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Application of the Software Fire Dynamics Simulator in Simulating Retail Shop Fires

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Abstract: Many combustibles are stored in small retail shops in big halls such as public transport terminals. It might not be feasible to provide dynamic smoke exhaust for the entire hall space in some terminals. Therefore, a roof was constructed above the retail areas with active fire protection systems including sprinkler and smoke exhaust systems provided inside. In case of fire, the shop will be enclosed by barriers. However, there are some concerns on the possibility of having flashover in such a small enclosed retail shop. Smoke might spread out from the shop when it is not completely sealed.

The fire field model Fire Dynamics Simulator FDS 3.01 available in the literature will be applied to study the fire environment of retail shops before operating the fire protection systems. This will give some useful information in assessing the decision made on the fire safety provisions and the associated design data. It is confirmed that a bigger plume will be formed for the case with a shop roof, if it is not completely sealed.

Further, performance of smoke extraction system and sprinkler system in controlling a small shop fire is evaluated.

Key words: Retail shop fire; Fire Dynamics Simulator; Numerical simulation

0 Introduction

Small retail shops packed with combustibles [e.g. 1] are found in big halls such as public transport terminals. There, it might not be feasible to protect the hall by dynamic smoke exhaust system and so retail areas are put beneath a roof with fire protection systems including sprinkler and smoke exhaust systems provided. This is similar to the 'cabin' design [e.g. 2]. However, there were concerns on flashover and the amount of smoke spreading out of the shops. Quite a large amount of combustibles might be stored in a shop and so its fire safety should be considered carefully, especially for those big terminals where the passenger loading is extremely high during rush hours. In designing appropriate fire protection system in such small shops, the possible fire environments before operating the dynamic smoke exhaust [3, 4] system and fire suppression system have to be understood.

Fire field model, or application of Computational Fluid Dynamics (CFD) is now very popular in studying smoke movement in buildings [e.g. 5]. As the fire-induced buoyancy flow is turbulent, a key element is how to deal with turbulence. The k-(types of turbulence models with averaging of the Navier-Stokes equations (RANS) technique are widely used for practical design [6]. It is widely used mainly because computing resources are not so demanding as in using other techniques. Application of those packages for predicting smoke movement in buildings [e.g. 5, 6] was reported in the literature, and used in many big projects. This approach might give results a-

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greed with those from experiments if empirical parameters are selected properly [6]. There are proposals on using alternatives like large eddy simulation (LES) [7] which is believed to give better predictions. The basic idea is to simulate the larger scales of turbulent motion with the smaller ones being approximated. LES options are starting to be included in some commercial CFD packages though it is still not practical in studying some flow problems such as vehicle aerodynamics [8]. With the current computing resources, the approach is now quite feasible to simulate some problems such as the fire plume and smoke movement.

A CFD program based on LES was developed at the Building and Fire Research Laboratory, National Institute of Standards and Technology (NIST) to simulate the transport of smoke and hot gases in an enclosure fire. This program, Fire Dynamics Simulator (FDS) version 3.01 [9], was based on years of research effort [e.g. 10, 11] and should be a key element in fire safety engineering. A series of validations and verifications were carried out during the past few years [11]. There, smaller scale chemical reactions were modelled by LES and the larger scale buoyancy-induced turbulence structure was simulated directly by solving a set of hydrodynamic equations with only low Mach number flow. This software is now applied to solve this practical fire design for retail shops in large halls.

1 Shop fires

As the shop is small, the minimum heat release rate for flashover is very low. It is easy to have flashover once an accidental fire is started. A very big fire can be resulted due to the large amount of combustibles stored. This part can be demonstrated by using the FDS for simulating the possible environments. Two scenarios are considered:

S1: Without downstand

A shop of size 3 m by 3 m by 3 m with only the roof as in Figure 1a was considered. A 5 MW fire of size 1 m by 1 m and height 0.5 m was put at the centre.

S2: With downstand of 1 m

Same as S1 but with a 1 m downstand as in Figure 1b.

