HALF-DAY SEMINAR ON

VENTILATION AND SMOKE EXTRACTION LIFE SAFETY SYSTEMS FOR ATRIA INSTALLATION IN BUILDINGS

SATURDAY, 16TH NOVEMBER 2002

YORK HOTEL

Organised by
Institution of Engineers Singapore
&
ASHRAE Singapore Chapter

CONTENTS

1. Seminar Program
2. ASHRAE, Singapore Objectives
3. IES Mission Statement
4. Seminar Objective
5. Resume of Mr. Jibril Shahbal Tan from Fire Safety & Shelter Bureau (FSSB)
6. Article of presentation by Mr. Jibril Shahbal Tan, *"Common Problems Encountered During the Testing of Atria Ventilation and Smoke Control Systems"*
7. Resume of Mr. Paul Compton from COLT International Ltd, UK HQ
8. Article of presentation by Mr. Paul Compton, *"Ventilation of Atria cum Smoke Extraction Life Safety Systems"*
9. Resume of Mr. Paul Compton from COLT International Ltd, UK HQ
10. Article of presentation by Mr. Paul Compton, *"Performance Based Design of Smoke Control and Smoke Extraction; and Associated Life Safety Systems of Atria"*
11. Resume of Dr. Alex K.H. Lee, Associate Member Technical Staff, CFD Division, of the Institute of High Performance Computing (IHPC)
12. Article of presentation by Dr. Alex K.H. Lee, *"Role of Computational Fluid Dynamics (CFD) Modelling in Atria Designs"*
13. Extracts of Fire Code 2002
14. Organizing Committees

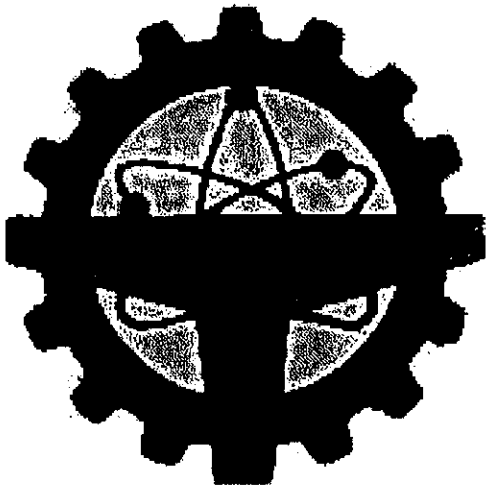
Programme

8.30a.m	**Registration** (Come early to peruse relevant products displayed at the various counters whilst sipping a cup of tea/coffee)
9.00a.m.	**Welcome Speech** (By Chairman, Organizing Committee, Er. Y P Chee)
9.05a.m.	**Opening of Seminar** (By President, ASHRAE Singapore Chapter, Dr. Jeremy Chia)
9.10a.m.	***1st Session*- Common Problems Encountered During the Testing of Atria Ventilation and Smoke Control Systems** (By LTA Jibril Shahbal Tan from Fire Safety & Shelter Bureau (FSSB) MC: by Er. Leong Cheng Wee)
9.45a.m.	***2nd Session* –Ventilation of Atria cum Smoke Extraction Life Safety Systems** (By Mr. Paul Compton from COLT International Ltd, UK HQ MC: by Er . Y P Chee)
10.45a.m.	Morning Break (Announcement: By VP, ASHRAE Singapore Chapter, Er. George Sze)
11.10a.m.	***3rd Session* – Performance Based Design of Smoke Control and Smoke Extraction; and Associated Life Safety Systems of Atria** (By Mr. Paul Compton from COLT International Ltd, UK HQ MC: by Mr Raymond Chang)
12.15p.m.	***4th Session* – Role of Computational Fluid Dynamics (CFD) Modelling in Atria Designs** and feast your eyes to an **ANIMATED MOVIE SHOW** on computer simulation of smoke behavioural patterns in Atria (By Dr. ALEX K.H. LEE, Associate Member Technical Staff, CFD Division, of the Institute of High Performance Computing (IHPC) MC: by Mr James Ong)
12.45p.m.	**Question and Answer Session** – to close by 1.15p.m. (MC: by Er . Y P Chee. Session-chair by Dr. Ng Eng Hong) (Memento presentation to speakers)
	Products display at the various counters will be on up to 1.45 p.m.



ASHRAE Singapore Chapter

To advance
the arts and sciences of heating, refrigeration,
air-conditioning and ventilation,
the applied arts and sciences and related factors
for the benefit
of the general public.



The Institution of Engineers, Singapore

Mission Statement

As the national society of engineers for the advancement of engineering in Singapore, our mission is to advance and to promote the science, art and the profession of engineering for the well-being of mankind.

Objectives

1. To enhance the character and status and to advance the interest of the profession of engineering and those engaged therein;
2. To promote honourable practice and mutual respect, and to decide all questions of engineering practice and etiquette affecting members of the Institution;
3. To provide quality service to its members and the nation; and
4. To provide opportunity for continuing professional development and promote fellowship among members.

ASHRAE

ASHRAE SINGAPORE CHAPTER

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. SINGAPORE CHAPTER
Mailing Address : Bukit Merah Central, P.O. Box 0626, Singapore 911535

Seminar Objective

This Seminar presents various aspects of Ventilation and Smoke Extraction Life Safety Systems for Atria in an interesting and condensed form. Within a half-day period, it intends to create an impact on participants to enhance their appreciation and awareness on this topic. In a nutshell, the objective of the seminar is to update participants with current practice and trend of Ventilation and Smoke Extraction Life Safety Systems for Atria. Experiences and know-how on common problems on testing of life safety systems for atria will be uniquely shared with the privileged participants. Expert in this field will critically examine current practices, and trends in developed countries, on ventilation, smoke extraction and smoke control systems for atria. Also included is an in-depth discussion on the impending performance base design for smoke control and extraction at the atria. Even the design flexibility and limitations of smoke control for atria would be expounded. With the advent of computer simulation, the screening of animated movies would certainly be an eye opener on the technology available for study of smoke behavioural patterns in atria. In addition, relevant products for atria application will be on display, outside the session proper.

Speakers Resume

LTA Jibril Shahbal Tan

LTA Jibril Shahbal Tan is a Senior Inspection Officer from the Singapore Civil Defence Force (SCDF), Fire Safety & Shelter Bureau (FSSB). He is currently a staff member in the Licensing & Enforcement Branch of FSSB, which oversees the fire safety testing & inspection of a number of atria in Singapore. Through the years the Branch has gathered much valuable feedback from Registered Inspectors (RI) on their practical experiences, when conducting fire safety testing of atria.

