International Journal on Engineering Performance-Based Fire Codes, Volume 11, Number 2, p.43-48, 2012

NUMERICAL STUDIES ON 'BARE CABIN' FIRES WITH OPERATION OF SMOKE EXTRACTION SYSTEM

Q. Kui
Institute of Building Fire Research, China Academy of Building Research, Beijing, China

W.K. Chow
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

(Received 3 January 2013; Accepted 6 February 2013)

ABSTRACT

Numerical studies on pre-flashover fires in a bare cabin were carried out with a fire field model through the application of Computational Fluid Dynamics (CFD).

The cabin was of size 4 m by 4 m by 3 m with a door of 2 m wide and 2.5 m high opened. Air flow and temperature field induced by a design fire were simulated. The CFD package PHOENICS was selected as the simulator.

Further, air flow in the compartment with the operation of a smoke extraction system was also simulated. The results were compared with those predicted by a two-layer zone model in the popular fire engineering tool FIREWIND.

1. INTRODUCTION

'Cabin' design [e.g. 1-5] is commonly used for fire protection in big halls in Hong Kong (now the Hong Kong Special Administrative Region HKSAR). This takes the advantage of utilizing more space for retailing in tall big halls without designing smoke management system with high extraction rates up to 12 air changes per hour (ACH) [e.g. 6]. No doubt, this design is appropriate in allocating retail areas with higher fire risk together in those halls.

However, the likelihood for flashover to occur in a cabin [7,8] should be watched carefully. Earlier theories and experiments demonstrated [8-14] that flashover occurs easily in small space with high contents of combustibles. Post-flashover retail shop fires should be assessed [14]. Bearing in mind that the main function of sprinkler systems is only to 'control' [15] a fire under a certain size, not to 'suppress' nor 'extinguish' the fire. Upon operating a sprinkler, the growth of heat release rates of the fire might be reduced if the system is reliable and designed properly. There might be problems due to the hot steam produced.

Detailed design of smoke extraction systems in cabins is not clearly described in the local codes [16]. There are also 'open' and 'closed' cabins. Therefore, the cabin design should be applied carefully by considering appropriate fire hazard scenarios, depending on the building occupancy, combustibles stored, location of the hall, culture, social and political stability.

Fires which occur in a cabin when the sprinkler system and smoke extraction system are not yet started to operate for whatever reasons, or known as 'bare cabin' fires [9-11], had been studied before. In case of the sprinkler system in a cabin does not work, a 'small' cabin might become a big hot object in the hall, in particular for shops selling alcohol. This would entrain huge amount of hot air as the perimeter of the fire grows bigger.

The effect of operating only the smoke extraction system in a 'bare cabin' fire without the operation of sprinkler will be studied using a fire field model in this paper. The Computational Fluid Dynamics (CFD) package PHOENICS [17] was selected as the simulator. The effect of smoke extraction operation in a cabin is also studied. Further, the results predicted by CFD are compared with those predicted by the two-layer zone model FIREWIND [18] version 3.4.

2. CFD SIMULATIONS

A cabin of length 4 m, width 4 m and height 3 m was studied. There is a door of height 2.5 m and width 2 m. For better description of the free boundary, the computing domain was extended 4 m outside the cabin. The geometry was divided into 25, 15 and 30 (with 15 parts assigned inside the cabin) parts along the x-, y- and z-directions as shown in Fig. 1. The grid sizes were smaller in the regions close to the fire and door. For example, at a distance 1 m away from the door, 4 parts were divided.

The effect of smoke exhaust system on the development of the fire environment was evaluated. A mechanical smoke exhaust system was assigned with hot air extracted through a ceiling vent of size 1 m by 1 m. Upward air speed of 0.53 ms^{-1} and differential pressure 100 Pa were assigned at the vent to give an extraction rate of 40 air changes per hour (ACH).

Two simulations were carried out:

- Case A: Cabin without the operation of a smoke exhaust system.
- Case B: Cabin with a smoke exhaust system operating at 40 ACH.

A fire of area 1 m by 1 m and height 0.5 m was assumed at the cabin centre. The heat release rate $\dot{Q}(t)$ (in kW) follows a NFPA slow t^2-fire [19] with a cut-off value of 1 MW as:

$$\dot{Q}(t) = \begin{cases} 1000\left(\dfrac{t}{600}\right)^2 & t < 600\,s \\ 1000 & t = 600\,s \end{cases}$$

The air flow patterns and temperature fields induced by the fire were simulated by the CFD package PHOENICS version 3.1.