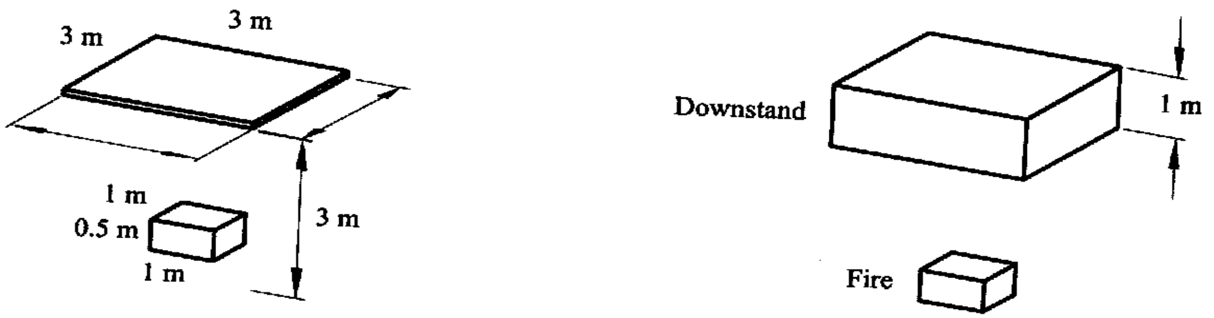


Fig. 1 Shop fire

Results on velocity vectors, temperature and streamlines at 100 s for these two scenarios are shown in Figure 2.

It is observed that flashover would occur as the gas temperature next to the ceiling is above 600 ℃.

2 Smoke spreading to a hall

Three scenarios were simulated for the shop located in a hall to study how smoke will spread out.

Scenario H1

The plume generated by a pool fire in a hall would be simulated. The hall is of length 40 m, width 40 m and height 40 m. There is a ceiling with the four sides opened. A 5 MW fire of length 1 m, width 1 m and height 0.5 m was located at the centre of the hall as in Figure 3a.

A grid system (48 (48 (96) was assigned with simulations up to 100 s. The time steps were adjusted automatically by the software to satisfy the convergence criterion during the calculation. Simulations were carried out in a personal computer, requiring about 50 hours of CPU time.

