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FIRE SAFETY ASPECTS OF REFUGE FLOORS IN SUPERTALL BUILDINGS WITH COMPUTATIONAL FLUID DYNAMICS

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Abstract. High-rise buildings in many big cities in the Far East, including Hong Kong, call for refuge floors as a matter of both practicality and compliance with regulations. Even though many countries' fire codes are not clear in spelling out the necessity for refuge floors, it is accepted within construction that such floors are essential in resisting fire, allowing users a means of escape and allowing emergency services a means of access to stricken buildings. This paper discusses the reasons behind providing refuge floors, while also considering related fire safety provisions, such as their enclosure behind fire-resistant construction or the protection of their openings behind a water curtain. Our discussion takes a tall building with balconies as a test example of refuge floors, running a hazard assessment based on Computational Fluid Dynamics assuming a fire of the broadly accepted level of 2 MW. The paper concludes that the design of the building's façade finally determines whether or not a refuge floor and associated fire safety provisions, such as a water curtain, can be waived. As the flat modelled used to store a high amount of combustibles up to 1135 MJm^{-2}, the breaking of large area of glass window could lead to a major conflagration. The consequences of a scenario with a fire of 25 MW are also discussed.

Keywords: refuge floor, supertall buildings, evacuation, fire safety provisions.

1. Introduction

The rapid development of big cities in the Far East, especially China (Chow 2007), has seen the construction of a large number of many high-rise buildings. Over half the top 100 high-rise residential buildings in the world – that is, of a height over 200 m – can be found in Hong Kong alone (Property Times 2004). Tall buildings of over 40 levels are also used as commercial buildings, office towers and shopping malls.

Fire 'safety' in such dense urban areas (Chow 1998) is clearly an issue of the first importance, not least because of many big accidental fires since the 1996 blaze at the Garley Building (South China Morning Post 1996) in Hong Kong. High-rise buildings may be especially vulnerable to safety concerns on the grounds of fire (Chow 2007). In the wake of the Garley fire, the local Hong Kong government both modified its existing fire code specifications (Buildings Department 1996a, 1996b; Fire Services Department 2004, 2005) and also:

– Requested older high-rise buildings, i.e. those erected before 1972 without tight fire regulations, to upgrade their fire safety provisions;
– Set up a New Fire Services Ordinance (2004) mandating rules for sprinkler systems;
– Implemented a Fire Safety Inspection Scheme (Buildings Department 1997), asking inspectors to pay particular attention to buildings' structural stability, external finish and fire safety.

One of the key fire safety provisions now required for tall buildings is refuge floors (Buildings Department 1996a, 1996b; Fire Services Department 2004, 2005), as shown (Chow and Ma 2006) in Fig. 1. In some tall buildings, refuge floors take the form of communal sky gardens (Niu *et al.* 2005). It is difficult to disagree with the necessity for such a requirement in supertall buildings (taking this term to mean a building of over 40 levels in Hong Kong and over 250 m in China). In-depth investigation, however, has not yet established the reasons for needing to have a refuge floor either empirically or theoretically, although these are thought to include the desirability of putting in place fire-resistant construction, and of providing a means of egress to building users and of ingress to fire and other emergency services. This paper, therefore, presents a rationale for the use of refuge floors. Necessity of installing drencher system is listed. We make use of a Computational Fluid Dynamics (CFD) fire model to assess the hazard posed by fires of certain strengths in an example building, using in particular the Fire Dynamics Simulator (FDS) at the National Institute of Standards and Technology (NIST) (McGrattan *et al.* 2007a, 2007b). Wind action on smoke spread will be discussed under a post-flashover apartment fire with heat release rate estimated.

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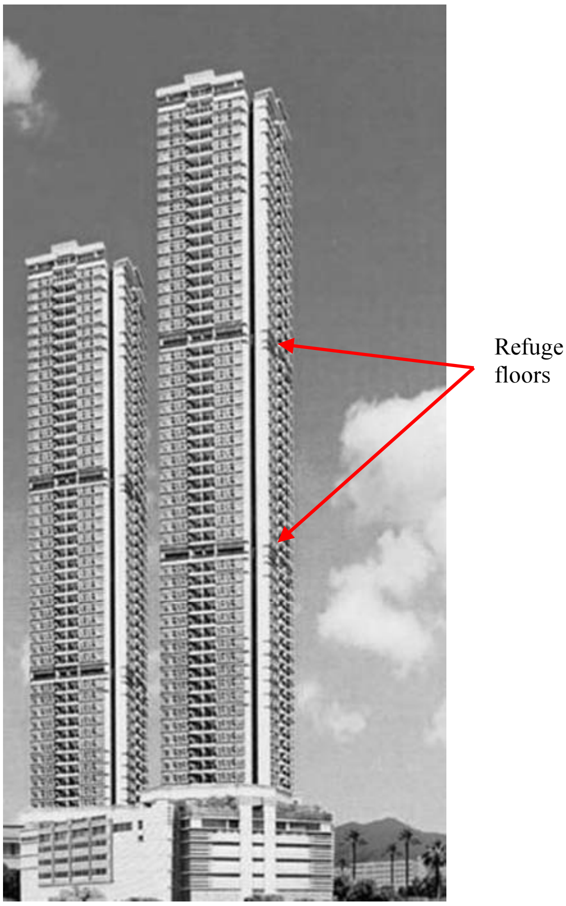


Fig. 1. Refuge floor

2. Local codes

Different Hong Kong fire codes specify a need for refuge floors. First, they are required as a means of escape (MoE) in code (Buildings Department 1996a) paragraph 21:

[21.1] *Refuge floors should be provided in all buildings exceeding 25 storeys in height above the lowest ground storey, at not more than 20 storeys and 25 storeys respectively for industrial and non-industrial buildings from any other refuge floor, or above the street or the open area referred to the code. The number of storeys may exclude storeys which contain solely mechanical plants.*

[21.5] *Does not apply to a domestic building or a composite building not exceeding 40 storeys in height above the lowest ground storey. In a domestic building or a composite building exceeding 25 storeys but not exceeding 40 storeys in height above the lowest ground storey, the main roof of the building should be a refuge floor and should comply with the requirements in the code.*

[21.2] *For every refuge floor, there [can be] no occupied accommodation or accessible mechanical plant room, except fire services water tanks and associated fire service installation plant room, at the same level as the refuge floor.*

Refuge floors are also called for under the Means of Access (MoA) code (Buildings Department 2004) in paragraph 17:

[17.5] *Every access staircase in a firefighting and rescue stairway passing through a refuge floor should discontinue at such level so that the access route is diverted to pass over the area for refuge before it is continued to access upwards.*

Under the requirements for Fire Resisting Construction (FRC) in code (Buildings Department 1996b), paragraph 18 reads:

[18.1] *The area for refuge on every refuge floor in a building should be separated from the rest of the building, including vertical shafts or ducts passing through such floor, by walls and floors having a fire resistance period (FRP) of not less than 2 hours. Vertical shafts or ducts passing through a refuge floor should not open directly onto that floor.*

[18.2] *Where the side of a refuge floor is required to be open, the open side should not directly or diagonally be within a distance of less than 6 m from:*

a) the opposite side of a street;
b) a common boundary with an adjoining site;
c) any other external wall having an FRP of less than 2 hours or other opening not protected by fixed light with an FRP of not less than 1 hour of the same building; or
d) any other building on the same site.

