Title: **Fire Engineering the Tallest Building in the Historic City of Manchester, UK**

Authors: Dean McGrail, Associate Director, WSP Group
Simon Lay, Technical Director, WSP Group
Wan-ki Chow, Chair Professor, The Hong Kong Polytechnic University

Subjects: Building Case Study
Fire & Safety

Keywords: CFD
Evacuation
Fire Safety

Publication Date: 2004

Original Publication: CTBUH 2004 Seoul Conference

Paper Type:

1. Book chapter/Part chapter
2. Journal paper
3. **Conference proceeding**
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Fire Engineering the Tallest Building in the Historic City of Manchester, UK

Dean Kevin McGrail[1], Simon Francis Lay[2], W.K. Chow[3]

[1] Associate Director, WSP Fire Engineering, China
[2]Technical Director, WSP Fire Engineering, UK
[3] Chair Professor, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

Abstract

This paper addresses the fire engineered design of the means of escape provisions from the residential areas of the New Landmark Beetham Tower in the Historic City of Manchester. When completed the residential tower will be the tallest residential high rise building in the UK.

Fire engineering techniques, including Computational Fluid Dynamics (CFD) analysis, where used to design an active fire protection system for the protected corridors within the residential areas of the scheme.

This fire engineered design provides a level of life safety for the building occupants which far exceeds that required under the prescriptive legislation, whilst also increasing the lettable area of the scheme and allowing the architects to achieve their aesthetic design aspirations.

Keywords: High Rise, Fire Engineering, Means of Escape, Computational Fluid Dynamics (CFD)

1. Introduction

The Landmark Beetham Tower in the Historic City of Manchester will become the UK's tallest residential building and the tallest high rise development outside of London when completed in 2005 at 47 Storeys and over 160m in height.

The building consists of a multi level Podium block containing; conferencing facilities, bars, restaurants, reception, open atrium and back of house areas. Rising from the podium is a single high rise tower which includes hotel accommodation (up to level 22), a 'Sky Bar' (level 23), plant areas (level 24), residential accommodation (levels 25 to 46) with a single penthouse apartment at the top floor level (level 47).

Due to the unique nature of the building and the complex integration of uses a fire engineered solution was deemed the only viable way to achieve the required level of life safety whilst ensuring that the innovation and cost of such a unique scheme was not constrained by the standard, prescriptive guidance.

This paper deals specifically with the fire engineered solution developed for means of escape from the main tower, however, it should be noted that this was not the only area of the building design which was dealt with using fire engineering techniques.

2. Fire Engineering Approach

The prescriptive legislation which is relevant to the design of Beetham Tower is as follows, The Building Regulations, The Fire Precautions Act 1971, The Greater Manchester Act and Local Licensing Requirements. The Building Regulations in England and Wales recognize that fire engineering can provide an alternative approach to fire safety and that in certain circumstances "it may be the only practical way to achieve a satisfactory standard of fire safety in some large and complex buildings[1]". In addition, unlike certain countries, the use of fire engineering in England & Wales is used to demonstrate fire safety as opposed to demonstrating equivalence to the prescriptive codes. By demonstrating equivalence to the code you are always assuming that the code solution is correct, which is obviously not always the case[2]. Thus, legislation in England & Wales permits much greater flexibility and allows the much wider application of fire engineering.

3. Methods

Due to the complex nature of the building the fire engineered solution developed for the scheme was segregated into a number of areas, based upon the hazards and risks relevant to each. The hazards and risks relevant to each area where then extensively analysed prior to encompassing them into the overall strategy for the building. By developing the fire engineered solution in this manner permits the maximum flexibility whilst ensuring that the life safety of the building occupants together with all the fire safety issues, in all areas, are comprehensively dealt with.

Contact Author: Dean McGrail, General Manager, WSP Shanghai, Unit 1507, Shanghai Oriental Centre, 31 Wujiang Road (699 Nanjing Road West), Shanghai 200041, Peoples Republic of China
Tel: +86 21 5211 0228 Fax: +86 21 5211 0075
e-mail: Dean.McGrail@wspgroup.com.hk

3.1 Means of Escape Philosophy

The classification of the occupancy type is the cornerstone for the traditional fire safety design of a building in the UK. The UK standard guidance relates the type of occupancy directly to the fire safety provisions, which need to be incorporated into a building for the purposes of life safety. Fundamentally, the UK legislation is relating the hazards and risks likely to be present within a certain building type to the anticipated persons who will occupy it.

Whilst the building comprises a hotel at low level and apartments at high level, segregated via the "Sky Bar' it was considered most appropriate to address the building as a residential tower (with two residential occupancies) with an assembly type occupancy located beside the tower at lower levels. This approach is fundamental to the proposed evacuation strategy.