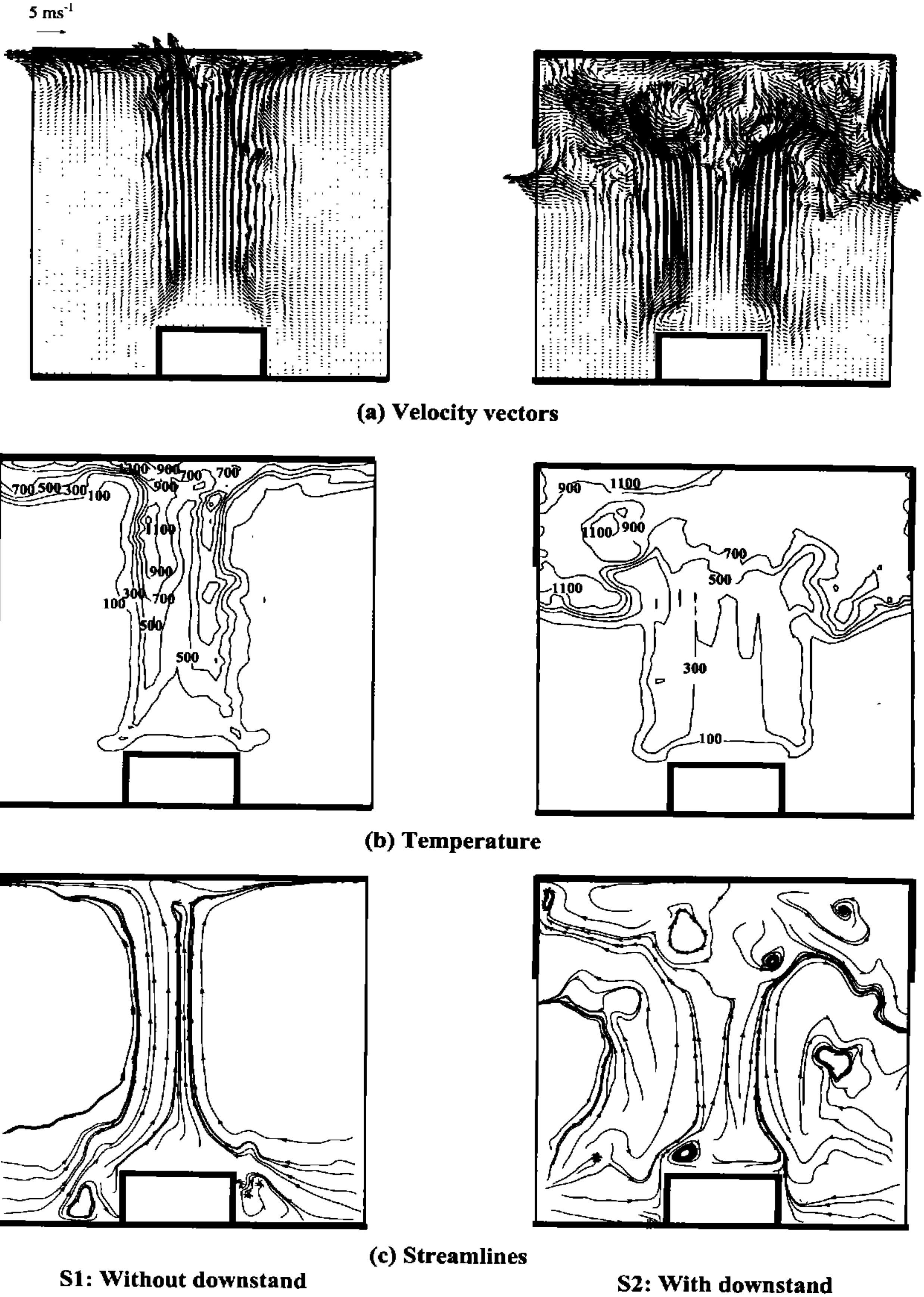
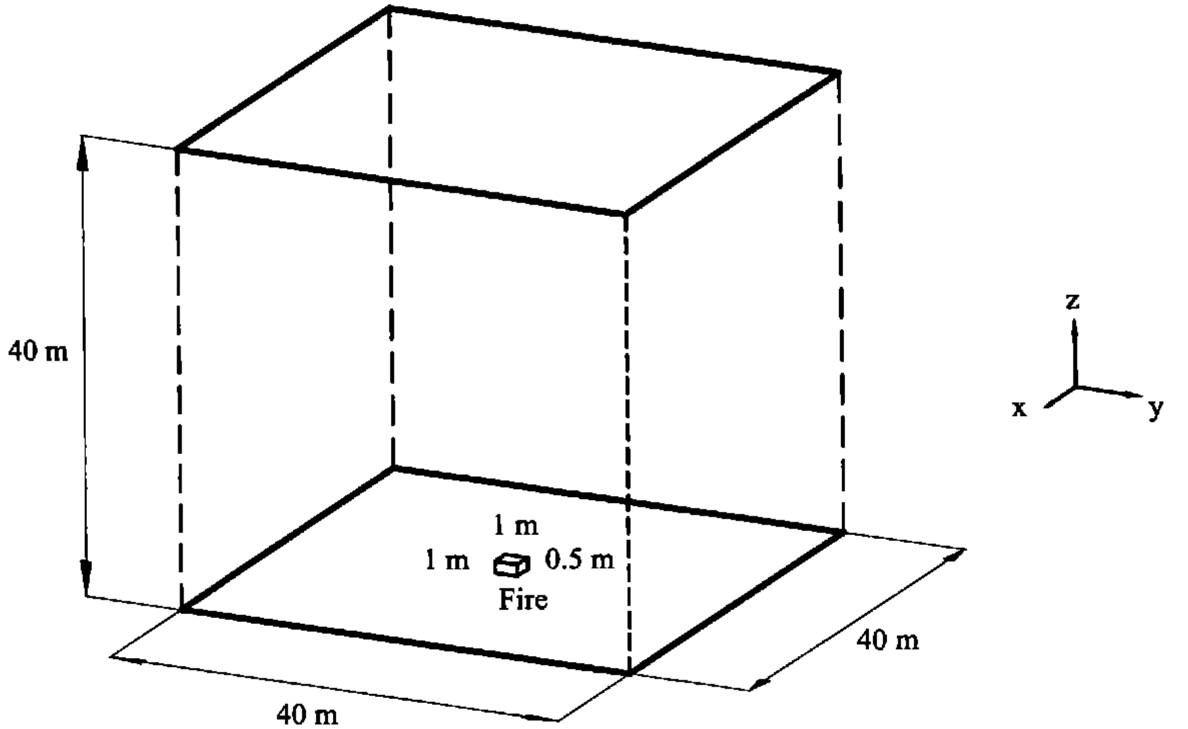