The Fire Service Installations (FSI) code (Fire Services Department 2005), paragraph 4.40, meanwhile, provides for floors in the context of building installations:

The fire service installations and equipment that are required to be provided in the building in accordance with relevant sections of this Code shall also be extended to the Refuge Floor(s) as appropriate; and

an external drencher system with an independent water supply shall be provided to protect all external wall openings. The system shall be automatically operated by a quick opening valve or deluge valve which is operated by a system of approved heat detectors or sprinklers installed in the same areas as the drencher system, together with manual control.

3. Possible functions of refuge floors

Despite specifying a refuge floor (Chow and Ma 2006) and related building safety installations, the codes do not offer a thorough rationale for the necessity of this building storey. The following functions of a refuge floor, though, have been put forward as reasons for including such floors in construction (Cheng and Yuen 2003; Chow and Ma 2006; Lo *et al.* 2002; Lo and Will 1997; Proulx 1999; The Institution of Structural Engineers 2002):

- Floors serve as a safe place for gathering in a very tall building. The existence of refuge floors reduces evacuation time, when compared to a system in which users are evacuated to some point outside the building. In evacuation, all users need not move together. Some can stay at safe places inside the building.
- Floors may serve as a 'command' point in firefighting.
- Floors may stop or retard the upward spreading of flames.

- Floors provide an area in which to change the vertical lift shafts to reduce the stack pressure on smoke movement, further facilitating the lift design in supertall buildings.
- Floors may reduce the wind loading onto the building.
- Floors may house certain special applications such as fire services plant rooms.
- Floors may house new design features e.g. communal sky gardens (Niu *et al*. 2005).

The FRC code (Buildings Department 1996b) lays down that refuge floors' external wall openings have to be covered in adequate FRP, as denoted in Fig. 2. Otherwise, an external drencher system is required by the FSI code (Fire Services Department 2005). The current practice is to discharge a water curtain through an external drencher system (Chow and Ma 2006), thereby protecting wall openings, as shown in Fig. 3.

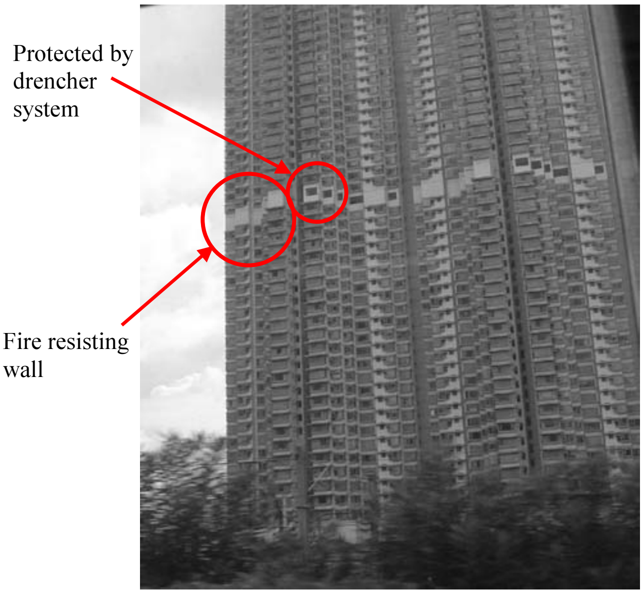


Fig. 2. Openings in refuge floor

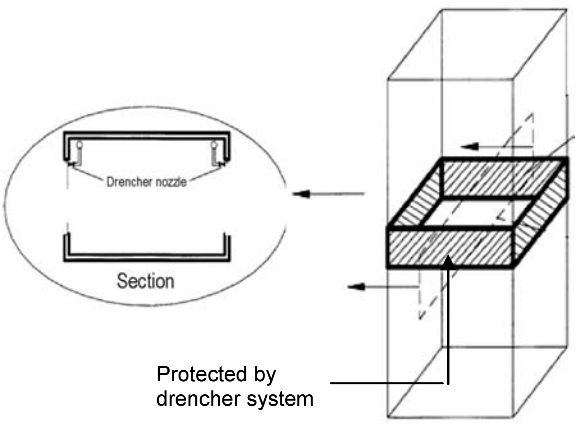


Fig. 3. Protection of refuge floor by drencher system

4. Refuge evacuation

Allowing for evacuation plays a central part in satisfying fire safety provisions, particularly those that concern life safety. Building specifications require an utterly clear plan for all occupants to evacuate the building (British Standards Institute 2001). Practical calculation methods assessing occupants' likely speed and routes of evacuation (Nelson and Maclenna 1995) are commonly applied to study buildings' evacuation time. Buildings' total evacuation time *TET* (in seconds) can be estimated by solving a 'hydraulic flow problem' assuming a total occupant loading N_T (i.e. a number of persons) and the total evacuation flow capacity F (in number of persons / s) for all staircases:

$$TET = \frac{N_T}{F}. \qquad (1)$$

As reported before (Chow 2004–2005), in a 65-level tall deluxe building with 2,275 occupants, F comes in at 48 person/s. The value of *TET* for occupant loading N_T in situations, where the door exit time to outside is unknown can likewise be calculated by the hydraulic flow equation:

$$TET = \frac{N_T}{F} \times 60 \quad \text{or} \quad TET = 1.25\, N_T. \qquad (2)$$

Following these calculations, it is clear that for a certain supertall building of 2,275 occupants with only 35 persons per level, the *TET* cannot be faster than 24 minutes (Chow 2004–2005). However, were such a building to have two refuge floors, the *TET* can be reduced by at least 1/3, i.e. bringing evacuation down to only 8 minutes. Occupants below the refuge floor can if necessary move up and need not move down, with the possibility of further reducing the *TET*. In this case, building occupants may have to remain on the refuge floor for some time until the hazard has been dealt with. In case where the refuge floor is a rooftop, the *TET* can come down still further, as top-floor building users can move upwards.

5. Drencher systems

Many large buildings in East Asia have drencher systems, with this feature being especially common in buildings which may only be divided into compartments with difficulty (Ng and Chow 2004; Tsui and Chow 2003). The system is taken as a fire safety provision in satisfying the fire codes equivalent to the installation of fire-resistance construction (Buildings Department 1996a, 1996b; Fire Services Department 2004, 2005). It is believed that discharging a water curtain (or water screens) might act in a single way to FRC in confining fires. A principal area of application for water curtain, screens or hoses is to protect large openings such as those giving access to refuge areas in the absence of fire resisting construction (Chow and Ma 2006; Ng and Chow 2004), as shown in Fig. 3. Drencher systems can be installed to cover external wall openings for all refuge floors. The jury is out on the efficacy of these systems, which in many instances have yet to be proven by either full-scale burning tests or in the case of bigger fires. Some refuge floors in residential buildings have been built without drencher systems, though in Hong Kong at least this is typically now prohibited by regulations. Very few works in the architectural literature investigate water curtains or screens (Amano *et al.* 2005; Chow and Ma 2004–2005; Coppalle *et al.* 1993; Dembele *et al.* 2001; Fong and Chan 2001; Fong *et al.* 2001; National Fire Protection Association 1982; Ravigururajan and Beltran 1989).