3. RESULTS

Velocity vectors predicted across the central vertical plane at x = 2 m for simulations A and B are shown in Fig. 2; temperature contours from 30 to 120°C at the same plane in Fig. 3; and pressure differential contours including the neutral lines in Fig. 4.

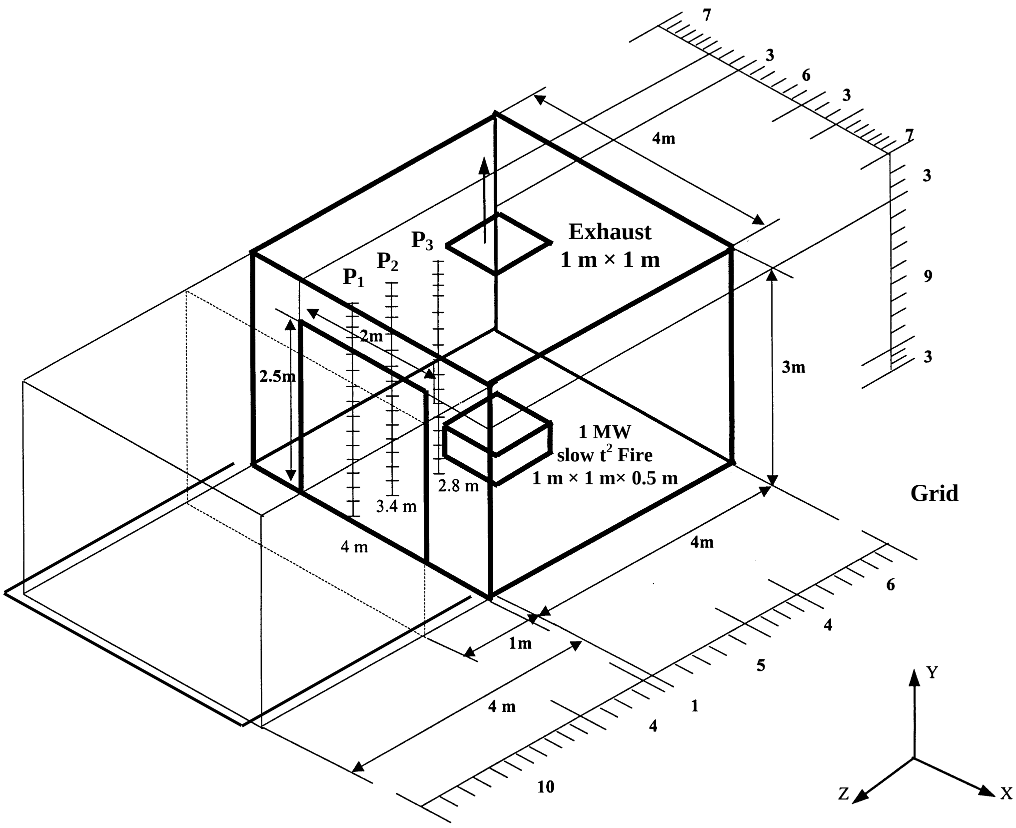
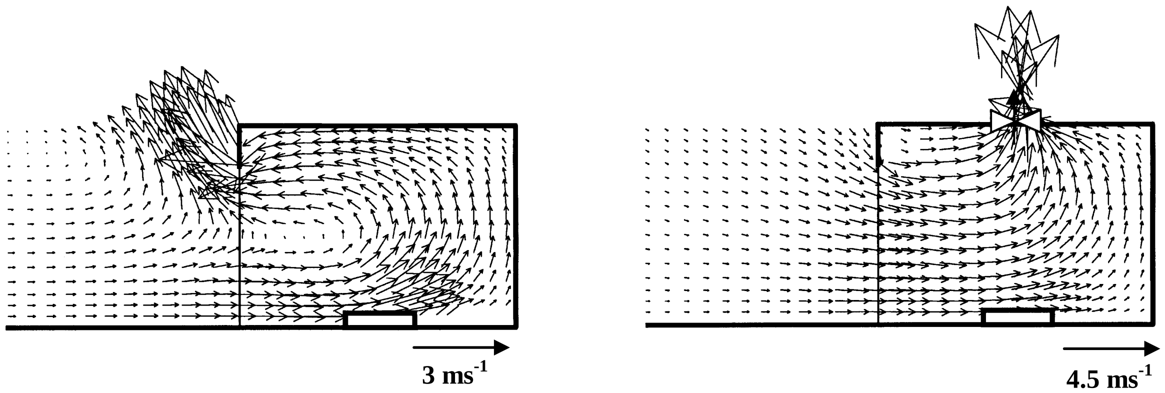
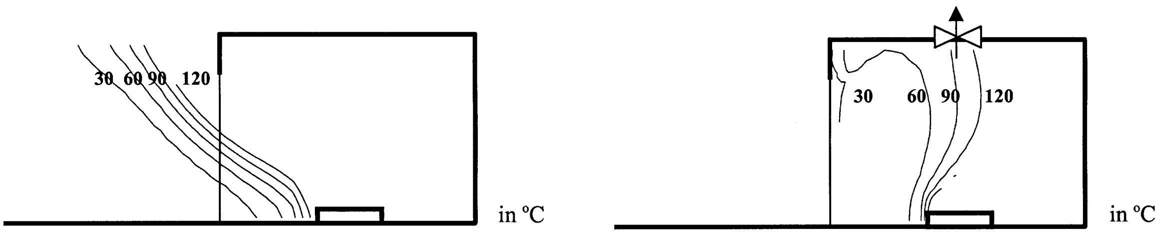