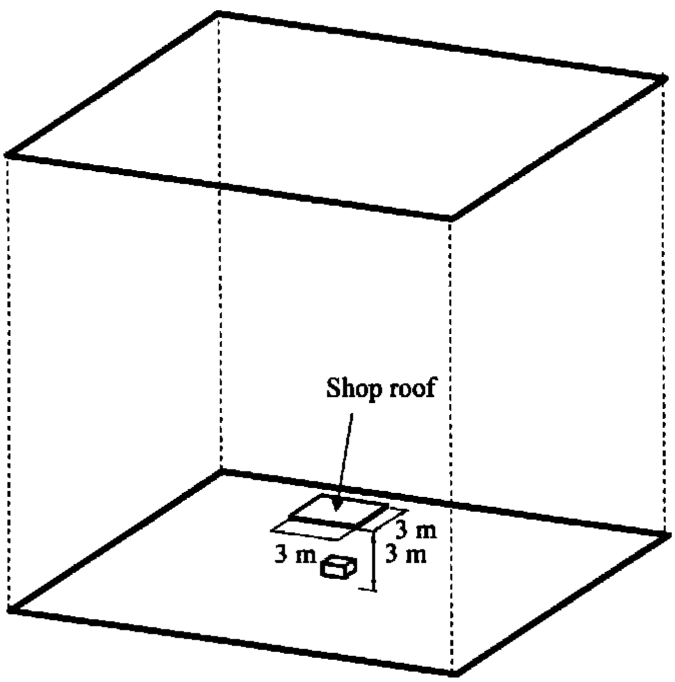