It is permitted to leave drencher systems out of the design of refuge floors if the building design can demonstrate an equivalent fire safety level through compliance with Hong Kong's prescriptive code. In these cases, performance-based design has to be applied. The essential hardware considerations are:

- the installation of a fire hydraulic and hosereel system;
- good cross-ventilation design;
- widely open building façades enhancing cross-ventilation on the refuge floor;
- the prevention of fire and smoke spreading to the refuge floor from below. This possibility depends on the design of the building's façade.

On the software side, meanwhile, a similar number of criteria need to be met before drenchers can be dispensed with:

- the fire risk must be very low;
- professional fire safety management would normally be able to restrict the fire load on the refuge floor;
- the occupants of a residential building can be assumed to be familiar with their environment;.
- management, staff and occupants have been trained in how to respond to an emergency.

6. Heat release rate in a flat

Fire safety engineering has to make a number of assumptions in its "design fire scenarios" (Garrad and Smith 1999), which are thus necessarily subject to uncertainty. A design fire depends on estimates of the use of the building and of the materials it stores. The heat release rate for an occupancy, to some extent, depends on the materials present, including construction materials, and how they are burnt. The type, quantity, orientation and position of materials used and stored; the availability of oxygen, i.e. ventilation conditions; and the presence and location of fire installations all affect the development of a fire.

However, very limited fire testing data is available on the above items in Hong Kong and elsewhere in East Asia. In designing shopping malls, architects assumed constant heat release rates for 5 or 2.5 MW blazes, to be doused by sprinklers of a physical size of 3 m by 3 m. All models calculating heat release rates need to be verified in terms of their estimates of thermal radiation, as this will be dependent in individual cases on burning surface, intermediate combustion chemistry and the turbulent mixing of air and fuel. It will be at least ten years before a satisfactory general model relating these elements can be determined for application in specific Hong Kong buildings. In the meantime, the probable heat release rate for a burning flat can only be estimated from some results found in the literature. In using existing overseas data (Garrad and Smith 1999), burning a pile of 340 soft toys of mass 46 kg piled up to a height of 0.95 m would give a heat release rate, as shown in Fig. 4. This can be fitted to a medium t^2-fire with a cut-off value of 1.3 MW.

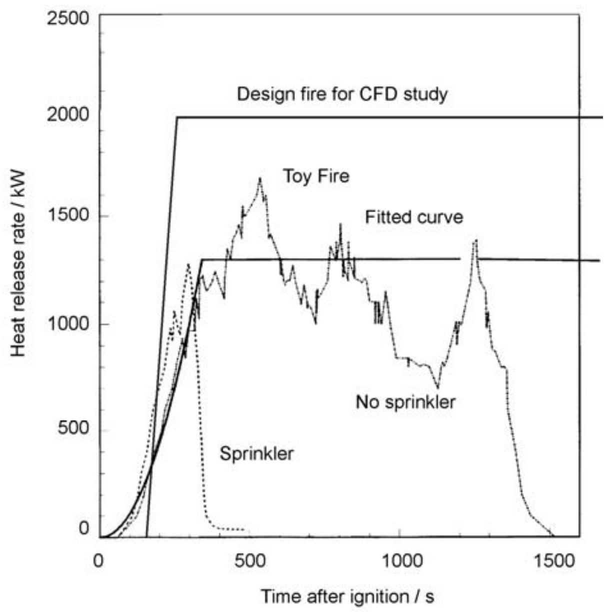


Fig. 4. Design fire based on reported experimental data (Garrad and Smith 1999)

A database of the heat release rate of common combustibles has to be developed to give realistic input parameters for fire models in hazard assessment. Such a database is not yet available for local combustibles, which vary from international or Western norms in terms of soft furnishing and certain decorative elements. In some fire scenarios, it is reasonable to assume an ultra-fast t^2-fire. The speed of the fire in modeling is, in fact, less of a crucial issue than the cut-off value. The common design value agreed in predicting fires is about 0.5 MWm^{-2} of burning area. In small residential flats, a lower value of only 1.5 MW has been assumed. This value might be adequate even for small retail shops, although no local database exists corroborating these values.

The combustibles in a residential building basically take the following forms:

- Furniture, including polyurethane (PU) foam sofas and cushions, coffee tables with wooden parts or other timber products, and chairs;
- Audio-visual equipment, sometimes housed in wooden or other timber cupboards;
- Paper;
- Clothes;
- Floor coverings and carpets;
- Partition walls made of timber hard board, chipboard, or plywood;
- Surface lining materials including wall coverings.

It is of the highest concern that sprinkler systems are generally not required in residential buildings. No suppression system thus exists to moderate or control the heat release rate in an accidental fire.

7. Wind-induced air flow

Wind-induced air flow (Chow 2003, 2004) is a transient phenomenon depending on global wind speed (an averaged value measured at designated positions), building geometry, the configuration of its openings, and adjacent objects. To understand how heat and smoke spread upwards from the source of fire, it is necessary to estimate patterns of air flow and temperature distribution. Again, computational fluid dynamics can represent the possible fire environment in a holistic manner (McGrattan *et al.* 2007a, 2007b). In this way, it is possible to study the movement of heat and smoke spreading out of building compartment on fire to the refuge level (both with and without drencher retardation).

This paper's CFD simulation selected an example building with balconies, as shown in Fig. 5. Our predictions of fire-induced air flow were good enough for a plausible visualization of smoke's movement from the room ablaze to the refuge floor in this design; however, it would not be legitimate to infer smoke movement for other building geometries on the basis of this model simulation. Smoke particles are taken to move along the paths of air flow.

Even with powerful computer hardware, it is impossible and unnecessary to simulate the effect of fire on the entire building. Instead, this work has simulated that part of the building as indicated on Fig. 6. The computing domain of interest is of 15 m long, 11 m wide and 10 m high. Simulating only two storeys above the fire room, including the refuge floor and the level above with all windows closed is sufficient to build up a picture of the most possibly damaging fire for the refuge floor. Here we can work with a section of the building of length 5.3 m. The computing domain was extended outside this designated area's free boundaries to give the configurations for CFD simulations shown in Fig. 7a.

Defaulted thermal radiation and combustion menus in FDS were used in the simulations. Building model for FDS simulations was constructed by setting up boundary walls at appropriate sizes to allow openings as in Fig. 7a. The computing domain was extended out of the building to avoid specifying pressure boundaries which are unknown at the opening. Free boundary conditions were specified at the extended free boundaries.

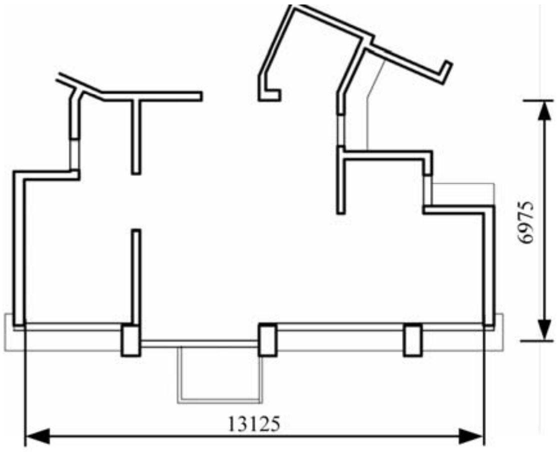
Two scenarios were carried out with the door in the fire room closed:

- S1: No wind;
- W1: Wind speed of 10 $ms^{-1.}$

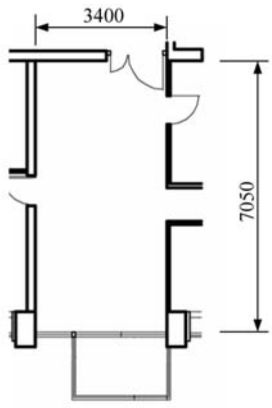
Two further simulations were repeated with the door in the fire room open (shaded in the diagram), according to the grid geometry shown in Fig. 7b:

- S2: No wind, door open;
- W2: Wind speed of 10 ms^{-1}, door open.

