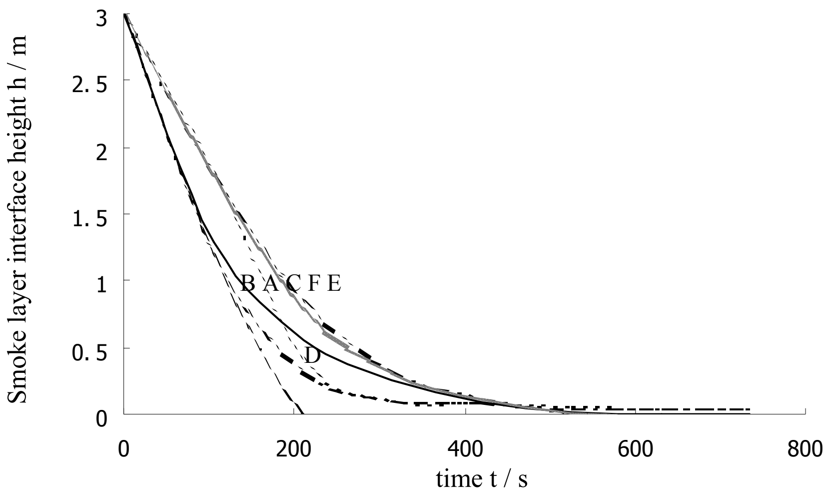
6. CONCLUSION

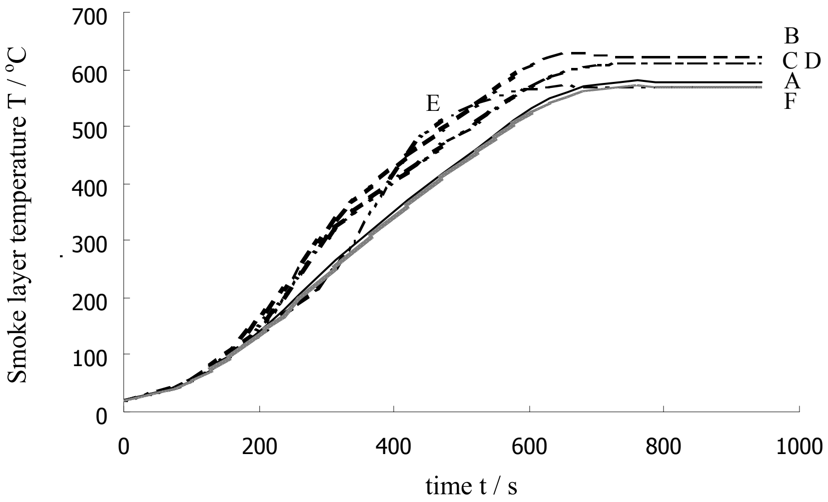
Forced-ventilation requirements in the China fire codes are reviewed with those related to ventilation control installation briefly outlined. The air changes per hour or fan extraction rate in both the China fire codes and the Hong Kong fire codes are compared. Two cases on an underground carpark and a single room in a tall building were used for illustrating the China fire codes. Results showed that the forced-ventilation requirements in the China fire codes are reasonable and would satisfy the fire safety objectives on life safety and properties protection. Following the requirements would give sufficient evacuation time inside the building. Fire fighters can then take appropriate action.



A	Natural ventilation
B	No ventilation
C	Smoke extraction system operated at smoke layer thickness of 0.45 m
D	Smoke extraction system operated at smoke layer temperature of 68°C
E	Smoke extraction system operated at smoke layer thickness of 0.45 m with door open
F	Smoke extraction system operated at smoke layer temperature of 68°C with door open