Fig. 2 Predicted fire environment at 100 s for shop fires



(a) Scenario H1: With a fire only



(b) Scenario H2: With a shop roof

Fig. 3 Geometry of the hall

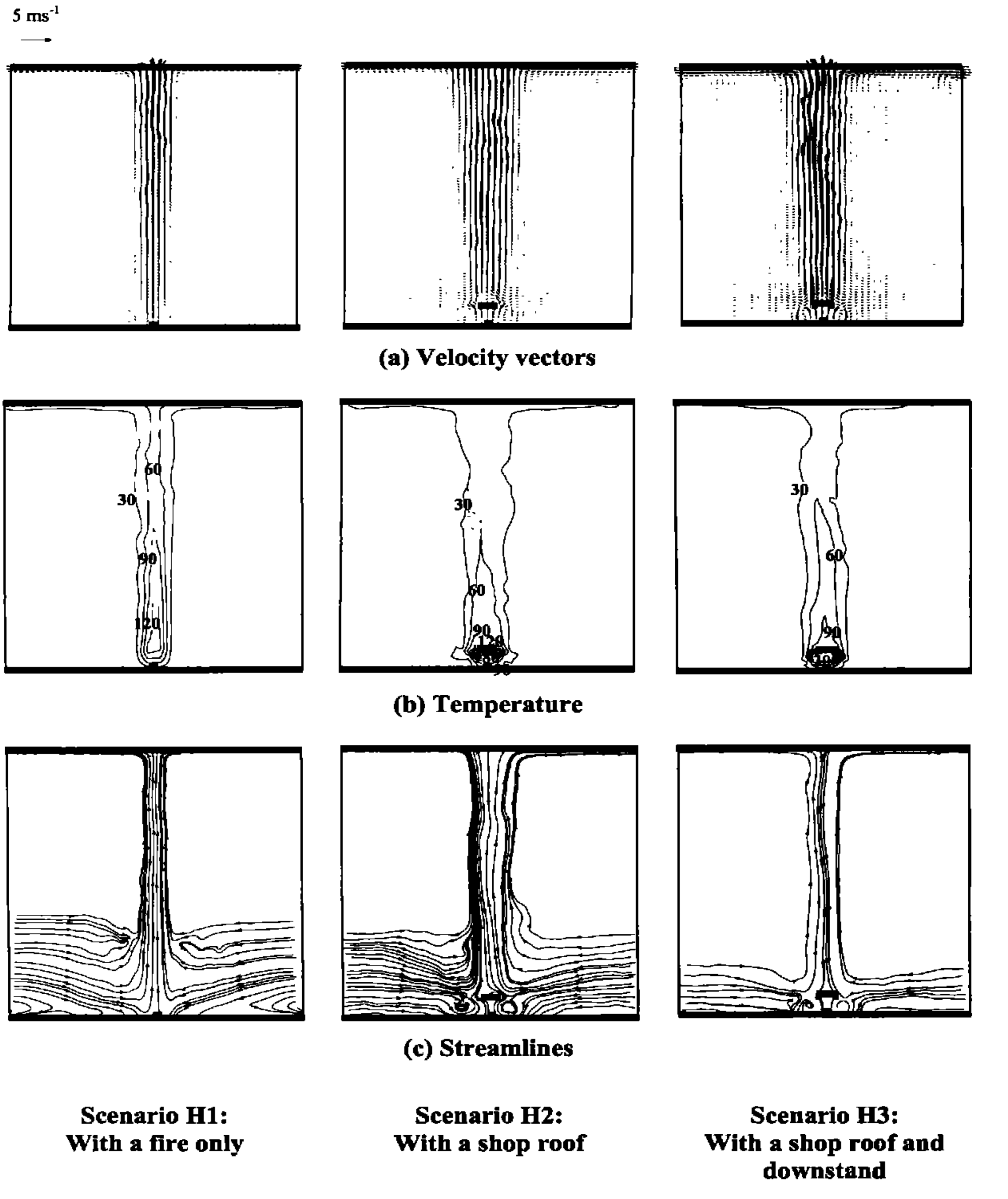


Fig. 4 Predicted fire environment for scenarios H1, H2 and H3

Results at 100 s on the velocity vectors, temperature contours and streamlines are shown in Figure 4.

Scenario H2

The hall and fire size are the same as in H1, but with a shop roof of area 3 m by 3 m placed above as in Figure 3b. This is part of the cabin design where fire shutters can be activated to enclose the shop. Sprinkler installed would be activated to suppress a fire; and smoke extraction systems would operate to extract the smoke generated. However, these suppression effects are not studied by FDS in this paper.

Results on the environment induced by the fire predicted by FDS at 100 s are shown in Figure 4 as well. It is well-demonstrated that the presence of the shop roof, i. e. scenario S2 would lead to a bigger plume, in comparing with scenario S1 without it.

These predictions agreed with the earlier CFD studies based on RANS [12] .

Scenario H3

With the same hall and fire size as in H2, a more practical design was assessed with smoke screens or downstands of depth 1 m installed below the shop roof.

The predicted results on velocity vectors, temperature and streamlines are shown in Figure 4.

Scenario H4

Same as H3 but a finer grid system (68 (68 (132) was assigned. Similar results were predicted as in Figure 5.

3 Active fire protection systems in the shops

Obviously, active fire protection systems must be installed in the retail shops. Sprinkler systems are required in shopping malls as stated in some codes [e.g. 4] . In the retail shop, smoke curtain or barrier will be installed and activated to enclose the shop. Dynamic smoke exhaust systems [4] are installed to extract smoke, say through underfloor ductworks through square air ducts of size 0.5 m. The following scenarios on active fire protection systems are simulated:

Scenario A1

Retail shop not yet enclosed, dynamic smoke exhaust system of high exhaust rate of 68 air changes per hour (ACH) is operating with an exhaust outlet at the corner. The sprinkler system is not yet operated.

Scenario A2

Retail shop enclosed with dynamic smoke exhaust system operating at 68 ACH.

Scenario A3

Retail shop not yet enclosed with installed sprinkler and dynamic smoke exhaust system operating.

Scenario A4

Retail shop enclosed, with both sprinkler and dynamic smoke exhaust system operating.