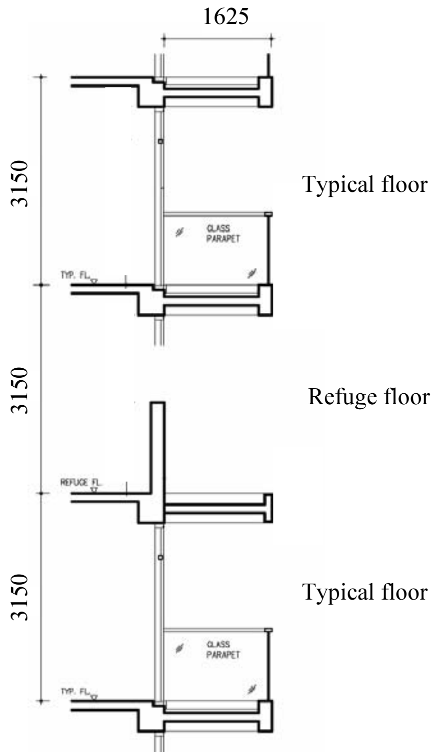
A fire of size 0.5 m by 0.5 m by 0.5 m with the heat release rates described by an ultra-fast t^2-fire with a 2.0 MW cut-off value was assigned to the 'fire room' as in Fig. 4. This fire is of a greater magnitude than those supposed in the design of retail shops in an airport terminal (Chow and Ng 2004), which had been accepted in several other construction projects.



a) Plan for a refuge floor



b) Plan for a flat in a typical floor



c) Section view All in mm

Fig. 5. The example building

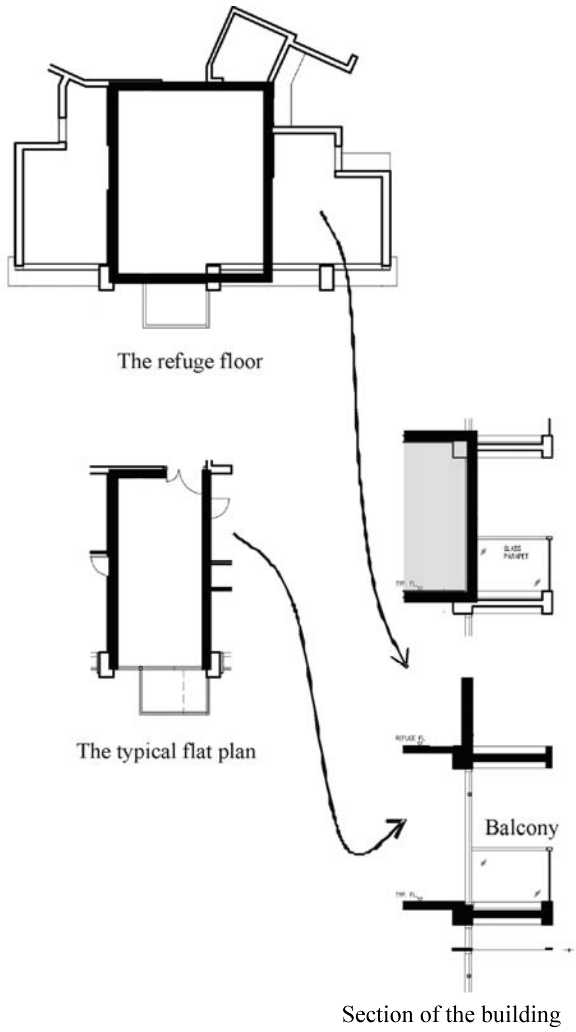


Fig. 6. Computing domains for regions of interest

FDS software was used to model heat and smoke diffusion (McGrattan *et al.* 2007a, 2007b) with turbulence modelled by Large Eddy Simulation (LES). Initial and ambient temperatures were set at 20 °C.

The building was divided into 94,640 parts, i.e. 52 × 52 × 35 along the x-, y- and z-axes. Transient simulations up to 100 were performed for constant time intervals of a second. The computation was performed on a Pentium desktop, taking around 3 hours of CPU time for each simulation run.

For simulations S1 for a fire in a room with a balcony, hot air spills out of the room on fire and rises. The long horizontal apron, however, prevents hot air spreading to the upper refuge floor as illustrated by Fig. 8. With wind blowing at 10 ms^{-1}, hot air fails to spread to the refuge floor even when the door of the burning room is closed, as shown in Fig. 9.

The results for S2 and W2 are shown in Figs 10 and 11. Again hot air rises but does not reach the refuge floor, presenting no fire hazard from warm air alone. Fig. 11 shows that smoke is generally contained within the burning room in cases where the building is exposed to a blowing wind.

As there are always queries on sensitivity of predicted results on varying the grid size. The case S1 was repeated by having 8 times on the number of grids by doubling along all the three directions to give 104 × 104 × 70, or 757,120 cells (labeled as fine grid system F1). Predicted results across the central plane of the fire (not across the central plane of the opening as in the above figures) for the two grid systems are shown in Fig. 12. It is observed that the results are rather similar, at least on the general smoke movement pattern.

As personal computers can only handle up to about 2 million grids, much finer grid systems by doubling the number of grids the grid system F1 that along x-, y- and z-directions i.e. 208 × 104 × 70 (grid system F2x), 104 × 208 × 70 (grid system F2y) and 104 × 104 × 140 (grid system F2z) to give 1,514,240 cells were carried out with results shown in Fig. 13.

Again, predicted velocity flow pattern and temperature contours of these grid systems are similar to the coarse grids.

Sensitivity of grid size on CFD predicted results depends on the problem. There is no sensitivity study on smoke movement in tall buildings as the present problems. Some results reported earlier on closed pressure chamber and atrium hot smoke tests (Chow and Zou 2009; Chow *et al.* 2009) indicated that grid size similar to this study would be adequate to understand the probable fire-induced flow pattern and air temperature contours.