3.2 Evacuation Strategy

The evacuation strategy for the residential apartments follows the recognized approach used in most large residential schemes in the UK of only sounding an alarm in the apartment of fire origin. This strategy means that only the persons in the apartment of fire origin are evacuated initially, the remainder of the building occupants remain in their apartments, where they are considered safest, protected from fire and smoke by the incorporation of extensive compartmentation. Escape routes are 'protected corridors' (passive fire protection and ventilation) such that further occupants can evacuate, assisted by the fire service if necessary.

A different strategy is normally applied to hotel accommodation with either simultaneous evacuation of all persons being applied; else, as is the case with the Beetham Tower; individual floors will be evacuated under management control.

A phased evacuation strategy is adopted in the hotel primarily to reduce the impact of false alarms, a well recognized problem in hotel accommodation. Further to this strategy the means of escape arrangements for the tower are designed such that simultaneous evacuation is readily achievable. In addition the fire alarm strategy includes a facility to effect simultaneous evacuation of the hotel if necessary and automatically upon failure of management control.

The means of escape routes from the 'residential' tower are separated from the assembly podium. As a result of this, a fire in the podium would not be expected to result in the evacuation of the tower and vice versa.

The provision of sprinklers within the hotel and the use of compartmentation between the hotel and residential areas of the scheme ensure that occupants in the residential areas are not evacuated initially in the event of a fire in the hotel. Similarly, occupants in the hotel are not required to evacuate if a fire occurs in an apartment. As a result of this, the number of persons entering the evacuation routes from the residential apartments in the event of a fire is small and does not impact upon the evacuation of the hotel.

3.3 Means of Escape from the Tower

Each apartment will be provided with a self contained, mains powered fire alarm system. This is a standard recommendation in the UK. However, in addition to this, provision to alert the attending fire service of the origin of the fire alarm is also to be incorporated.

In high rise residential schemes in the UK, common corridors are protected with passive fire protection measures (fire & smoke resisting construction) and ventilation. Traditionally, in hotels, the corridors are protected (to a lower level than apartments) and no ventilation is provided to common corridors.

The fire engineered design for the scheme proposes that the common corridors in both the residential and hotel areas of the development be separated by compartment walls from the accommodation and be well ventilated. Due to the configuration of the building, the residential floors required a ducted system, as the common corridors have no direct access to external air, two ducts are utilized. Prior to settling for the final solution three ventilation strategies where considered as detailed below and illustrated in figure 1: -

- Natural ventilation where smoke would be expected to flow up one duct with the other providing make up air
- Mechanical system using one duct to provide 'natural' make up air whilst air is drawn out of the other using a fan
- Mechanical ventilation using one duct to provide a 'natural' relief path whilst air is forced into the other using a fan (also known as a flushing system)

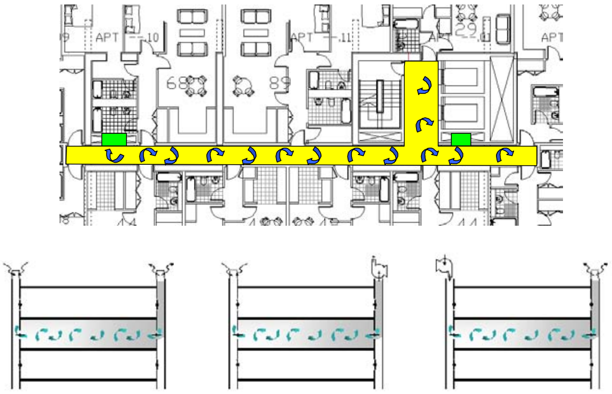

Fig. 1. Ventilation Options

It was considered that an all natural solution could not readily provide smoke control on the fire floor, although it could provide an effective smoke clearance provision. A system based on drawing air up through a duct with a fan, could be effective, but also has the potential to draw additional smoke into the protected corridor space if not correctly balanced. Therefore a flushing system was deemed the most viable solution, whereby air is supplied to the common corridors creating a positive pressure, with natural relief.

A flushing system has the added advantage that where the fire door to an apartment is closed, the effectiveness of the smoke sealing is significantly enhanced by the corridor being at positive pressure with respect to the apartments. Also, when persons are escaping from the apartment of fire origin and the apartment door is open, air is encouraged to flow through the apartment door opening, reducing the quantity of smoke, which enters the common corridor.

In the event of a fire in residential buildings in the UK, smoke spread to corridors is traditionally assumed to be limited (by closing of the fire doors behind escaping occupants). During fire fighting operations, untenable quantities of high temperature combustion products can enter the common corridor. This is a feature of the standard UK design solution for residential common corridors, with no requirement to dilute the smoke or attempt to address this issue.