Results on the velocity vectors and temperature

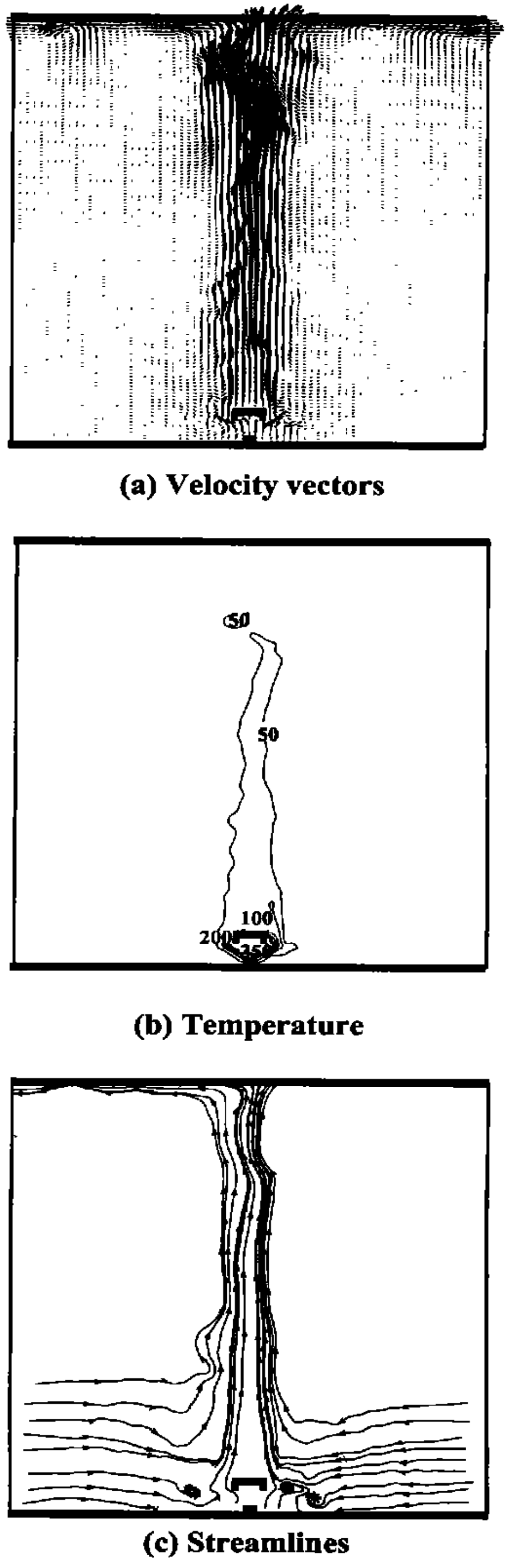
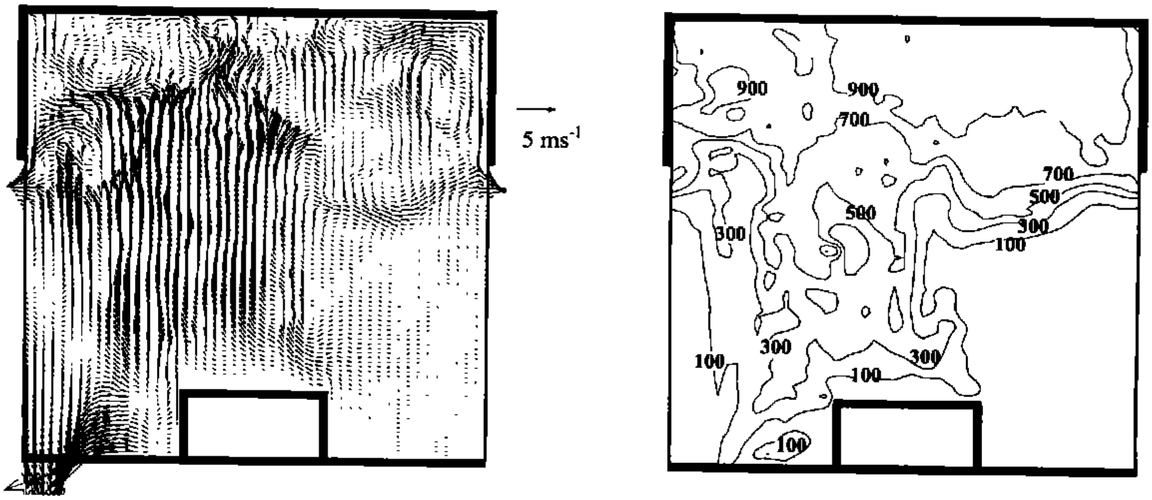


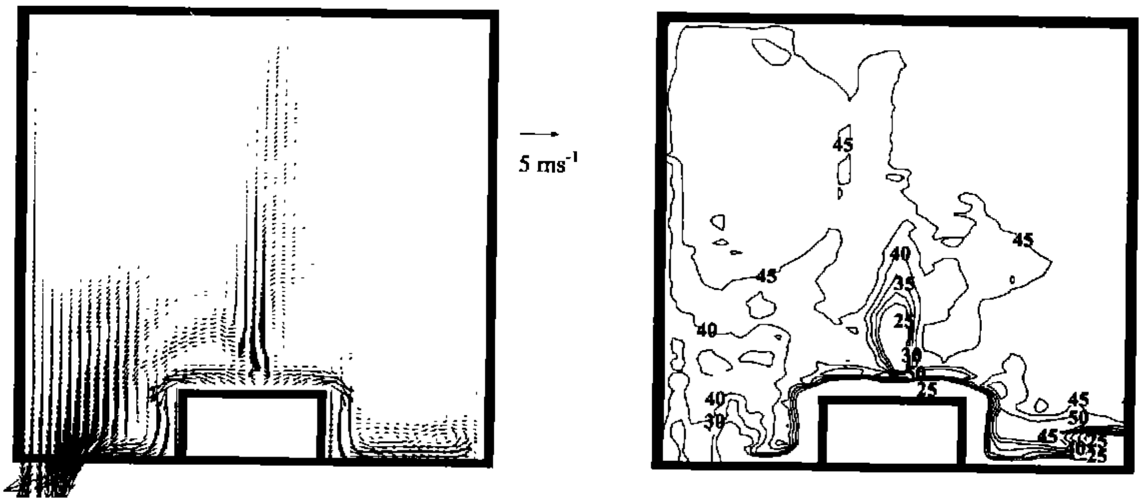
Fig. 5 Predicted results at 100 s for H4 with finer grids

distributions at 100 s after operating the systems are shown in Figures 6 and 7.