There were sensitivity studies (Ma and Quintiere 2003) with grid size on estimating flame length and thermal plume properties of a pool fire using earlier version of FDS. A characteristic plume length scale z^* was defined in terms of the effective diameter D (diameter of the circle with equivalent fuel area) in dimensionless fire power Q_D^* as:

$$z^* = (Q_D^*)^{2/5} D. \tag{3}$$

Q_D^* is related to heat release rate of the fire Q^* (in kW), specific heat capacity of air (1 $Jg^{-1}K^{-1}$), ambient temperature T_∞ and ambient density ρ_∞ as:

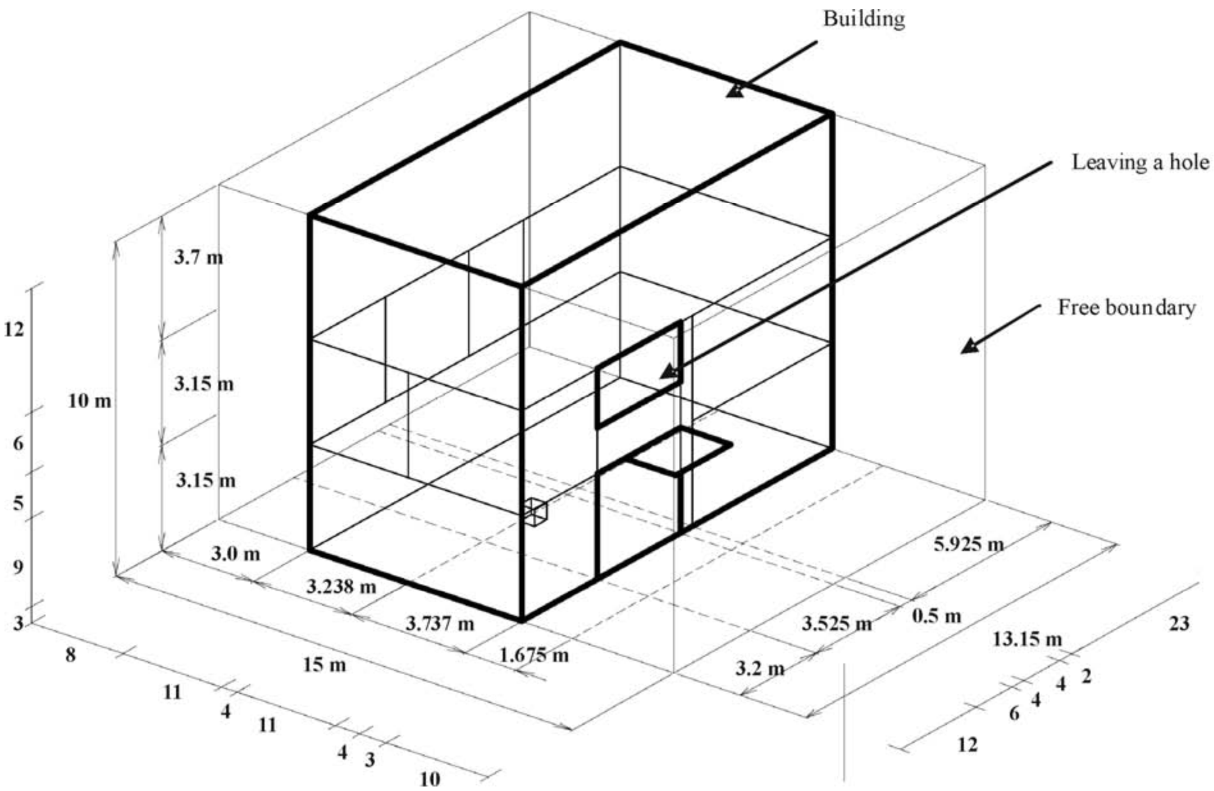
$$Q_D^* = \frac{Q}{\rho_\infty C_p T_\infty \sqrt{gD} \cdot D^2} \tag{4}$$

A dimensionless number R^* on resolution is defined in terms of grid size Δx, Δy and Δz along the three directions:

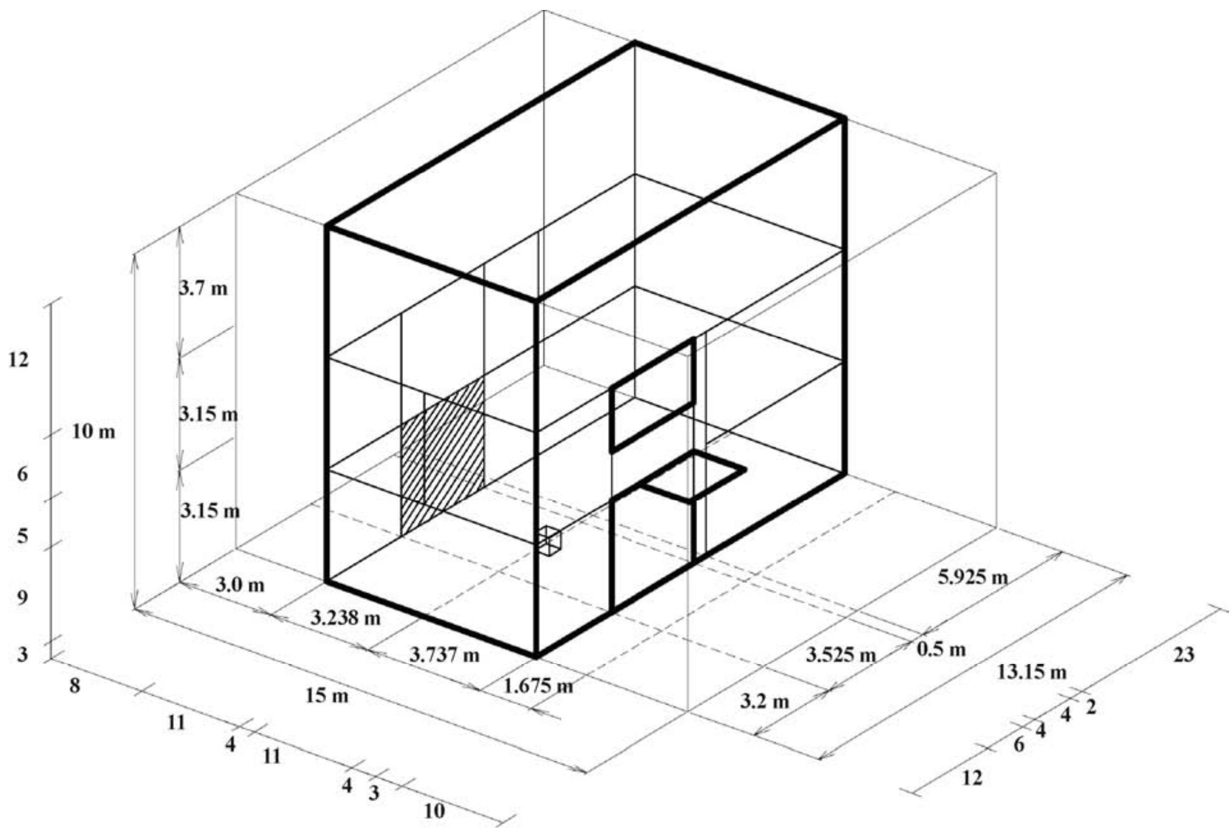
$$R^* = \frac{\mathrm{Max}(\Delta x, \Delta y, \Delta z)}{z^*}. \tag{5}$$

Optimum resolution was found when R^* is smaller than 0.1; and even down to 0.05 for studying flame length induced by a pool fire. In this study, Q is about 2 MW giving Q_D^* of 8 for T_∞ at 298 K. The fuel area 0.5 m by 0.5 m gives D of 0.564 m. The value of z^* is then 1.29. Therefore, R^* is 0.2 for the coarse grid system of 0.26 m.

The coarse grid size would not give fine resolution as proposed by Ma and Quintiere (2003) on predicting accurately flame length and thermal plumes for pool fires using FDS 2.0. However, such grid system would give reasonable predictions on flow pattern and shapes of temperature contours.