Prior to his current position, LTA Jibril was Rota Commander of an operational HAZMAT emergency response crew on the Jurong Island petrochemical hub. Trained as a Civil Structural engineer from Nanyang Technological University, Lta Jibril has been a member of the life saving force since 1999.

COMMON PROBLEMS ENCOUNTERED DURING THE TESTING OF ATRIA VENTILATION & SMOKE CONTROL SYSYEM

BY JIBRIL SHAHBAL TAN
Fire Safety Shelter Bureau (FSSB)

SCOPE

SCOPE

- **Introduction**
- **Design & Commissioning**
- **Testing Procedures**
- **Common Problems**
- **Conclusion**

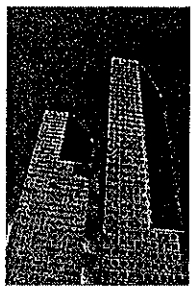
Introduction

- **Registered Inspectors (RI) inspect & test New buildings as part of the TFP / FSC process**



Introduction

- **In addition, FSSB also conducts inspections on a random basis of these new buildings**



Introduction



- **RI are the key players in this process & their vast experiences and feedbacks will be highlighted in this presentation**

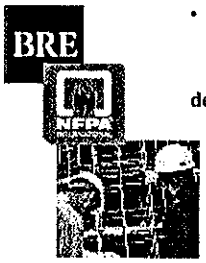
Introduction

- **Existing buildings are required to renew Fire Certificate on a yearly basis**



- **This ensures fire safety systems are maintained and kept operational**

Design & Commissioning



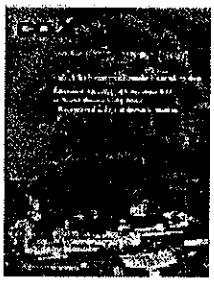
- FSSB accepts atrium smoke control systems which are designed to BR 258 , NFPA 92 or any other internationally acceptable standards

Design & Commissioning

- Professional Engineer shall commission the atrium's smoke control system before RI inspection is arranged



Design & Commissioning



- Availability of the Smoke Control Test Report is essential for the inspection by both the RI and FSSB

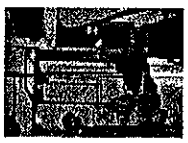
Testing Procedures



- Hot smoke preferred but not a must
- Smoke grenades or fogging machines

Testing Procedures

- Another testing procedure involves the direct activation of a smoke detector in a smoke zone using aerosol spray





Testing Procedures

- New buildings Vs Existing Buildings



- Site constraints due to building operations or reservations of owners



Testing Procedures



- Smoke creation for the various scenarios as detailed in the smoke test report

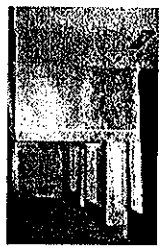


- To see actual channelling & extraction of smoke through the atrium space

Some Common Problems

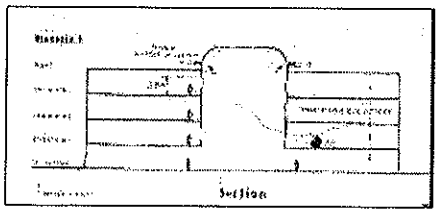
Curtain activated in the wrong sequence

- During Testing of smoke zones
- Either drop when not needed or do not drop when needed



Some Common Problems

Curtain activated in the wrong sequence



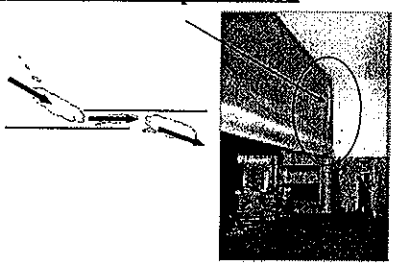
Analysis of Common Problems

Curtain activated in the wrong sequence

- Commissioning tests conducted not thoroughly carried out
- Smoke control system programming altered accidentally, usual in FC buildings after a number of years

Some Common Problems

Gaps created between dropped curtains which allows for smoke penetration



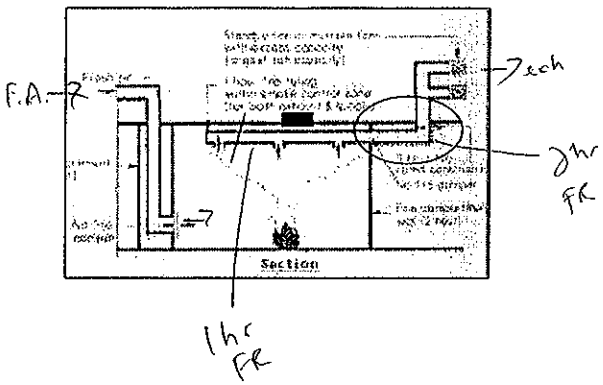
Analysis of Common Problems

Smoke penetrating gaps created between dropped curtains

- Quality of workmanship during construction & installation for new premises
- A & A works done subsequently affect alignment of curtain
- Fixtures and furniture known to hinder curtain operation

Some Common Problems

Duct works re-routed / non fire-rated outside zone



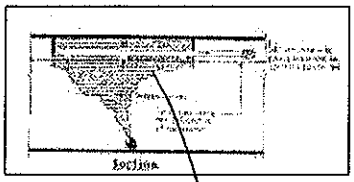
Analysis of Common Problems

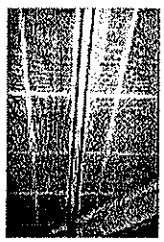
Duct works re-routed / non fire rated outside zone

- **Frequent change in tenants**
- **Alterations to ductwork based on wishes of tenant**
- **Overall effectiveness of smoke control system affected**
- **Worse case, resulting in failure of smoke control system**

Some Common Problems

False ceiling not satisfying the 25% minimum perforation requirement





mid >25% perforation

Analysis of Common Problems

False ceiling not satisfying the 25% minimum perforation requirement

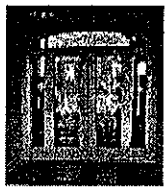
- **False ceiling with minimum 25% perforation requirement changed to a type that affects the smoke reservoir (eg, Non-perforated)**

Else, smoke depth will be lower.