It is observed that operating only the smoke exhaust system when the retail shop is not yet enclosed would not have any effects on fire control. Flashover will occur with hot smoke spreading out of the shop. Even discharging water from the sprinkler as in A3 will not help.



(a) A1: Retail shop not yet enclosed



(b) A2: Retail shop enclosed

Fig. 6 Performance of active fire protection systems

When the shop is enclosed, the combustibles might not burn as no oxygen is available. ‘Backdraft’ would occur when a door opens and this point has to be watched carefully in fire safety management [e.g. 13]. But when sprinkler is in operation, there is a possibility of controlling the fire.

4 Conclusion

Fire safety provisions are normally designed for protection against accidental fires. However, the number of arson fires over the world appears to be increasing [14]. The general public is now very concerned about the hidden fire hazard, even when they are traveling on an underground railway [14] . Perhaps, it is the right time to review the fire safety codes and the government is doing that at the moment. Shopping malls with small retail shops are always crowded with people. For those malls having difficulties to install smoke management system [3] for the entire hall space, a roof has to be put above the retail areas. Active fire protection systems including sprinkler and dynamic smoke exhaust system are installed. The shop should be enclosed when there is a fire. Oxygen might not be adequate to sustain burning with the fire extinguished by itself. However, backdraft might occur if a door opens. But, if the shop is not enclosed properly, there is a possibility of having flashover in the shop with hot smoke spreading out as demonstrated by CFD studies.