The solution adopted for the Beetham Tower addresses these issues. The flushing system not only reduces smoke spread to the corridors, but also provides a dilution effect should any smoke spill into this area.

The system was designed initially based upon detailed fire engineering calculations, these calculations where used in the preliminary stages of the design to set the performance parameters. Following the preliminary calculations extensive computational fluid dynamics (CFD) modeling was applied to fully assess and verify the performance parameters and to enable optimisation of the preliminary design.

3.4 Computational Fluid Dynamics (CFD)

In the event of a fire in a residential apartment occupants should remain in the safety of their apartments, as discussed previously. However, the fire engineered design for the common corridors was based upon achieving the following design objectives: -

- Assist occupants if they want to escape
- Limit smoke ingress to apartments other than the apartment of fire origin
- Support fire fighting activities

It should be noted at this stage that a prescriptive design solution does not require that any design objectives are achieved, safety is just assumed because it is detailed within a code, this assumption can often be incorrect and may in some circumstances lead to an unsafe design.

Prior to the arrival of fire fighters, the door to the fire apartment should be closed, as the doors into the common corridor from apartments are provided with self closures, however, for the purpose of the analysis the door into the fire compartment was conservatively assumed to be open. The criteria set for effective operation of the system was that a minimum visibility of 10m be maintained within the corridors (this is commensurate with the more stringent recommendations of DD240[3] for large open spaces).

After fire fighters arrive, it was considered unreasonable to attempt to maintain visibility in the common corridor as fire fighting operations may result in a sustained flow of smoke into the common corridor. However, again conservatively, following fire fighting operations the system was designed to rapidly remove smoke, such that visibility levels within the corridor are returned to a minimum of 10m (criteria prior to fire fighting operations) within 60 seconds.

A period of 30 minutes was assumed from initiation of the fire until arrival of the fire fighters. Visibility was measured at head height and was to an illuminated sign (as will be installed).

The fire scenario considered for the model is set out below: -

- The fire in an apartment was based on the ATF standard room model as validated by NIST and ATF[4]. The dimensions of the room are c. 4m x 5m, which are similar to those within the development
- The fire was initiated by a small pilot heat source located on flammable soft furnishings and then assumed to spread throughout the room following the fire dynamics of the enclosure and room contents (see figures below)
- The accommodation on the project has large picture windows to outside for each apartment. These are assumed to be toughened glass and to fail when a temperature of 200^{o}C is reached. This is modelled by setting a heat detector next to the glass façade wall which removes the wall when a temperature of 200’C is seen by this detector.
- Prior to the breaking of windows to outside, the ventilation is restricted to the fire compartment, but once this window is broken, a significant increase in fire severity is anticipated (see figures below) and follows a familiar flashover process.
- Prior to the window failing, a small vent is located in the façade to simulate the nominal building leakage and apartment ventilation.
- The door between the fire room and the protected corridor within the apartment is assumed to be open throughout the fire. This not only allows for the possibility of occupants blocking doors open, but also allows for the possibility of having an apartment without a protected internal corridor.
- The door between the apartment and common corridor is assumed to not be fully closed and is set ajar by approximately 200mm. This is considered to be a particularly conservative assumption within the model.
- Fire fighting activities will be simulated by opening the apartment door fully, 30 minutes after the fire has started and then closing the door completely 5 minutes later. This will prevent

further smoke from entering the common corridor.

- The powered inlet air to the common corridor will be simulated by a mass flux source at the fire level.
- Natural vent shafts are to be modelled as shafts 60m tall. This represents a fire on the lowest residential level and the most difficult case for a mechanical smoke extract system to clear. Wind effects are taken to be neutral.

The modelling of fire growth within the fire compartment is computationally very intensive and requires a much finer computational grid than other aspects of the CFD modeling, as such a 0.1m x 0.1m x 0.1m grid was adopted for this initial computation to ensure accurate fire spread analysis. The smoke spread analysis to the remaining areas of the model was based upon a 0.125m – 0.5m grid.

In order to study a wide range of ventilation scenarios, it was necessary to reduce the implications of this computational intensity on the model. This was achieved by initially modelling the room fire in isolation of the corridor (as shown in Figure 2). This allowed a heat release curve to be established for the room fire. This fire curve was then used an input to the large model which includes the common corridor and ventilation system.