Some Common Problems

Alteration of door types affecting natural fresh air intake





e.g. auto sliding door change to manual
∴ Not F.A

Analysis of Common Problems

Alteration of door types affecting natural fresh air intake

- **Fresh air intake is affected when doors are changed to a type which fail to be open during the fire mode**
- **Reduced door width affect fresh air intake quantities**

Some Common Problems

Failure of automatic sliding doors to remain in the open position when fire alarm is activated



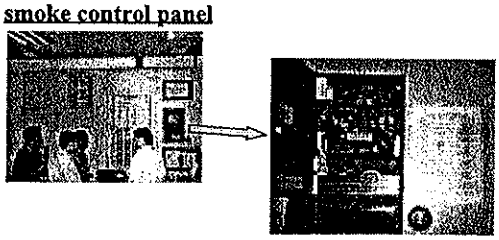
Analysis of Common Problems

Failure of automatic sliding doors to remain in the open position when fire alarm is activated

- Similar to the case of changing the original doors, the automatic sliding doors have to be properly programmed & serviced so as not to affect the fresh air intake

Some Common Problems

Inadequate / incorrect labelling of smoke control panel



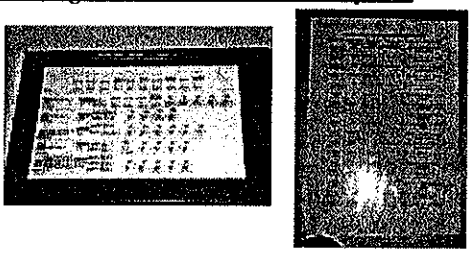
Analysis of Common Problems

Inadequate / incorrect labelling of smoke control panel

- Indicators on control panel does not reflect the actual operations accurately
- Inadequate labelling coupled with the above will pose problems to those monitoring the system

Some Common Problems

Schematic diagram not provided at control panel to give overview of the whole system



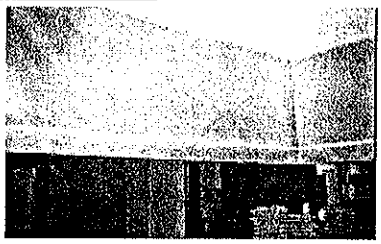
Analysis of Common Problems

Schematic diagram not provided at control panel to give overview of the whole system

- A good practice so as to allow operators to easily orientate themselves to actual layout
- Easy to appreciate the sequence of smoke control operations

Some Common Problems

Smoke curtain drop upon power failure without fire alarm activation



Analysis of Common Problems

Smoke curtain drop upon power failure without fire alarm activation

- **No need for the above to take place immediately upon power failure**
- **Battery pack should be provided to hold curtains in place for at least 1/2 hour**

Conclusion

- **Generally, level of compliance with requirements during atria testing is satisfactory**
- **Common faults identified are easily rectified once made known to the PE**

Thank You

COMMON PROBLEMS ENCOUNTERED DURING THE TESTING OF ATRIA VENTILATION AND SMOKE CONTROL SYSTEMS

Jibril Shahbal Tan

Senior Inspection Officer
Singapore Civil Defence Force (SCDF),
Fire Safety & Shelter Bureau (FSSB)

INTRODUCTION

1. The Fire Safety & Shelter Bureau (FSSB) randomly inspects new buildings having atrium spaces prior to the issuance of the Temporary Fire Permit (TFP) / Fire Safety Certificate (FSC). The TFP / FSC is a pre-requisite before the premises is allowed to be occupied. All such buildings are firstly inspected and tested by Registered Inspectors (RI) and only after they have been found to comply with the requirements, is the TFP / FSC application made to FSSB. Besides new buildings, FSSB also conducts inspection and testing of existing commercial buildings (including those having atrium spaces) for the renewal of the building's Fire Certificate (FC). The purpose of the FC renewal is to ensure that the fire safety systems of such buildings are maintained and kept operational. Most of the buildings having atrium spaces are commercial in nature.

2. In addition to its own inspections, FSSB has gathered feedback mostly from RIs about their experiences in the testing of building atria and would like to highlight in this paper, the common problems encountered during the testing of atria ventilation and smoke control systems.

DISCUSSION

Design & Commissioning

3. For the purpose of this paper, design and commissioning of the atrium's smoke control system would not be discussed. This aspect is handled by the professional engineer (PE) in charge of this system and who is responsible to commission the system which should function in accordance to the smoke control test report prepared for the system. Only when the system has been successfully commissioned should the inspection by the RI be called for. However, in practice it is quite common for the RIs to be called to witness the commissioning tests of the system. We understand that this is done because of the inconvenience of conducting a smoke test on separate occasions.

4. Though it is alright in calling the RIs to witness the commissioning tests, the PE should still be responsible to gauge the effectiveness of the designed system and not expect the RI to make comments at this juncture. The role of the RI is to act as

an independent party to test the system on a separate occasion as part of the overall inspection of the project and this will include integrated system tests.

5. The atrium smoke control system may be designed to NFPA standards or to some other standards acceptable / recognised by FSSB but whatever the case may be, the smoke control test report is essential and must be made available to the RIs (and FSSB) to enable them to assess the performance of the system.

Testing Procedures

6. Testing atria of new buildings before they are allowed to be occupied is usually less problematic than testing atria of existing buildings. The reasons are obvious and there is no need for further elaboration. Even for new buildings, FSSB has encountered problems with owners who are afraid that the smoke test will damage or stain the interior finishes. The tests that FSSB does are in addition to those done by the PE and RI.

7. The smoke control system of the atrium is tested by the creation of smoke for the various scenarios as given in the smoke test report. The creation of smoke which is representative of an actual fire, is something difficult to achieve. For testing purposes, the use of smoke grenades or fogging machines by the PE are acceptable to FSSB although it would prefer hot smoke to be generated. Generating sufficiently large quantities of smoke for the worst-case scenario also tends to be a problem during testing. Another testing procedure is the direct activation of a smoke detector by use of a spray canister to trigger a particular smoke zone.

Some Common Problems

8. The most common problem encountered during testing of the atrium smoke control system is the failure of the smoke curtains to drop according to what they were designed to. The following are the examples:

    a. Some or the appropriate smoke curtains fail to drop in accordance to the proper sequence upon fire alarm activation.
    b. Smoke curtains do not fall into alignment and gaps are created between them.