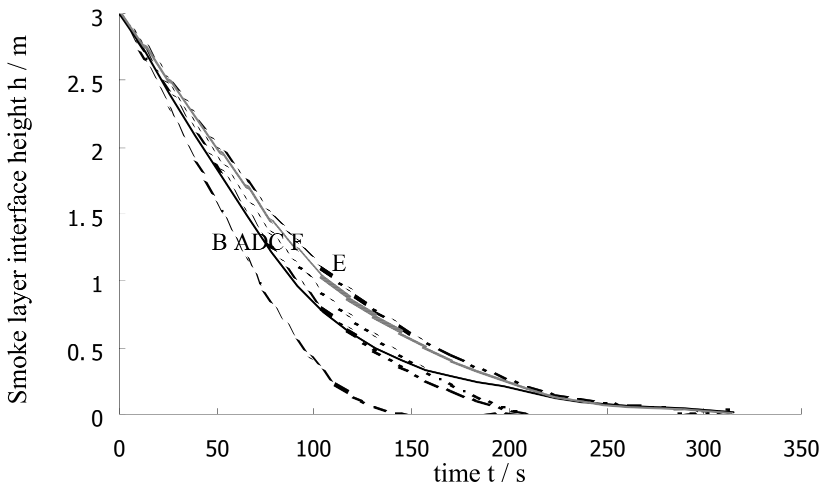
Fig. 5: Smoke layer interface height and temperature in the single room under an NFPA slow t^2-fire

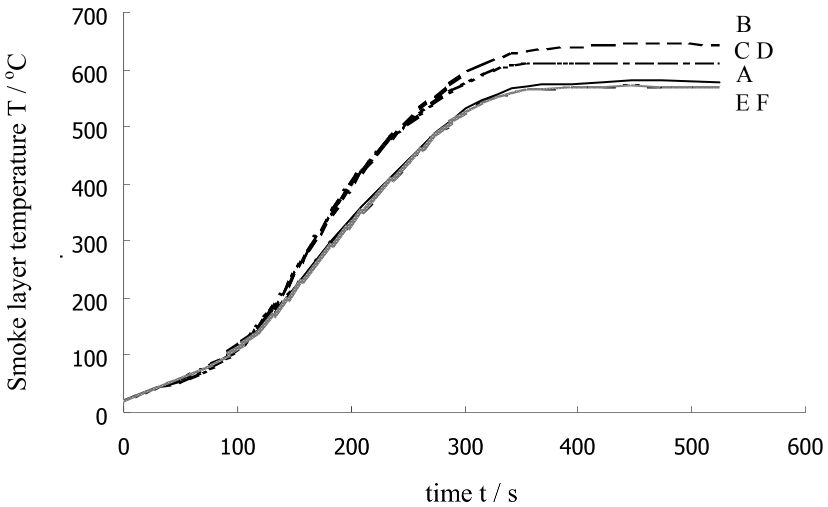




A	Natural ventilation
B	No ventilation
C	Smoke extraction system operated at smoke layer thickness of 0.45 m
D	Smoke extraction system operated at smoke layer temperature of 68°C
E	Smoke extraction system operated at smoke layer thickness of 0.45 m with door open
F	Smoke extraction system operated at smoke layer temperature of 68°C with door open

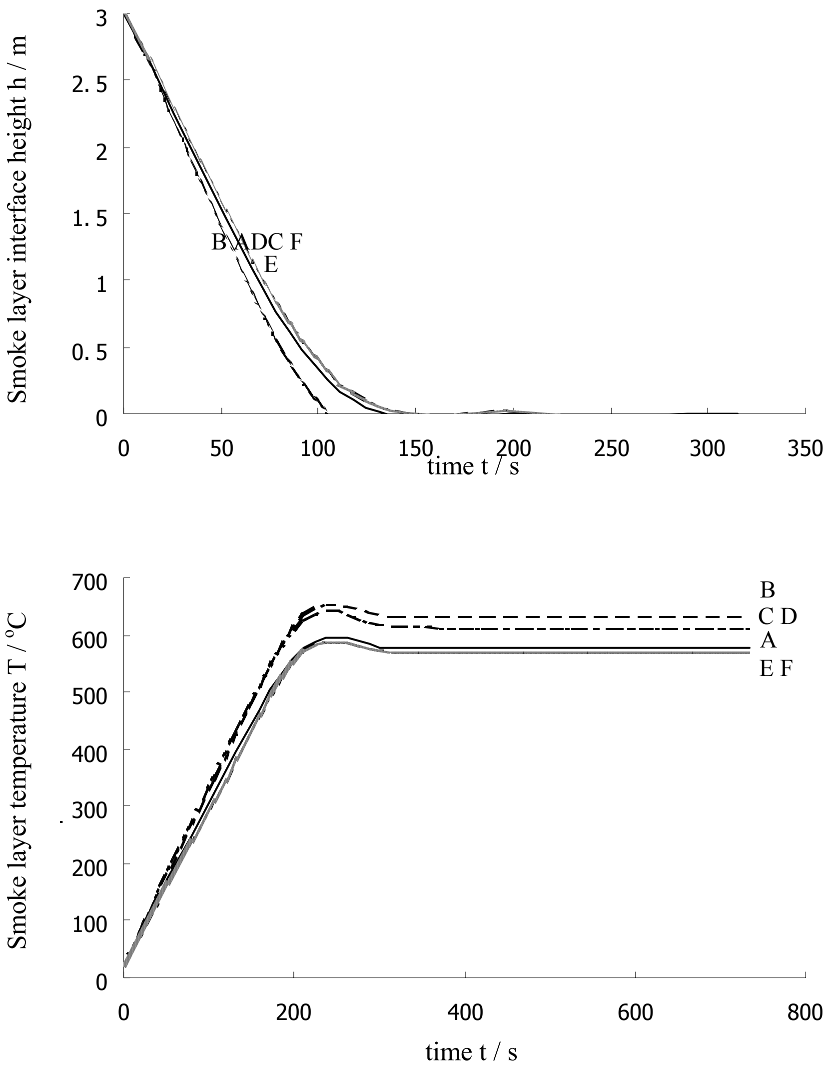
Fig. 6: Smoke layer interface height and temperature in the single room under an NFPA medium t^2-fire