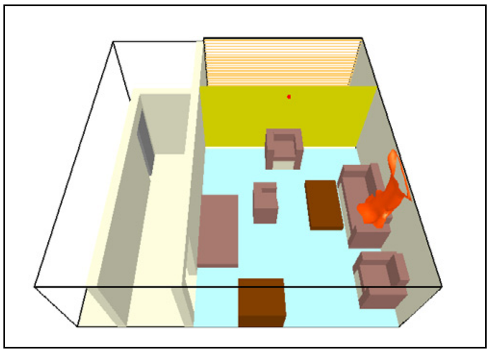

Fig.2. Fire Room Geometry

The fire curve which was established from the room fire is shown below in Figure 2a. This curve was then smoothed and sampled to provide the input data for the ventilation investigation cases. The data is entered into the model as a fraction of the maximum heat release rate. The input curve for the model, based on the data from the room fire is shown in Figure 2b.

It can be seen from Figure 2a that the fire scenario under consideration is an extreme scenario. The typical fire size considered to apply to hotel bedrooms and apartments is a heat release rate of no more than 2,500 kW. The fire in this case peaks at up to 14,000 kW. This very high heat release rate arises because of the high level of ventilation available in this fire once the window breaks. Failure of the window occurs at c. 380s. The failure of the window leads to an initial increase in fire size (ending the incipient fire scenario which was occurring up to that point), this then leads to a flashover in the apartment and a sudden, very rapid growth in the fire.

In addition to the high level of ventilation, the fire compartment is loaded with uncharacteristically flammable products. The soft furnishings are made of basic foam upholstery which has none of the flame retardant properties of modern furnishings. These modern materials are known to significantly enhance the level of fire safety in buildings and the anticipated fire scenario for apartments in this building is a fire much closer to the typically assumed value of 2,500 kW. However, the more severe fire curve predicted by the room fire model has been applied as this ensures a conservative basis to the design and adds extra confidence to the findings.

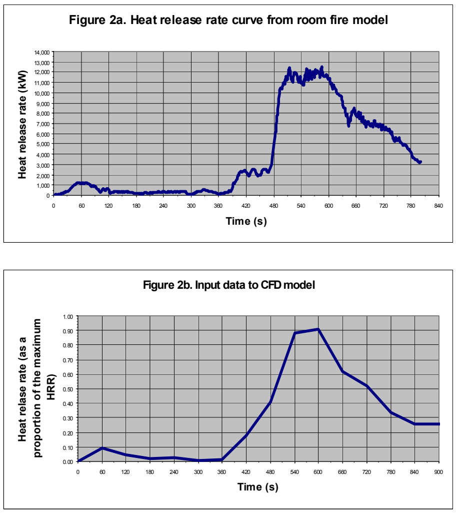

Fig.2a & 2b. Fire Curves

3.5 CFD Model

The CFD model used for the analysis was the NIST Fire Dynamics Simulator (FDS) version 3.1 and its visualization program Smokeview. The program can be downloaded free of charge from the NIST homepage (http://fire.nist.gov), a factor that results in the software being widely used and one which also ensures that the programme is undergoing continual development. FDS is a computational fluid dynamics model of fire driven flow. The program numerically solves a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flow with an emphasis on smoke and heat transport from fires. FDS, as well as the other CFD software, consists of three parts, the pre-processor, the calculation software and the postprocessor. As FDS was originally designed primarily as a tool to predict the transport of heat and smoke from a fire the code has undergone a considerable amount of validation work using data taken from real fire tests. Many of these works are presented at the NIST homepage. For a more thorough description of the program it is recommended to read the technical reference guide provided by NIST and Kevin McGrattan[4].

The model was a multi-block model set up to provide representative dimension for common areas (see Figure 3).

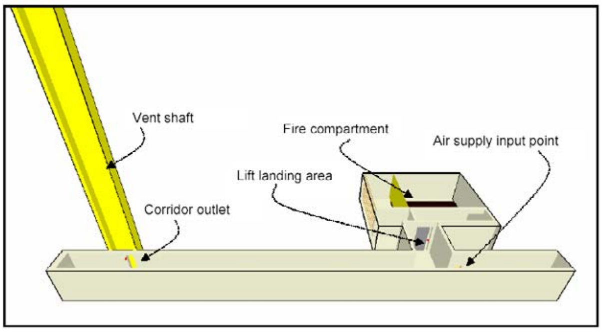

Fig.3. Model Geometry – Corridor Vent System

3.6 Ventilation Cases Considered

Six scenarios were considered to investigate different aspects of the proposed system. These cases are summarized below: -