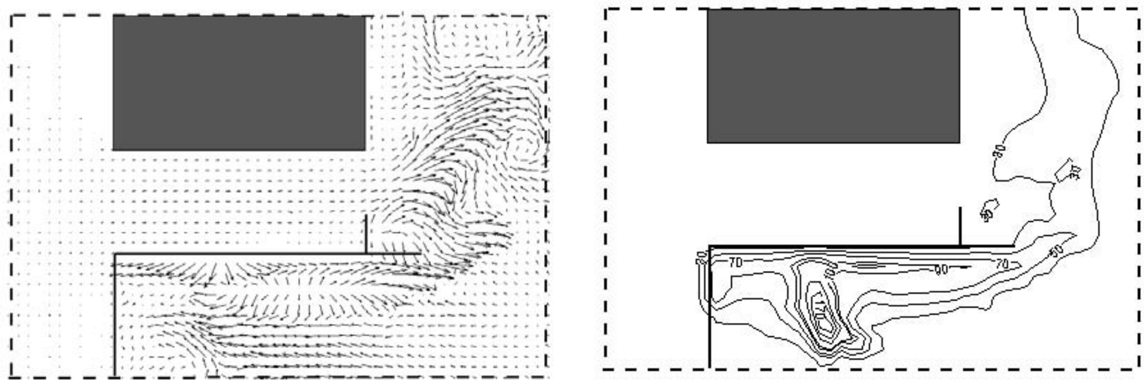


(a) Door closed



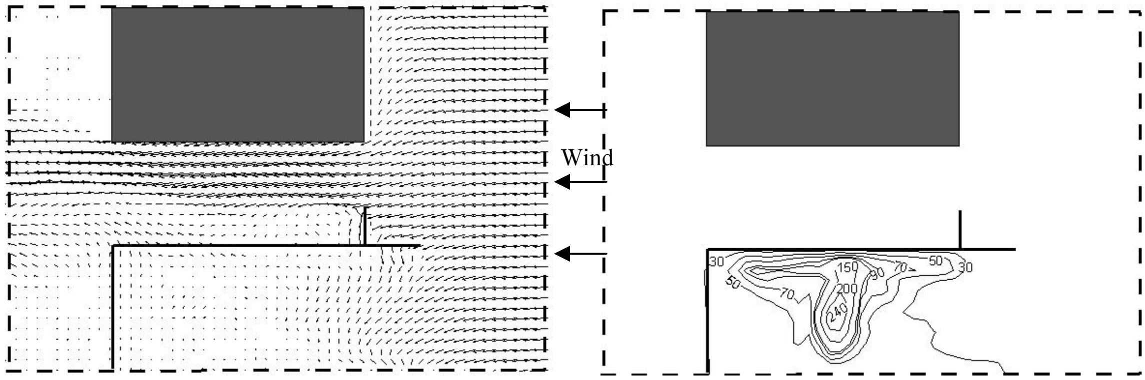
(b) Door opened

Fig. 7. CFD configurations



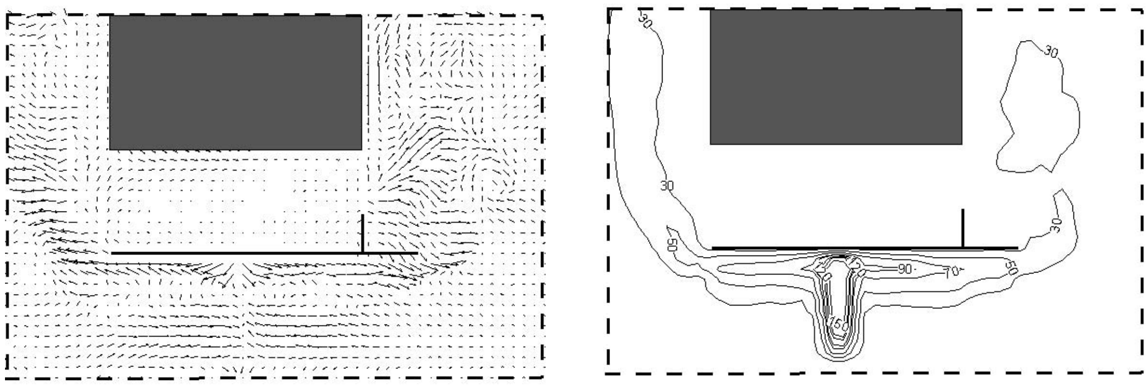
2 ms^{-1}

Fig. 8. S1: Back door closed with no wind action



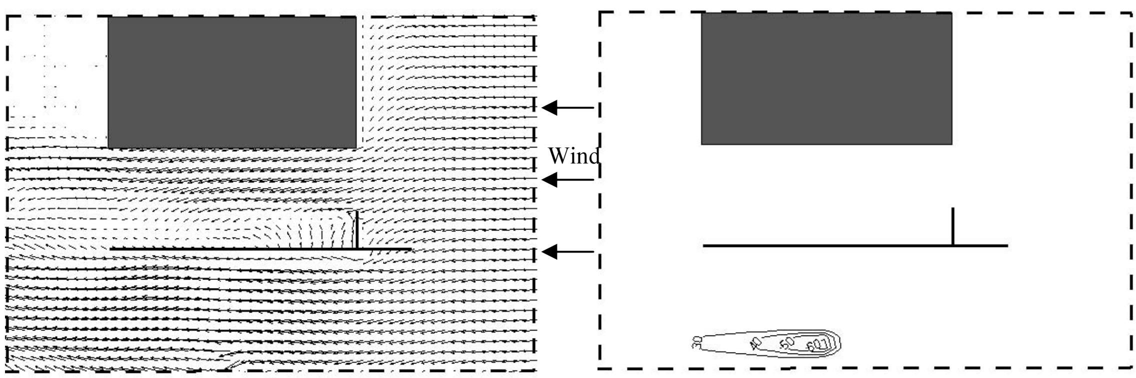
10 ms^{-1}

Fig. 9. W1: Back door closed with wind action



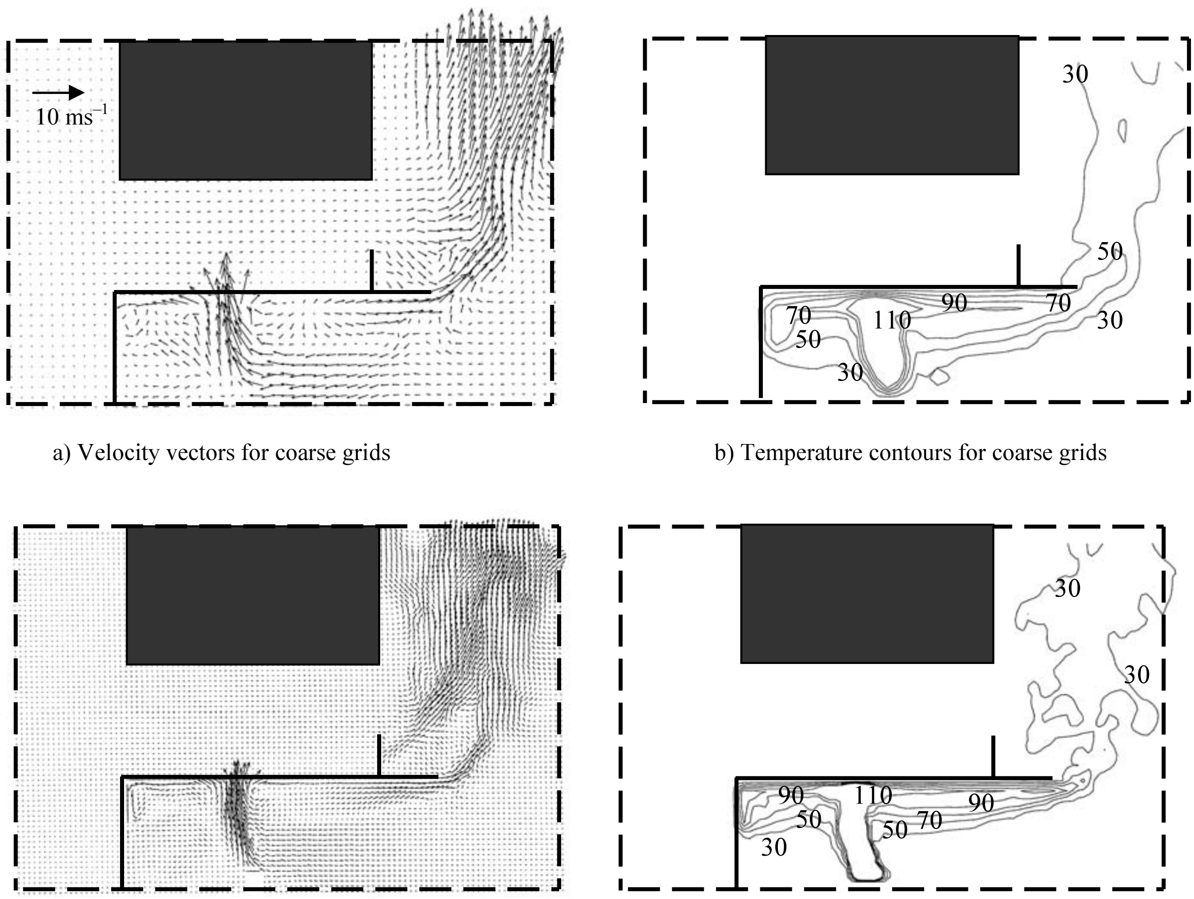
1 ms^{-1}

Fig. 10. S2: Back door opened with no wind action



10 ms^{-1}

Fig. 11. W2: Back door opened with wind action



a) Velocity vectors for coarse grids b) Temperature contours for coarse grids

c) Velocity vectors for fine grids F1 d) Temperature contours for fine grids F1

Fig. 12. Results across central plane of fire for S1

The finer grid systems F1 and F2x, F2y and F2z would give R^* of 0.1 and 0.05, should be able to give reasonable predictions on flame length and thermal plume. However, it is not critical as the objective of this study is to understand the flow pattern and temperature contours.

8. Post-flashover fires

A very low design fire with a cut-off value at 1.5 MW has been used (Chow and Ng 2004) for fire assessment in big construction projects with high risk, such as in an airport terminal. Fire levels were raised to 2.5 MW for cabin design (Yin and Luo 2007), though this level has come in for criticism for probably underestimating a likely fire's energy intensity (Chow 2007b). As post-flashover fires are likely to have more fuel than air, the air flow rate through the openings to a space becomes the governing factor in determining the burning rate of fuel. Therefore, the cut-off heat release rate of well-developed fires can be estimated using equations established as far back as the 70 s.