A	Natural ventilation
B	No ventilation
C	Smoke extraction system operated at smoke layer thickness of 0.45 m
D	Smoke extraction system operated at smoke layer temperature of 68°C
E	Smoke extraction system operated at smoke layer thickness of 0.45 m with door open
F	Smoke extraction system operated at smoke layer temperature of 68°C with door open

Fig. 7: Smoke layer interface height and temperature in the single room under an NFPA fast t^2-fire



A Natural ventilation
B No ventilation
C Smoke extraction system operated at smoke layer thickness of 0.45 m
D Smoke extraction system operated at smoke layer temperature of 68°C
E Smoke extraction system operated at smoke layer thickness of 0.45 m with door open
F Smoke extraction system operated at smoke layer temperature of 68°C with door open

Fig. 8: Smoke layer interface height and temperature in the single room under an NFPA ultra-fast t^2-fire

REFERENCES

1. NFPA 92A, Recommended practice for smoke control system, National Fire Protection Association, Quincy, MA, USA (2001).
2. NFPA 92B, Guide for smoke management systems in malls, atria and large areas, National Fire Protection Association, Quincy, MA, USA (2001).
3. Clause explanation of design code for residential buildings (GB50045-95), Ministry of Construction, P.R. China (1995).
4. Design code for residential buildings (GB50096-1999), Ministry of Construction, P.R. China (1999).
5. Code for fire protection design of industrial building, stores and general apartments (GBJ-16-87, 1995), Ministry of Public Security, Ministry of Construction, P.R. China (1995).
6. Code for fire protection design of tall buildings (GB50045-95, 1997), Ministry of Public Security, Ministry of Construction, P.R. China (1997).
7. Code for fire protection design of commercial buildings (JGJ48-88, 1989), Ministry of Public

Security, Ministry of Construction, P.R. China (1989).

8. Code for fire protection design of garage, motor-repair-shop and parking-area (GB50067-97, 1998), Ministry of Public Security, Ministry of Construction, P.R. China (1998).

9. Chapter 123 Buildings Ordinance, Laws of Hong Kong, Buildings Department, Hong Kong (1997).

10. Practice of design and commissioning of the smoke control systems for Hong Kong, Fire Services Department, Hong Kong (1994).

11. Codes of Practice for Minimum Fire Service Installations and Equipment and Inspection and Testing of Installations and Equipment, Fire Services Department, Hong Kong (1994).

12. Ministry of Construction of Japan, The Building Standard Law of Japan/ August 1994, The Building Center of Japan, Tokyo.

13. British Standard 5839, BS 5839 Part 6, Code of practice for the design and installation of fire detection and alarm systems in dwellings, British Standards Institution, London, UK (1995).

14. FIREWIND user's manual version 3.3, Fire modelling & computing (FMC), 66 Westbrook Avenue, Wahroonga, N.S.W. 2074, Australia (1997).

15. Code of Practice for the Provision of Means of Escape in Case of Fire, Buildings Department, Hong Kong (1996).

16. Code of Practice for Fire Resisting Construction, Buildings Department, Hong Kong (1996).