Scenario 1	• Fire compartment located adjacent to the lift landing area. • Air supply rate to corridor 1.0 m3/s. • Air input and vent operated simultaneously upon activation of smoke detector in common corridor.
Scenario 2	• Fire compartment located adjacent to the lift landing area. • Air supply rate to corridor 1.0 m3/s. • Air input and vent operated independently, the vent being activated only when smoke reaches a detector close to the vent.
Scenario 3	• Fire compartment located adjacent to the lift landing area. • Air supply rate to corridor 1.5 m3/s. • Air input and vent operated simultaneously upon activation of smoke detector in common corridor.
Scenario 4	• Fire compartment located adjacent to the lift landing area. • Air supply rate to corridor 2.0 m3/s. • Air input and vent operated simultaneously upon activation of smoke detector in common corridor.
Scenario 5	• Fire compartment located at the end of the common corridor. • Air supply rate to corridor 2.0 m3/s. • Air input and vent operated simultaneously upon activation of smoke detector in common corridor.
Scenario 6	• Fire compartment located adjacent to the lift landing area. • Air supply rate to corridor 2.0 m3/s. • Air input and vent operated simultaneously upon activation of smoke detector in common corridor. • Fire fighting shaft included in model with leakage to fire fighting shaft assessed.

The scenarios considered a range of air supply rates through the ventilation system until a flow rate which satisfied the acceptance targets set out above was achieved.

It was also considered useful to compare two activation scenarios for the system. As the system creates a positive pressure, there was a possibility that activating the vent some time after the mechanical supply is activated could enhance this effect. Scenario 2 investigated this option.

There is a particular apartment (Type 1) within the scheme which has it's door within the lift landing area. This apartment location is considered to be the most challenging for the system. However, as a comparison, Scenario 5 was set up with a fire located at one end of the corridor.

Following consultation with Manchester Building Control and GM Fire Service, an additional scenario (Scenario 6) was added to the study. This scenario included the addition of a fire fighting shaft within the model. The door to the fire fighting shaft was propped open to form an opening approximately 200mm wide (to represent the obstruction of the door opening by a hose connected from the floor below).

In practice, the smoke control system on the corridors should maintain clear conditions in the corridor of the fire floor, allowing the fire service to connect to the dry riser on the fire floor and hence leave the door to the fire fighting shaft closed. However, as standard fire fighting practice would be based on approaching from the floor below the fire, this more onerous condition was investigated. In addition to the opening to the fire fighting stair, a vent at high level in the fire fighting shaft (the 1.0m2 vent at the head of the shaft) was incorporated, allowing air and smoke to flow into this shaft.

Scenario 6 was carried out with the fire in the steady state condition, following the initial fire growth period in the apartment. During the simulation, the door to the apartment was opened briefly and then closed to leave a gap approximately 200mm gap. This is understood to be commensurate with GM Fire Service practice of closing the apartment door behind them once fire fighting begins, but with the door being propped open by a hose.

With some opening provided between the fire fighting lobby and the fire fighting shaft, one would expect some limited smoke ingress into the fire fighting shaft. This would occur with a traditional natural ventilation solution as well as the proposed mechanical solution. However, it was considered necessary to check that the smoke could be quickly cleared from the shaft using the system and also to ensure that the additional leakage into the shaft did not result in the effectiveness of the system on the common corridors being adversely affected.

3.7 Results – Scenario 4

The first 4 scenarios where carried out to optimize the system design, both in terms of the required air flow rate into the corridors as well as the sequence of operation of the supply fans and natural smoke extract duct.

From the first 4 scenarios, scenario 4 with a flow rate into the corridor of $2m^3/s$ and simultaneous operation of the supply fan and natural smoke extract duct was found to be the most suitable system design configuration.

Upon operation of the smoke clearance system, conditions the corridor is almost clear of smoke within 120s.

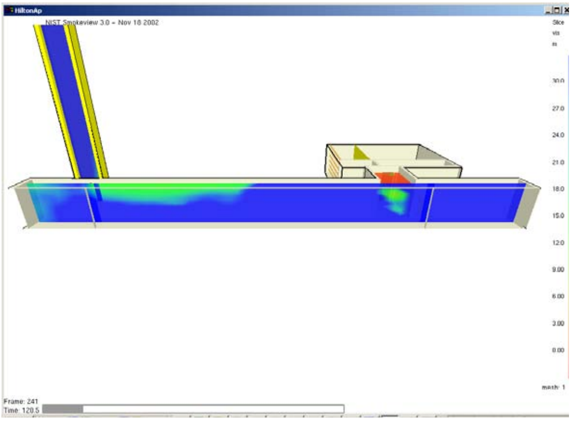

Fig. 4. 120 seconds after ignition

Some residual smoke is left in the lift lobby area. However, even this residual smoke is quickly cleared within 180s.