9. The example mentioned in 8a usually occurs when a particular smoke zone is tested. The smoke curtains that are required to drop at other smoke zones, do not drop as required. Sometimes the reverse occurs when smoke curtains at some other zones that are not required to drop, drop into place. One reason could be that a comprehensive commissioning where all fire scenarios were supposed to be tested, were not tested. This problem is more pronounced in existing buildings and the reason could be because of unintentional changes that are made to the smoke control system's programme over time.

10. The other problem mentioned in 8b occurs when some of the curtains do not drop fully while in some other cases the dropped curtains are not in alignment, leaving gaps for smoke penetration. This could be due to the quality of workmanship during construction and installation. This problem is more prevalent in existing buildings where over time, because of poor maintenance and the creation of obstructions resulting from addition & alteration works, the smoke curtains have been affected. In some of the commercial buildings, fixtures and furniture hinder the drop of the smoke curtains.

11. Another common problem is the removal or re-routing of smoke control ductworks in existing buildings. This problem occurs because of the frequent change in tenants in commercial buildings and the tenants' PEs do not have a full understanding or appreciation of the smoke control system that is present in the premises. As a result of the works carried out according to the wishes of the tenant, the smoke control ductworks are affected. In some cases such works are even carried out by the tenants without the supervision of a PE.

12. In relation to tenancy works in existing buildings, another problem is the changes made to the false ceiling over time where the minimum 25% perforation requirement is no more satisfied. Again this is the result of the architects and contractors undertaking the works who not have an appreciation of the building's smoke control system and do not understand the smoke control requirements. False ceilings are changed to suit the taste of the tenants and some ceilings become fully closed.

13. Another problem noticed in commercial buildings is that the natural fresh air intake is affected because of changes to the doors. For example, an automatic sliding door which is linked to the fire alarm system and which is designed to be kept open during fire mode to allow for fresh air intake, is changed to some other type of swing door which does not automatically open during fire mode. In some other instances, the door width has been reduced. All these affect the fresh air intake. Again, this is an example of changes that are made without an appreciation of the building's smoke control system.

14. Some buildings are initially designed for office use and the smoke control system is designed for a certain fire size. Over time, the building slowly undergoes a change and becomes a mostly commercial premise. The fire size to be used for the smoke control system has now to be bigger and in some instances this aspect is overlooked resulting in the exhaust fans becoming undersized in design.

15. During testing of new buildings it has been found that the indicators on smoke control panels are labelled incorrectly and/or there is inadequate labelling / information. For example exhaust fans on the panel are labelled wrongly though the smoke control system is functioning correctly. Another issue is the absence of schematic diagrams at the smoke control panel to provide an overview of the operation of the designed smoke control system. Even though, this not a requirement, it is good practice so that one can easily orientate themselves to the layout of the atrium & its surroundings and understand the sequence of smoke control operations for the different fire scenarios.

16. Another issue is that ducts for smoke control systems are to be of the fire-rated type. In some instances, non fire-rated ducts were found to be installed above the fire-rated ducts of the smoke control system and this is not to be the case.

17. Some other cases encountered are:

    a. The failure of the automatic sliding door to remain in the open position after fire alarm activation. This will affect the fresh air intake.
    b. Smoke curtains drop upon power failure but without fire alarm activation. There is no necessity for the smoke control system to be activated under power failure.

CONCLUSION

18. Generally, there has been satisfactory compliance with the requirements during the atria smoke control tests conducted by FSSB. The common problem with the drop of the smoke curtains in the proper sequence, is easily rectified after the faults have been detected.

Speakers Resume

Paul David Compton

Paul David Compton is an experienced Consultant of International Fire Technology Limited, (a subsidiary of Colt International), and the Fire and Smoke Control Executive of Colt International Limited. He joined Colt in 1982. Born in 1951, he is armed with a Bachelor of Science (BSc) in Mechanical Engineering, Southampton; and a Master of Business Administration (MBA) from Portsmouth. He is an active member serving in several fire safety technical committees, including BSI FSH/25 Smoke and heat control systems; BSI FSH/18 Fixed fire fighting equipment; CEN/TC191/SC1 Smoke and heat control systems, and various working groups of the National Fire Protection Association (NFPA) Smoke management committee. On publications, he was Volume chairman of the Chartered Institute of Building Services Engineers (CIBSE) Guides C and B1; and a Co-author (with H Morgan) for a recent technical paper on plug-holing in time dependent fire design.

He had delivered several papers in the UK, which are recognized structured activities from the Curriculum Professional Development Programme. His sharing of his in-depth knowledge of his specialized topic and his vast experiences with fire safety systems for atria, is a seminar not to be missed.

VENTILATION OF ATRIA
LIFE SAFETY SMOKE EXTRACT SYSTEMS

Mr. Paul David Compton

Consultant, International Fire Technology Ltd
Fire and Smoke Control Executive, Colt International Ltd

Building safety codes or regulations are a fact of life. Every country has them and, unfortunately, every country needs them to ensure that commercial pressures do not override safety considerations. Building codes vary tremendously, needing to match local culture, environmental conditions and building types and methods. They also vary in their intent. In the UK the primary objective of building regulations is life safety of occupants of the building and prevention of fire spread to neighbouring buildings. In other cultures building codes may also consider protection of the building, its contents and the environment.

Building codes have been around for a long time. After the great fire of London in 1606, a law was passed prohibiting building in timber in London. As well as providing an interesting early example of building safety legislation it also illustrates two regular features of such legislation: it was developed quickly as a response to a tragedy and it was prescriptive.

The entire history of development of building codes and regulations is largely based on responses to tragedy. This is almost inevitable, after all designers are constantly pushing the boundaries of the possible and conceiving buildings that earlier regulators could never have dreamt of. A feature of new designs is that they create new challenges and often do not accommodate prescriptive design requirements very well. In some cases the designers will incorporate the prescriptive design features, but it can be questionable whether they provide the protection originally envisaged, and in others an alternative may be offered, with the intention of providing a similar level of protection, however that may be defined. Whether the protection works is not known until there is a serious fire, at which point the regulations are likely to change if the fire leads to tragedy.

Comparison of innovative solutions with prescriptive requirements is often difficult due to the lack of supporting design documentation for prescriptive requirements. For instance, how do you design a mechanical extract to match a prescribed natural ventilation requirement that is based on area of ventilation and gives no indication of the expected performance.