The ventilation factor V_f (in $m^{5/2}$) for an opening of height H_v and area A_u (in m^2) is the key parameter here, given by:

$$V_f = A_u \sqrt{H_v} \ . \tag{6}$$

As shown in the literature, the mass of air intake rate $\dot{m}_{air}$ (in kgs^{-1}) is stated in terms of the ventilation factor V_f (in $m^{5/2}$) as:

$$\dot{m}_{air} = 0.5 V_f \ . \tag{7}$$

Burning 1 kg of air thus yields 3 MJ of heat (e.g. Chow 2007b). For well-developed ventilation-controlled fires, where the heat of combustion or gasification has no effect on the heat release rate, the maximum heat release rate Q_{vent} (in kW) comes in at:

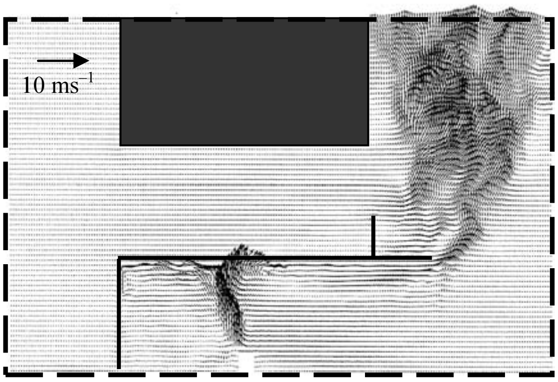
$$Q_{vent} = 3000 \, \dot{m}_{air} \tag{8}$$

or

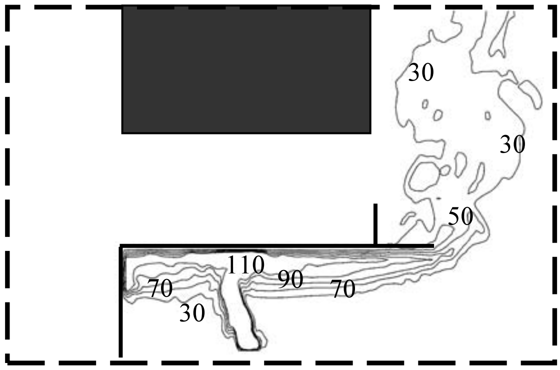
$$Q_{vent} = 1500 \, V_f \ . \tag{9}$$

When a whole glass envelope of width 2.4 m and height 2.7 m is broken opening up an access area, V_f is 10.6 $m^{5/2}$, up to a maximum value of 16 MW Q_{vent}. Even if the whole width of a 3.3 m glass façade is broken, V_f can be no more than 14.6 $m^{5/2}$, giving a Q_{vent} of 22 MW.

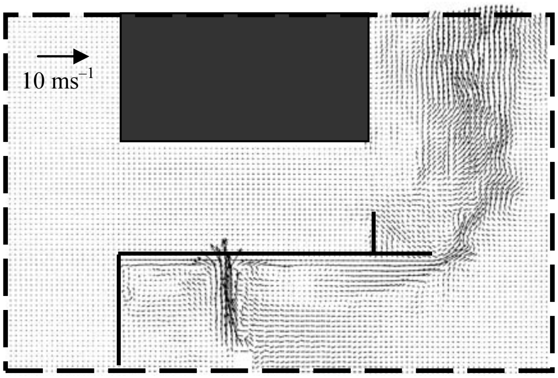
Another scenario W3 was assessed supposing a large fire of 25 MW. Modelling assigned a high wind speed of 10 $ms^{-1}$and an open entryway. The results for W3 are shown in Fig. 14. This big fire of 25 MW seems to prove conclusively that fire-induced hot air under a wind speed of 10 ms^{-1} fails to heat the air temperature on the upper refuge floor for this façade design. Furthermore, such a big fire in a residential flat will take a long time to develop.