Fig. 1: Geometry of the cabin



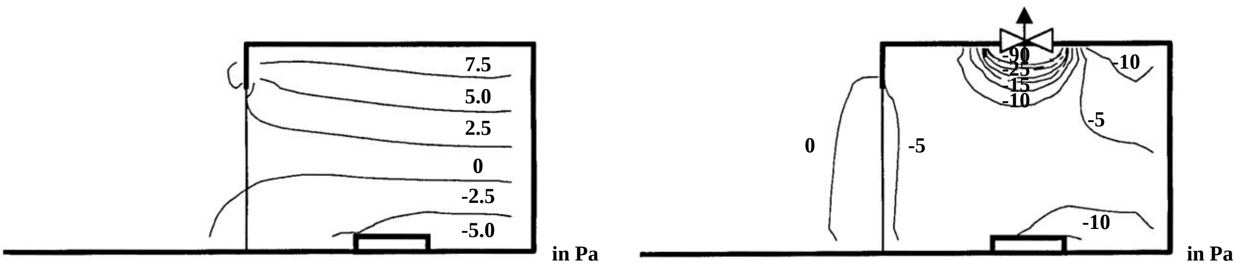
(a) Simulation A (b) Simulation B

Fig. 2: Velocity vectors across the central plane at x = 2 m



(a) Simulation A (b) Simulation B

Fig. 3: Temperature contours across the central plane at x = 2 m



(a) Simulation A (b) Simulation B

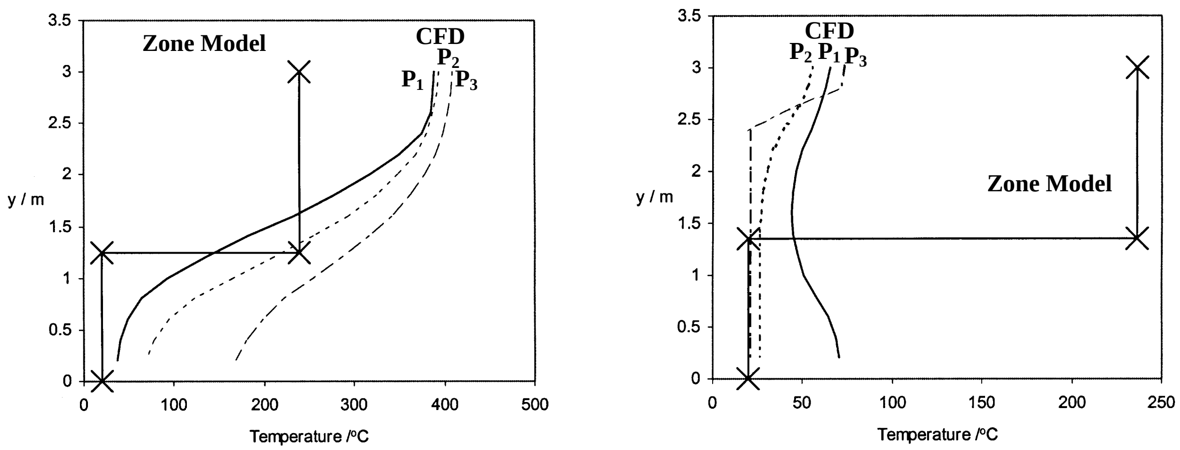
Fig. 4: Pressure distribution across the central plane at x = 2 m

From the velocity vector diagrams, it is observed that hot air moved out of the ceiling vent upon activation of the smoke extraction system. High amount of air was drawn in through the door due to the fire and operation of the extraction fan. Consequently, indoor temperature in most part of the room fell below 60°C. The differential pressure contours are different from the case without the operation of the fan. A possible explanation is that a differential pressure of 100 Pa was induced at the exhaust outlet.