Of course we can argue today that with our sophisticated design tools we can consider all the scenarios and be confident that our designs will work, in a way that was impossible in the past. To some extent this is true, but of course if our aim is merely to match the protection provided by existing prescriptive requirements we may be missing the point entirely in an innovative building. We are also limited by our imagination; the designers of the World Trade Centre towers in New York considered

the effect of aircraft impact, but not of the size, speed and fuel load of the aircraft that hit them.

This sounds as if prescriptive building codes are a poor means of ensuring a reasonable level of safety. Of course this is not true. For the majority of buildings in the majority of cases, prescriptive codes provide a sensible solution. Prescriptive codes have 3 main advantages:

Ease of use. A prescriptive code provides a set of easily understood and applied rules. This means that any competent person should be able to follow the rules and provide a suitably safe building. It also means that standard products can be developed and certified as complying with the code requirements.

Ease of enforcement. A prescriptive code makes checking and enforcement relatively simple. Proof of compliance can be demonstrated by product certificates, site inspections, etc. Enforcement officers generally do not need advanced design and analytical skills.

Body of experience. Prescriptive codes are built upon years of accumulated experience and wisdom. They generally include features that are known to work and often include significant safety margins.

In the UK we have two different regimes. In Scotland the Building Regulations, which are couched in terms of general objectives only, are backed by a series of mandatory Technical Standards that contain the prescriptive requirements. Deviations are only permitted by means of an official relaxation. In England and Wales the regulations are again couched in terms of general objectives, but the Approved Documents that contain the prescriptive requirements are advisory only. Any methods providing equivalent protection are allowed with the agreement of Building Control. Thus performance based design is commonly used when designers wish to avoid the constrictions of the Approved Documents.

Atria are a good example of an innovative building type which challenged then current prescriptive codes. The term atrium is taken from the Latin for the open courtyard in Roman villas. However, the modern atrium has been developed over only the last 30 years or so. The modern atrium immediately broke the usual prescriptive requirement for fire compartmentation between floors by providing a large multi-storey void through the heart of a building. New prescriptive requirements were needed to deal with this.

In the UK the prescriptive requirements specifically relating to atria are not provided in the Building Regulations or the Approved Documents supporting them, but in British Standard BS5588-7, which is specifically referenced in Approved Document B.

Since buildings and their atria are so diverse, BS5588-7 categorises atria by means of building usage, type of atrium, height of atrium and evacuation method. This results

in 23 different categories, each with its own specific set of fire protection requirements. To simplify choice of category, a series of flow charts are used, each leading to the correct categorisation, which are then represented diagrammatically to identify the fire protection required. Samples of these are shown below.

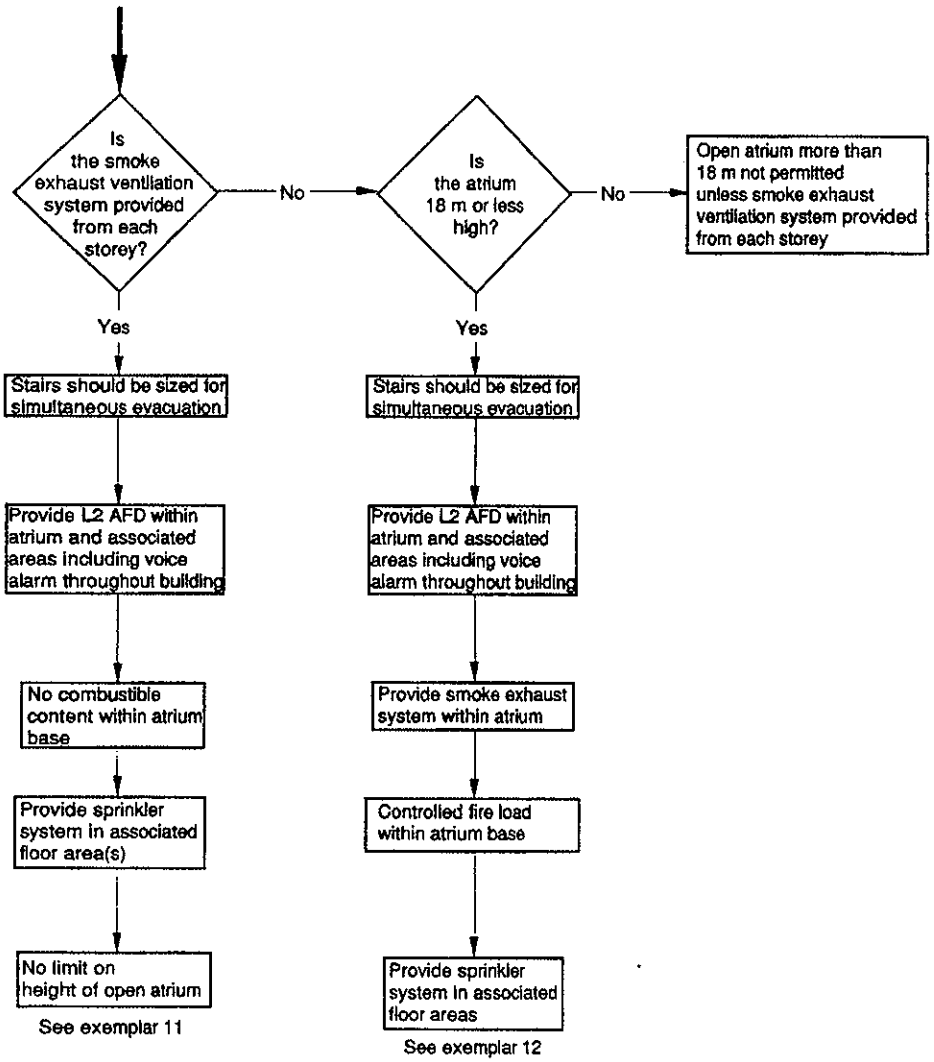
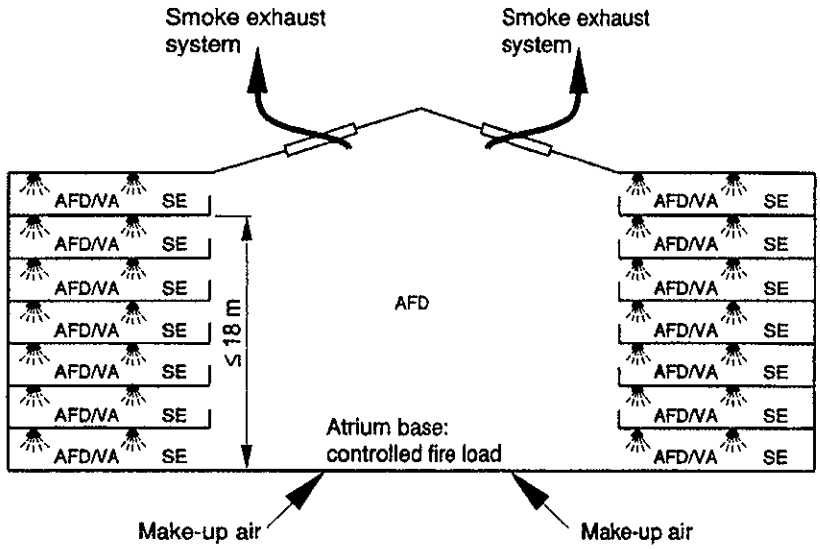