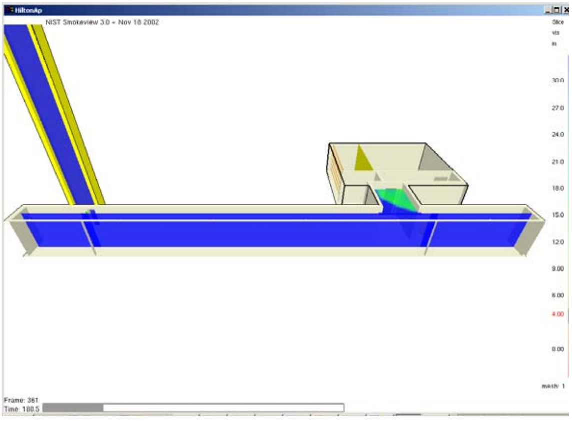

Fig 5. 180 seconds after ignition

With the increased flow rate for used in this scenario, the system was able to cope with the rapid growth in the fire size which occurred after 400s and also the post flashover fully developed fire with very small quantities of smoke entering the corridor. Throughout the pre-fire fighting period, the corridors remain clear and it is not until fire fighting begins, that conditions deteriorate on the corridor.

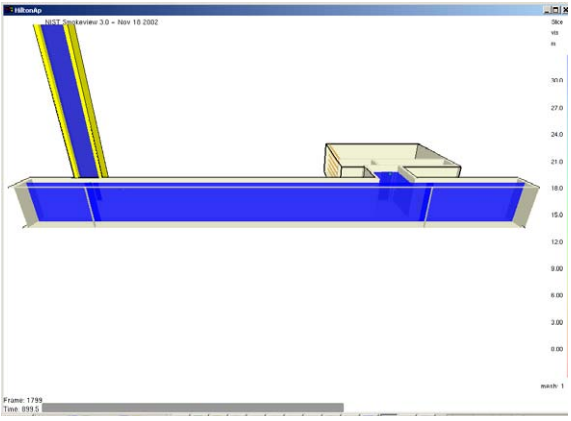

Fig. 6. 900 seconds after fire ignition

As expected, at the end of fire fighting operations the conditions on the corridor are untenable.

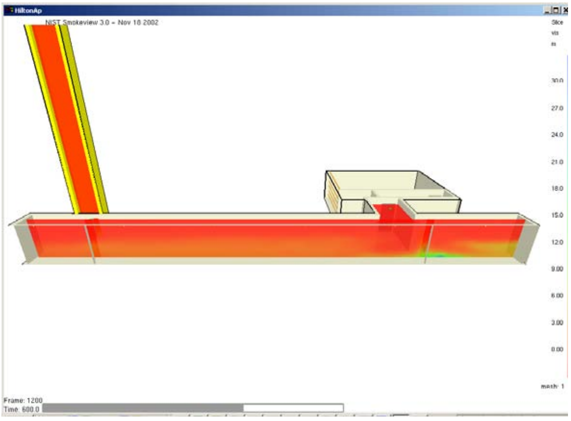

Fig. 7. 2100 seconds after fire ignition (end of fire fighting operations)

After fire fighting, operations are completed, the conditions on the common corridors begin to improve rapidly and within 60 seconds tenable conditions are achieved on most of the corridor. There is still a small quantity of smoke in the lift lobby area. However, this is cleared within 90s after fire fighting is completed.

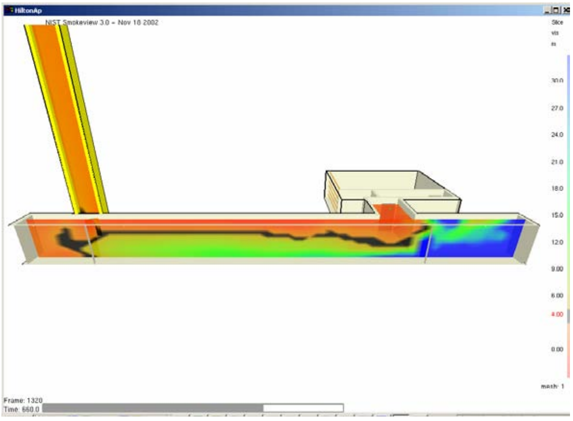

Fig. 8. 2160 seconds after fire ignition (end of fire fighting operations)

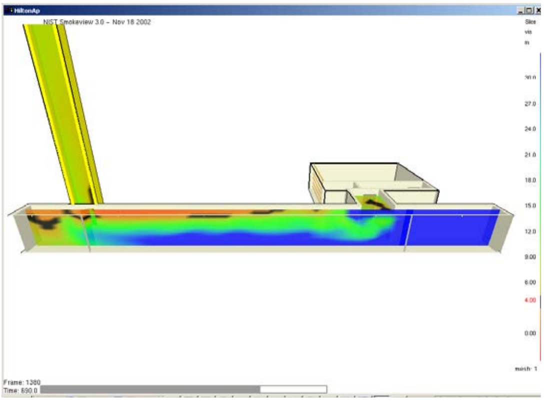

Fig. 9. 2190 seconds after fire ignition (end of fire fighting operations)

120s after fire fighting is completed, the corridor is essentially clear of smoke.