A comparison of the results predicted by CFD and by the zone model is shown in Fig. 5. In order to compare with the hot layer positions predicted by the zone model, CFD results in three positions at P_1, P_2 and P_3 as shown in Fig. 1 (i.e. at room center and x = 4 m, 3.4 m and 3.8 m respectively) are shown.

Vertical temperature profiles predicted by the CFD model at P_1, P_2 and P_3 and by the zone model are shown in Fig. 5. Agreements between the results predicted by the two models are fair for simulation A, but not for simulation B with the smoke extraction fan switched on. However, it is clear from Figs. 2 to 4 that a stable thermal stratified layer would not be formed for simulation B. As pointed out recently, there might be mixing across the smoke layer interface upon operation of the exhaust fan. A two-layer zone model might not work as pointed out earlier [20].

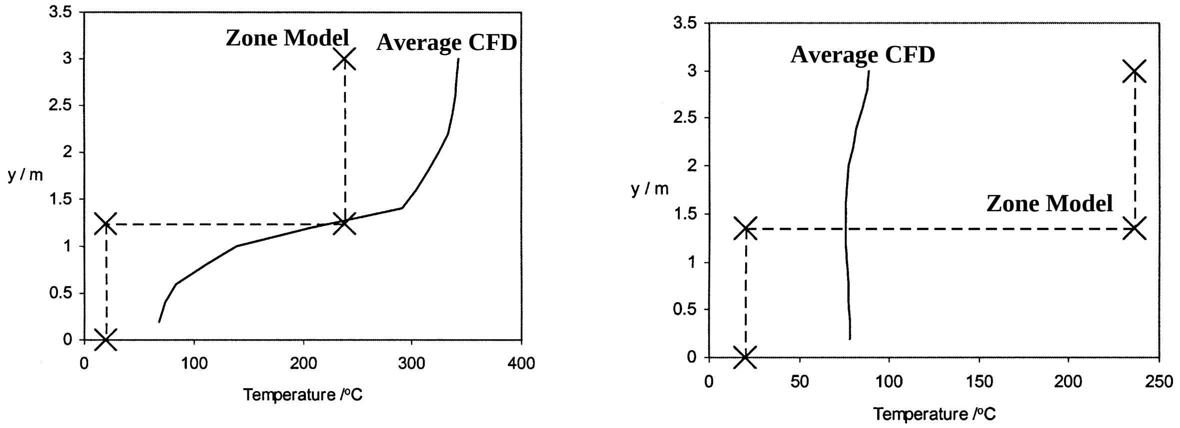
The average vertical temperature profiles predicted by CFD over the three positions P_1, P_2 and P_3 are shown in Fig. 6 together with those predicted by the zone model. The patterns look similar for simulation A but not for simulation B.



(a) Simulation A

(b) Simulation B

Fig. 5: Air temperature and hot layer height in CFD and zone model



(a) Simulation A

(b) Simulation B

Fig. 6: Average vertical profiles of CFD models

4. CONCLUSION

'Bare cabin' fires with only the smoke extraction system operating under a 1 MW NFPA slow-t^2 fire [19] were studied using fire field modeling. The CFD model PHOENICS was used as the simulator.

From the results, it is observed that when the smoke exhaust system was operating, air temperature did not change much. However, the position of the neutral pressure plane changed.

Detailed experiments on cabin fires, especially those 'open' cabins, should be carried out with some studies on retail shops selling books, video compact discs and clothings. The following should be studied as fire protection systems including fire detection system, sprinkler system and smoke extraction system are expected in each cabin:

- performance of the systems integrated;
- whether the sprinkler system or smoke extraction system should be operated first;
- the time for detecting a fire, operating the sprinkler to discharge water, turning on the smoke extraction system and the time for people staying inside to escape;
- whether the cabin should be enclosed completely in case of a fire;
- the impact of exposure of occupants to the steam generated by the sprinkler water;
- performance of new fire services installation such as total gas flooding systems with clean agent heptafluoropropane.

The results are useful for the Authority to inspect new projects of this kind, especially for those who are not so experienced in using fire models while implementing engineering performance-based fire codes [21].