Figure 4a. Occupancy category B: occupants who are awake but may be unfamiliar with the building — atrium open



AFD/VA denotes L2 automatic fire detection within the atrium and associated floor areas and voice alarm throughout the building
AFD denotes automatic fire detection connected to building alarm system
SE denotes simultaneous evacuation
denotes automatic sprinkler protection

NOTE. Not applicable for atria uniting two storeys only (see 1e)).

Exemplar 12. Occupancy category B (occupants who are awake but may be unfamiliar with the building): 18 m or less in height, open, simultaneous evacuation

An anomaly in the Building Regulations means that the requirements of BS5588-7 do not apply until the atrium is more than 30m high.

The categorisations in BS5588-7 mean that when smoke ventilation is required it is relatively simple to design a smoke ventilation scheme for an atrium since the other fire protection devices are preset. Design is carried out using the guidance in BR368, 'Design methodologies for smoke and heat exhaust ventilation'. This is the replacement for BR258, the design guide specifically referenced in the BS.

In some cases the standard simply requires smoke clearance rather than smoke ventilation. The difference is simple in concept: smoke ventilation is designed to be active during the course of the fire to keep escape routes clear of smoke and smoke clearance is designed to assist the fire brigade and to allow smoke to be quickly cleared from the building. The two systems may of course be similar and can be used interchangeably in some cases, as long as suitable controls are provided.

The requirements for smoke clearance are simple and prescriptive, 10% floor area natural ventilation for atria up to 18m in height or 4 (sprinklered) or 6 (unsprinklered) air changes per hour of mechanical ventilation.

It is worth noting that a designed smoke ventilation system for the same atrium will often have a lower requirement than a smoke clearance system. So why use smoke clearance? There are two main reasons. Firstly there is no design involved so anyone can specify the system very easily. Secondly the requirements for the ventilators and controls are less well defined. Whether by intent or lack of precision, the wording of

the standard can be read to require ventilators complying with BS7346 for smoke ventilation systems but not for smoke clearance systems. Therefore less expensive automatic windows or fans are sometimes specified for smoke clearance systems.

If we look at the issue of ventilator specification a little more carefully we can see arguments for both views. BS7346 is written for smoke ventilators that are operated early in the course of a fire and are then expected to exhaust smoke at the peak temperatures developed in the smoke layer during the course of the fire. It does not address the issue of ventilators that may sit unused for some time at the start of the fire and then be expected to operate later, perhaps when the smoke has cooled, so compliance cannot be used to prove suitability for smoke clearance. Nevertheless, a compliant ventilator has shown some resistance to heat and it is reasonable to expect better reliability in a fire. In the absence of a specific standard for smoke clearance ventilators it makes sense to specify BS7346 ventilators.

Before moving on to discuss the design of smoke ventilation systems it is worth considering requirements elsewhere.

In Singapore, your fire code is largely prescriptive and in the case of smoke ventilation is based on UK requirements and recommendations. In addition your prescription includes a requirement for a full sprinkler system, a limitation on atrium cross section and a limitation on content (low or ordinary hazard). Smoke ventilation is required, engineered in accordance with BR186, BR258 or other acceptable standards.

In America there are a number of Building Codes, but where atria are concerned the design standard most often used is NFPA 92B 'Guide for smoke management systems in malls, atria and large areas. This is currently being rewritten to change the format from a 'guide' to a mandatable standard to allow Building Codes to reference it directly as a mandated design standard. This follows the precedent of the latest version of NFPA 204, published earlier this year.

It is interesting to note that all these codes refer to external documents for engineered smoke ventilation systems. Some countries go even further in prescription. France and Germany, for example, provide tables of ventilation area or smoke extract rate, related to building usage and height. This of course makes enforcement extremely simple. The regulators desire to keep this simple system has been one of the major problems preventing introduction of a European Standard for engineered smoke ventilation systems.

Design of engineered smoke ventilation systems generally follows either BRE or NFPA guidance, or some variation on these.

The calculation methods in these two sets of guidance, while totally different, are both empirically based on the same test data sets and therefore should provide similar final results. It is however important to stick to one set for calculation as the results at the intermediate calculation stages can differ. A mix and match solution selecting the method providing the lowest answer at each stage can result in a significantly under designed system.

Even before we start to look at the calculations there is a major difference in philosophy. The BRE method is predominantly based on a 'steady state' design fire. The NFPA method uses a 'growing' fire. This is a historical difference, with research and development taking different paths in the UK and USA.

In the UK, statistical data was taken and used to estimate the likely maximum size that a fire in a given occupancy would grow to in the majority (80 to 90%) of cases. This size was then taken as the 'steady state' design fire size. Calculations are carried out to ensure that sufficient ventilation is provided for a fire of this size. It is not assumed that the fire instantaneously reaches this size, but that the designed ventilation system will be adequate for all stages of the fire until the design fire size is reached. This design method is suitable for manual calculation and generally provides conservative results.

In the USA it was felt that suitable statistical data was not available, so efforts centred on modelling the growth and decay of a fire, resulting in the familiar t^2 model of fire growth. Calculations are carried out iteratively over time, with the results of the previous time period used as the basic data for the next. For accuracy, the iterations need to be in short time steps, so this method is tedious for manual calculation and needs use of a computer. This design method is inherently less conservative than steady state design, placing a much greater requirement on reliability of input data (fire growth rate). However, since the relationship of the height of the smoke layer with time is known, a safety factor is generally introduced by allowing a suitable delay between the design escape time and the design tenability time for the atrium.