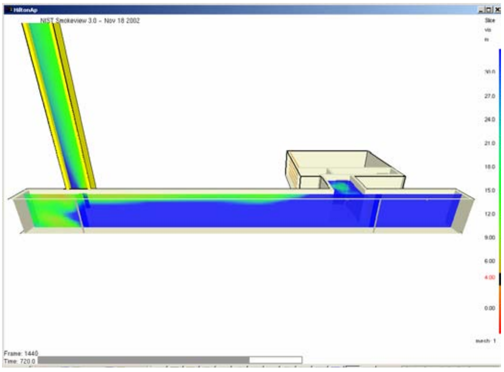

Fig. 10. 2220 seconds after fire ignition (end of fire fighting operations)

Results – Scenario 6

Scenario 6 represents a considerable deviation from the other scenarios as we are required to look at maintaining the fire fighting shaft free of smoke as well as the common corridor. The geometry of the CFD model for scenario 6 is illustrated in figure 11.

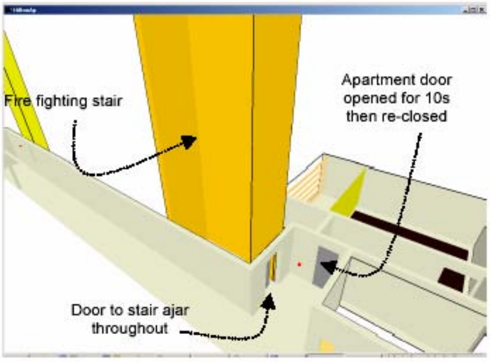

Fig 11. Model Geometry Scenario 6

Prior to fire fighters opening the door to the apartment the door to the apartment is ajar and the fire fighting stair door is ajar. However, as can be seen from Figure 12, the corridor conditions are the same as those found in Scenario 4 and the leakage to the shaft does not have a significant impact on conditions in the common corridor.

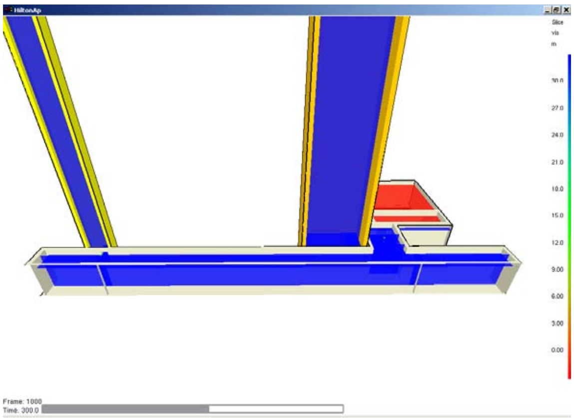

Fig 12. At the start of fire fighting

Figure 6 shows the impact of opening the door to the apartment (the figure is taken after the door is re-closed). Smoke enters the common corridor and some smoke enters the fire fighting shaft (this would not occur if fire fighting took place from the same floor as the fire and the door to the shaft was closed).

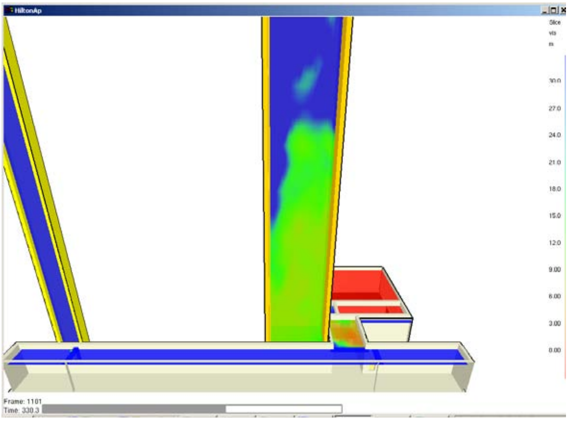

Fig 13. 20s after door to apartment re-closed

The smoke in the shaft is much more dilute than smoke in the corridor (Figure 14) and visibility in the shaft to a non-illuminated point is c. 10m or more (c. 3 storeys).