As raised recently [22], cabin design is not enclosed as a submarine compartment. Flame and smoke can spread out from the opening when there is a fire. Appropriate protection must be provided for new buildings. Existing buildings with cabin design must be reviewed to put in additional systems [23].

ACKNOWLEDGEMENTS

Thanks are due to Dr. Victor Shestopal for his advice on the proper use of the software FIREWIND.

REFERENCES

1. M. Law, "Fire and smoke models - their use on the design of some large buildings", ASHRAE Transactions, Vol. 96, No. 1, pp. 963-971 (1990).
2. P. Beever, "Cabins and islands: a fire protection strategy for an international airport terminal building", Third International Fire Safety Science Symposium, IAFSS, Edinburgh, Scotland, UK, pp. 709-718 (1991).
3. P. Beever, "Design in international airport terminals", Fire East '95 Conference and Exhibition, Hong Kong, 7 November 1995, pp. 4.1-4.5 (1995).
4. P. Bressington, "Railway link to Chek Lap Kok", Fire East '95 Conference and Exhibition, Hong Kong, 7 November 1995, pp. 5.1-5.8 (1995).
5. P. Bressington, "Retail premise," Fire Prevention, No. 321, pp. 22-23, June (1999).
6. W.K. Chow, "On carrying out atrium hot smoke tests", Architectural Science Review, Vol. 48, No. 1, pp. 105-107 (2005).
7. P.H. Thomas, "Testing products and materials for their contribution to flashover in rooms", Fire and Materials, Vol. 5, pp. 103-111 (1981).
8. W.K. Chow, Y. Gao, H. Dong, G.W. Zou, Z. Luo, and L. Meng, "Experimental studies on minimum heat release rates for flashover with oxygen consumption calorimetry", Architectural Science Review, Vol. 46, No. 3, pp. 291-296 (2003).
9. W.K. Chow, "A preliminary study on the fire protection aspects of the new airport terminal building", Journal of Applied Fire Science, Vol. 6, No. 4, pp. 327-338 (1997).
10. W.K. Chow, "On the 'cabins' fire safety design concept in the new Hong Kong airport terminal buildings", Journal of Fire Sciences, Vol. 15, No. 5, pp. 404-423 (1997).
11. W.K. Chow, "Application of Computational Fluid Dynamics on evaluating 'bare cabin' design for large halls", The PHOENICS Journal of Computational Fluid Dynamics & Its Applications, Vol. 11, No. 4, pp. 429-453 (1998).
12. Q. Kui, and W.K. Chow, "Numerical studies on retail shop fires with a zone model", ASHRAE Transactions, Vol. 111, Part 1, pp. 407-415 (2005).
13. Q. Kui, "A study on enclosure fires with mechanical ventilation system", PhD Thesis, The Hong Kong Polytechnic University, Hong Kong (2003).
14. W.K. Chow, "Smoke control for retail shops with cabin design", ASHRAE Transactions, Vol. 110, Part 2, pp. 417-423 (2004).
15. NFPA 750 Standard on water mist fire protection systems, National Fire Protection Association, Quincy, Mass, USA (2000).

16. Fire Services Department, Codes of practice for minimum fire service installations and equipment and inspection and testing of installations and equipment, Hong Kong (1994).

17. Documentation for PHOENICS, Version 3.1, Concentration, Heat & Momentum Limited, Bakery House, 40 High Street, Wimbledon, London SW19 5AU, UK (1998).

18. FIREWIND, Computer software for the fire engineering professional – User's manual version 3.4, Fire Modelling & Computing, Wahroonga, NSW, Australia (1997).

19. NFPA 92B Guide for smoke management system in malls, atria and large area, National Fire Protection Association, Quincy, Mass, USA (1995).

20. W.K. Chow, L. Yi, C.L. Shi, Y.Z. Li and R. Huo, "Mass flow rates across layer interface in a two-layer zone model in an atrium with mechanical exhaust system", Building and Environment, Vol. 41, No. 9, pp. 1198-1202 (2006).

21. CIBSE Guide E: Fire engineering, The Chartered Institution of Building Services Engineers, London, UK (2010).

22. W.K. Chow, "Cabin design for big halls : An enclosed compartment or not?", Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, January (2013). Available at: http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/Hot_Issues.html.

23. W.K. Chow, "Experience on implementing performance-based design in Hong Kong", Welcome speech - The 9th Asia-Oceania Symposium on Fire Science and Technology, 17-20 October 2012, Hefei, China (2012).