There is a further difference in that the NFPA code concentrates on conventional through flow design with the aim of controlling the depth of the smoke layer to maintain a clear layer underneath to allow safe escape, although other objectives are briefly discussed. This design method is also the main method proposed by BRE, but other options are also considered, using depressurisation or hybrid techniques. These techniques allow greater design flexibility for the atrium itself, assuming that Building Codes allow such flexibility, but in return demand much greater precision in both smoke ventilation design and building design and construction.

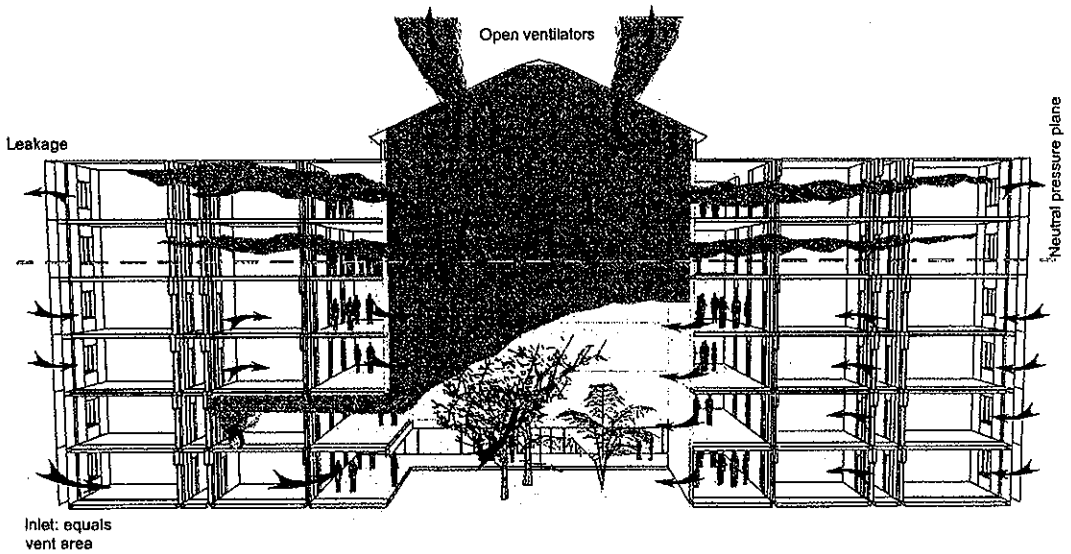


Figure 43 Neutral pressure plane (NPP): throughflow ventilation

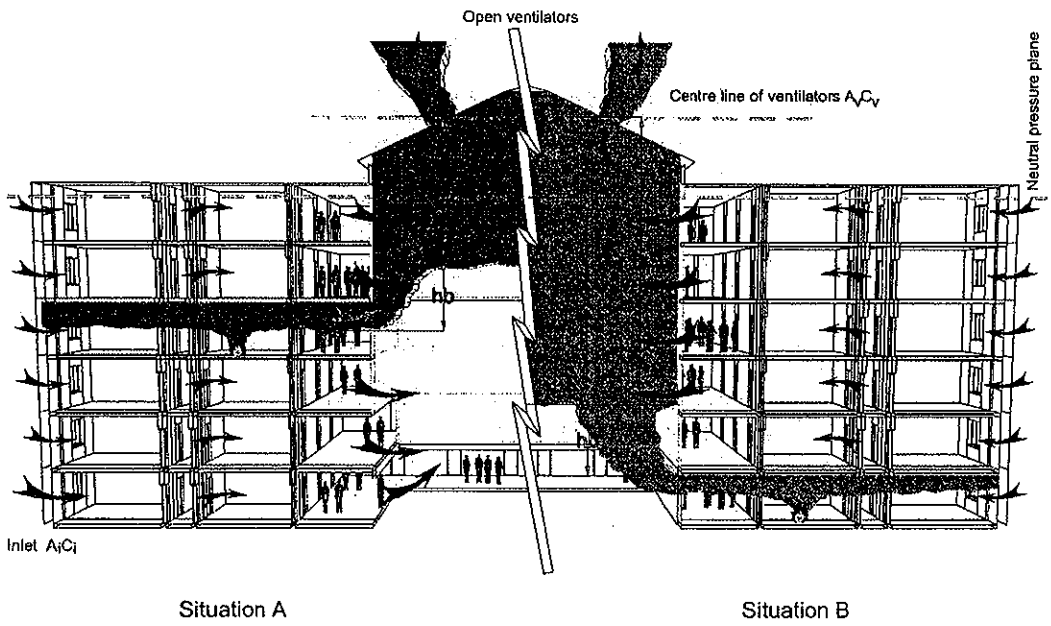


Figure 50 Principles of 'hybrid' smoke ventilation system: temperature-based approach

The main restriction on conventional design is that it is generally impossible to design for a steady state smoke layer much above 12 to 18m from the atrium floor. This is due to the dilution of the smoke plume as it rises through clean air, causing the plume to cool and eventually lose its buoyancy. A smoke temperature rise of 15 to 20°C is generally regarded as being the minimum acceptable for design purposes. This then leads to a requirement for all floors above this height to be sealed from the atrium to prevent smoke spreading from the atrium smoke layer into the adjacent spaces.

Various techniques are used to seal the adjacent spaces from the atrium. Fixed walls and windows are the obvious solution, but automatic movable smoke curtains or fire shutters may be used in their place. This is a common solution in Singapore. NFPA

also discuss use of the building ventilation system to pressurise the spaces relative to the atrium or provide an opposing air flow, but the pressures and volume flow rates required often make this impractical. Some pressurisation may be beneficial when using movable barriers, to prevent smoke leakage through the inevitable gaps.

A difficulty with growing fire design for tall atria is modelling what happens in the early stages of a fire, where the smoke is cool and the fire small. For design purposes all that can be done using conventional algebraic calculation is to assume that the smoke rises to the roof and forms a stable layer. In practice of course the smoke may form a stratified smoke layer partway up the atrium, especially if the temperature in the upper part of the atrium is allowed to float under normal conditions and may therefore already be at an elevated temperature. In time the warm air above the stratified layer will be vented by the smoke control system and the system will equalise towards the calculated condition. This is not normally a critical issue, but it does need to be considered to avoid the risk of smoke logging of intermediate floors before the smoke control system is in full operation.