4. System Design Specification

The results of the CFD analysis resulted in the following design specification for the common corridor flushing system: -

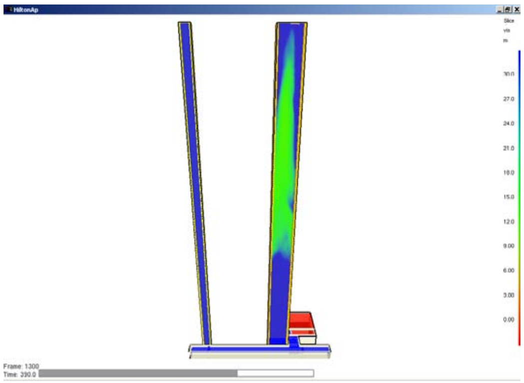

Fig 14. 90s after door to apartment re-closed

However, as can be seen in Figure 15, the smoke rapidly clears from the shaft (due to air flow through the shaft) and the shaft is clear again within c. 130 seconds.

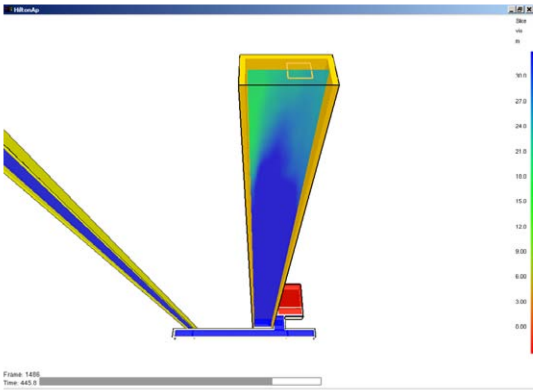

Fig 15. 130s after door to apartment re-closed

- An inlet shaft is provided serving all residential levels (except the penthouse level). The inlet shaft has a fire rated, motorised damper at each level (which is normally in the closed position).
- Smoke detectors on the common corridors (2 no. per level are proposed) that will (via a common fire alarm system) instruct the damper on the fire floor to open. The fire alarm system will also start up an air supply fan, attached to the inlet shaft at the Level 24 plant room level.
- A back-up fan is provided and a minimum 2 no. power supplies are taken to the fans and dampers
- The air supply fans provide a minimum of 2.0 m3/s at any given residential floor. The location of the inlet shaft is to be as indicated in Figure 1 (a design rate of at least 2.5 m^3/s is recommended as the target for the system).
- An exhaust shaft is provided serving all residential levels (except the penthouse level). The outlet shaft will be provided with a fire rated, motorised damper at each level.
- The location of the exhaust shaft is as indicated in Figure 1.
- The smoke detectors which activate the supply air system also instruct the damper to the exhaust shaft on the fire floor to open.
- The fire alarm system also opens a damper at roof level.
- All dampers are motorised and provided with a back-up power provision.
- The exhaust shaft (and inlets to the exhaust shaft) have a minimum clear area of 0.5m2 and are provided with cowl at roof level to prevent adverse wind effects on the shaft.
- The smoke clearance system is programmed to activate on the floor of fire origin. Later smoke spread to other areas does not automatically change the system operation.

Flushing System – Reliability

Like all fire safety systems (including fire doors and other mechanical devices) the reliability of the flushing system is paramount and requires regular testing (monthly). An additional reason for selecting the flushing system is that unlike traditionally accepted systems such as pressurization, the flushing system comprises a natural smoke vent shaft in addition to the mechanical system supplying air. This improves the system reliability as in the highly unlikely event that the fan where to fail natural ventilation can still be achieved in the corridor.

5. Conclusions

The provision of adequate ventilation to protect common corridors in high rise buildings is a matter of much debate. Traditional solutions such as the provision of vents directly to outside are susceptible to adverse wind effects whilst ducted solutions can be costly and have reliability concerns.

An alternative solution to the above has been presented and a range of scenarios analysed using the CFD software FDS. The heat release rate of a typical apartment room fire was estimated, based initially on the thermal data of the fire source. The calculated heat release rate curve from FDS was then re inputted into the CFD model to simulate smoke spreading into the larger model of the evacuation network.

The solution developed for this project achieves a high level of redundancy and reliability whilst at the same time occupying a smaller floor area than traditional solutions. Also, by demonstrating than an appropriate level of safety is being achieved for a long single direction travel distance, the system enables the number of cores in the building to be safely reduced from 2 no. to a single core. This has considerable cost and lettable area advantages to the client, which offset any additional system costs.

References

---

1 Approved Document B (2000 Edition) to the Building Regulation 1991

2 Wood, A. McGrail, D. and Chow W.K. (2003) Immediate action in providing fire safety in cities with dense high rise populations: The possibility of incorporating sky bridges. 2004 Mainland – Hong Kong Joint Symposium HKIE-BSD, ASHRAE, CIBSE. A77-A85

3 DD 240, Fire Safety Engineering in buildings, Part 1, Guide to Application of Fire Engineering Principles (DD240, currently undergoing conversion to BS 7974).

4 Fire Dynamics Simulator (Version 3.1) – User's Guide