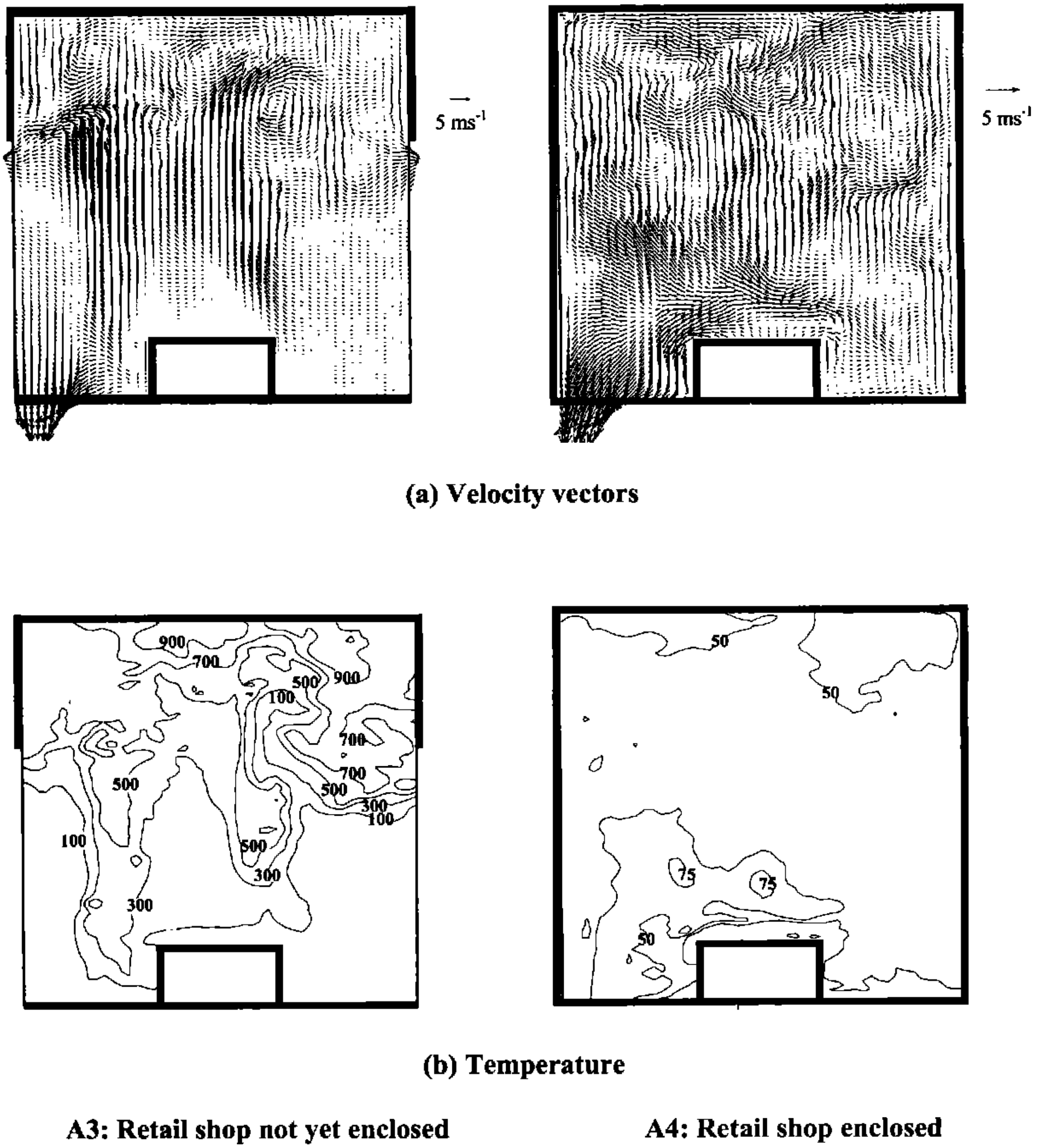


Fig. 7 Results for scenarios A3 and A4

Putting in sprinkler systems would help to cool down the hot environment. As reviewed before [15], fire suppression system such as the water mist system might improve the situation. Note that a very big plume [12] will form as demonstrated also by simulating with FDS. But performance of water mist fire suppression systems should be evaluated by similar full-scale burning tests [16] and studying that is in progress.

Obviously, a heat release rate database for local combustibles should be developed [e.g. 17] and carrying out full-scale burning tests [18] is necessary. Results are useful for specifying the design fire for smoke management system [12] in those big halls. Fire safety management [13] can be recommended based on such studies. For example, books and magazines are suggested not to be displayed vertically. Doors of shops should not be opened without caring about backdraft.

For higher level development works with more serious assessment of fire safety design involving CFD by the Authority, software based on LES [7] such as FDS [9] would be a good choice of simulation tool. Now, both pre-processors and post-processors are fairly user-friendly. It is obvious that experimental verification on the predicted is necessary. The study is in progress and will be reported separately.

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应用 FDS 软件对零售店铺火灾的数值模拟

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摘要: 客运总站等大空间建筑物中的小零售店铺通常会堆放许多可燃物。在此类建筑中都安装用于整个大厅的机械排烟系统似乎不太可行。因此, 在店铺中建造了包括水喷淋以及排烟等主动式消防系统的屋顶, 着火时挡板将落下封闭店铺。此时应关注在封闭的小空间内发生轰燃的可能性。如果店铺没有完全封闭, 烟气可能会扩散到店铺以外的空间。

文中用火灾场模拟软件 FDS3.1 模拟了消防系统启动前店铺内的火灾环境。模拟的结果将有助于评估制定的消防安全条例以及相关的设计参数。研究结果证实了如果着火的店铺没有完全封闭, 更大的烟气羽流将会在店铺以外的大空间中形成。此外, 文中还对控制店铺火灾用的排烟系统及水喷淋系统的性能进行了评估。

关键词: 零售店铺火灾; 数值模拟; FDS 软件
中图分类号: X928.02　　文献标识码: A

研究进展

多组分细水雾灭火原理技术与系统

该项成果在预防火灾事故、减少人民生命和财产损失, 节约水资源、替代哈龙和实现清洁高效灭火等方面具有广阔的应用前景。

在系统的研制过程中, 成功的开展了以下的基础研究工作: 利用三维 LDV/APV 系统对喷头各项雾特性参数进行了测量, 优化了细水雾的发生方法; 以现代激光技术、电子技术和图象处理技术为基础, 发展和建立了多参数、非接触性雾场特性诊断方法与系统; 完成了添加剂的制备与筛选和多组分细水雾灭火系统的集成; 发展建立了细水雾灭火实验模拟实验平台, 并进行了实验, 完成了对系统灭火有效性评价。

创新之处在于: 与传统的细水雾灭火技术相比, 多组分细水雾的灭火机理是物理化学耦合作用机制, 成功找到了灭火速度快、效率高、成本低、有添加剂配方, 减少用水量; 而添加剂的存在以及雾发生方法的革新使得系统能够在低压下工作, 从而大大降低了系统造价, 提高了系统的可靠性和安全性。

该成果通过了 2003 年 9 月 18 日安徽省科技厅组织的专家鉴定。鉴定委员会一致认为"本系统达到了国际先进水平, 填补了国内空白, 建议进一步开展产品的系统列化研制, 加快成果转化进程。"

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