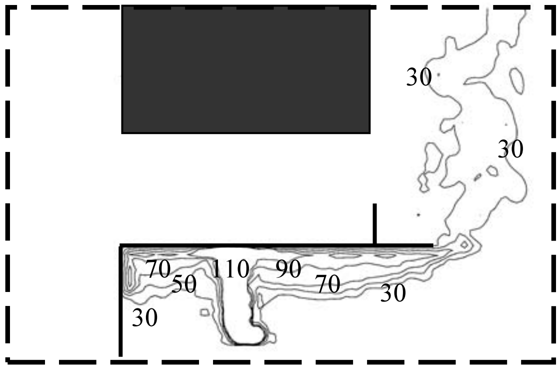
a) Velocity vectors for fine grids F2x



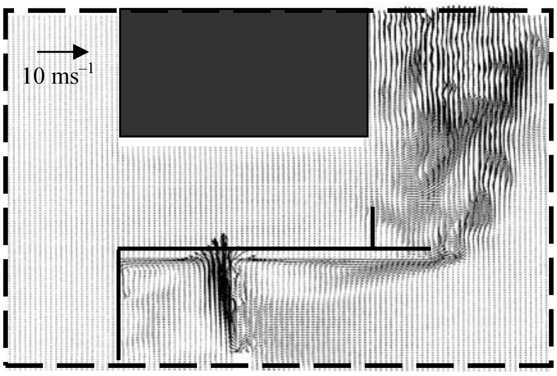
b) Temperature contours for find grids F2x



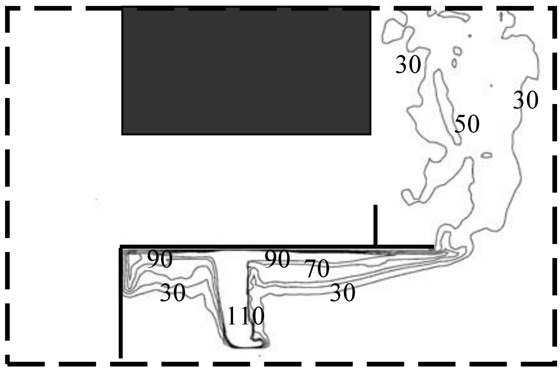
c) Velocity vectors for fine grids F2z



d) Temperature contours for fine grids F2z



e) Velocity vectors for fine grids F2y



f) Temperature contours for fine grids F2y

Fig. 13. Results across central plane for S1 with fine grids

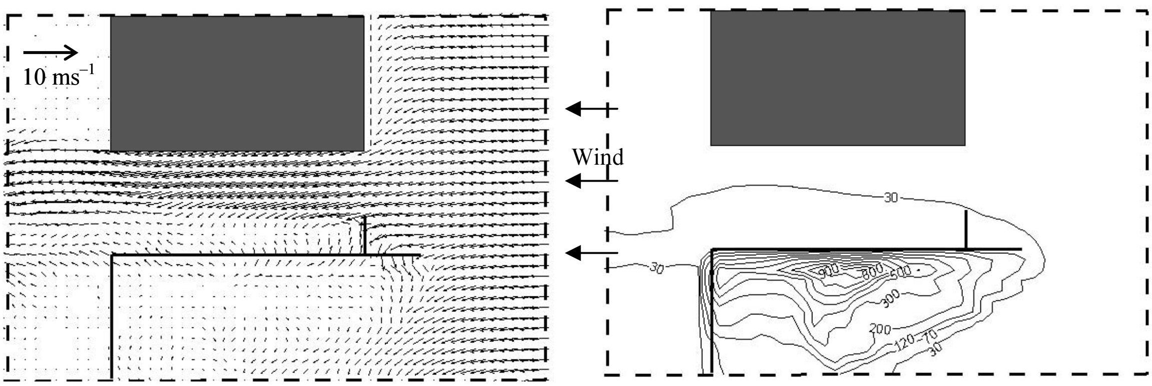


Fig. 14. W3: Back door closed with wind action under a big 25 MW fire

9. Conclusions

This paper sets out a summative rationale of the functions of refuge floors in supertall buildings. The paper broadly accepted the case for having a refuge door as a strategy for halving or even further reducing buildings' evacuation time (Chow 2004-2005), while also cautioning that such floors must be adequately protected from fire.

In investigating the safety of a refuge floor one storey away from a large fire in an example building, this work undertook a simulated hazard assessment using the computational fluid dynamics in the FDS package. The results predicted that hot air would not spread up to the refuge floor in the case of a 2 MW fire. In this example, moreover, the façade design of a building with balconies obviated the need for a drencher system. Even a strong wind up to 10 ms^{-1} would not carry smoke to the refuge floor should the fire even exceed 25 MW in strength. If there are clear demonstrations on hot gases would not spread up to the refuge floor, it is unnecessary to put in the passive fire resisting construction to cover the opening nor active water curtain system to shelter the opening in case of fires.

The use of refuge floors as 'sky gardens' in some supertall residential buildings should be assessed (Niu *et al.* 2005) carefully. The CFD simulations above suggested that refuge floors are safe under a normal fire of 2 MW, and relatively safe from fires of 25 MW. However, in fires of the magnitude of those in the World Trade Center (National Institute of Standards and Technology 2005), occupants are reluctant to remain on the refuge floor. It would be desirable to carry out some full-scale burning tests (Chow 2008) to demonstrate whether protection is adequate for specific buildings, and potentially to convince occupants to gather on designated refuge floors.

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YPAČ AUKŠTŲ PASTATŲ SAUGOS AUKŠTŲ GAISRINĖS SAUGOS YPATUMAI ĮVERTINANT SKYSČIŲ DINAMIKOS MODELIAVIMĄ

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Santrauka

Daugelio Tolimųjų Rytų didžiųjų miestų aukštuminiuose pastatuose, taip pat ir Honkongo, reikalingi saugos aukštai, paisant praktiškumo ir atitikimo reikalavimus. Netgi jei daugelio šalių gaisrinės saugos normos aiškiai nereglamentuoja būtinybės įrengti saugos aukštų, konstrukciniu požiūriu tokie aukštai yra būtini gaisrinei saugai, užtikrinant pastato naudotojams evakuacijos galimybę ir avarinėms tarnyboms patekimą į pastatą. Straipsnyje aptariamos saugos aukštų įrengimo priežastys, taip pat įvertinamos susijusios tokios gaisrinės saugos priemonės, kaip atsparių ugniai konstrukcijų įrengimas arba angų apsauga vandens užuolaida. Nagrinėjamas aukštuminis pastatas su balkonais, kaip eksperimentinis saugos aukštų pavyzdys, įvertinant pavojų. Tai daroma naudojant skysčių dinamikos modeliavimą ir plačiai pripažintą 2 MW galios gaisrą. Straipsnyje daromos išvados, kad pastato fasado projektiniai sprendiniai daro įtaką, ar saugos aukštai ir susijusios tokios gaisrinės saugos priemonės, kaip vandens užuolaida, gali būti nenumatomi. Jei pastate numatoma saugoti daug degiųjų medžiagų viršijant 1135 MJm^{-2} gaisro apkrovą, didelio ploto langų išdužimas gali veikti visuminį užsidegimą. Aptariami ir 25 MW galios gaisro scenarijaus padariniai.

Reikšminiai žodžiai: saugos aukštas, ypač aukšti pastatai, evakuacija, gaisrinės saugos priemonės.

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