The above paragraphs of course are based on the assumption that smoke is to be allowed into the atrium. This is not necessarily the case. It is possible to design a smoke control system to prevent smoke from entering the atrium from adjacent spaces, either by using the building ventilation system, suitably designed for smoke ventilation use, or separate smoke extract systems. However, if this solution is used, then the atrium itself must be managed to have a very limited fire load, a limitation that is often undesirable and difficult to maintain over time.

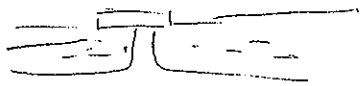
It is clear that, even where a prescriptive Building Code is operated, smoke control is generally treated as a prescribed system, but one that needs to be individually engineered. Smoke control is therefore the part of the building fire precautions that is most advanced towards performance based design. Nevertheless, movement toward performance based design for the entire building fire precautions provides new challenges and opportunities for smoke control.

As plume ht increases, temp ↓, buoyancy ↓, higher smoke extraction reqd
- here it is desirable to minimise plume ht.
- Smoke curtain provide protection to the patrons on floor cabinet the fire floor from rising plume
- Smoke will stratify at intermediate level in tall atrium, where they are A/C.

Speakers Resume

Performance based vs Prescriptive based.

note plugholing effect



Paul David Compton

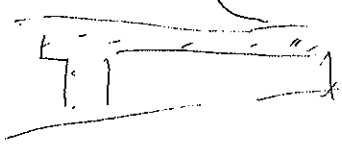
Paul David Compton is an experienced Consultant of International Fire Technology Limited, (a subsidiary of Colt International), and the Fire and Smoke Control Executive of Colt International Limited. He joined Colt in 1982. Born in 1951, he is armed with a Bachelor of Science (BSc) in Mechanical Engineering, Southampton; and a Master of Business Administration (MBA) from Portsmouth. He is an active member serving in several fire safety technical committees, including BSI FSH/25 Smoke and heat control systems; BSI FSH/18 Fixed fire fighting equipment; CEN/TC191/SC1 Smoke and heat control systems, and various working groups of the National Fire Protection Association (NFPA) Smoke management committee. On publications, he was Volume chairman of the Chartered Institute of Building Services Engineers (CIBSE) Guides C and B1; and a Co-author (with H Morgan) for a recent technical paper on plug-holing in time dependent fire design.

He had delivered several papers in the UK, which are recognized structured activities from the Curriculum Professional Development Programme. His sharing of his in-depth knowledge of his specialized topic and his vast experiences with fire safety systems for atria, is a seminar not to be missed.

> 10m, no pt putting sprinkler in the atrium.

Consider putting smoke detectors at intermediate level for effective detection of smoke.

- Deepening effect of smoke has to be calculated.
- take role of sloping floor.



— min clear height to be maintained

7.6.23 — Electricity supply — cable to have min 1 hr FR

— Smoke clearance System ≠ Smoke Control based on A/C or 10% ~~opening~~ Floor area at high & low level

smoke curtain shall be fail safe in the design position.

PERFORMANCE BASED DESIGN OF ATRIUM SMOKE CONTROL

Mr. Paul David Compton

Consultant, International Fire Technology Ltd
Fire and Smoke Control Executive, Colt International Ltd

There is a slow but insistent move from prescriptive to performance based Building Safety Codes.

Performance based design goes by different names around the world: fire engineering in the UK and rational design in South Africa for example. However it is named, the basic principle is the same, to provide fire safety by means of design to achieve certain objectives rather than by applying standard prescriptive solutions.

In the UK we already have a specific clause in our Building Regulations Approved Document B allowing use of fire engineering methods as an alternative to the prescriptive requirements. We also have proposals for new fire safety legislation that will be based on risk assessment instead of the current more prescriptive requirements.

This change is being driven primarily by commercial interests. As performance based design becomes a more mature science it becomes possible to design fire precautions for specific buildings with greater confidence. This allows the option of designing precautions that can be shown to provide equivalent safety to prescriptive precautions, potentially allowing more scope for innovative building design or for more cost effective fire precautions. This commonly happens now, but it is of course only a stage in the move to full performance based design.

Ultimately, for performance based design to have maximum effect, it is necessary to remove prescriptive codes with their inherent conservatism and move to codes that specify only the required objectives. Fire engineers can then work to meet those objectives in the most cost effective manner, factoring in specific safety factors where necessary.

Cost effectiveness is the critical issue here. Commercial pressure is for the lowest cost solution that will be approved by Building Control authorities. Therefore the requirements in the Building Code are probably more critical for performance based design than for prescriptive design. The recent Benefeu report, 'The potential benefits of fire safety engineering in the European Union', estimates that in Europe fire precautions account for some 10% of building costs and that performance based design could result in a saving of up to 3% of building cost.

Set against this commercial benefit are the potential for abuse of the system and the increased complexity for designers, manufacturers and approving authorities.

When, or indeed whether, to adopt performance based codes is of course a national decision that will depend upon local culture and conditions. One factor that will be

critical is the number and competence of fire engineers available. The Benefeu report has indicated that for fire engineering to become the norm, Europe needs 300+ fire engineering graduates per year, against a current output of approximately 50. It has also highlighted major areas where further research is needed to underpin performance based design.

One type of structure that has probably only been made possible by performance based design is the atria building. By their very nature atria do not lend themselves to older prescriptive codes based on separation of storeys, so prescriptive codes took some time to catch up with atrium design, making some kind of performance based design essential.

Additionally, as atria have become taller and more complex, they have exceeded the limitations of the empirical algebraic design calculations used for engineered smoke control systems. Other design methods, such as CFD or physical modelling have therefore become essential to ensure life safety in tall or complex atria.

Under existing prescriptive codes we already have the situation where smoke control systems are engineered solutions. A move to performance based codes and design will therefore probably impact less on smoke control design methods than upon other fire precautions, but it will almost inevitably mean a change from steady state to growing fire design when using BRE design guidance. This is not a particular problem since the BRE calculations can be used iteratively for growing fire design. It will of course change the context in which the smoke control system operates. Examples of this could be changes in fire detection system or sprinkler provision, both of which have an influence on the design and effectiveness of smoke control.

Fire detection systems are the normal method of initiating smoke control system operation. Early detection has several benefits, the most obvious one being an early alarm to allow people to evacuate the building and to call the fire brigade. Early detection will also allow early operation of the smoke control system, maximising its effectiveness. In smaller spaces this can make the difference between maintaining a clear layer and temporarily smoke logging the space.

Smoke control systems can also dictate some requirements for detection. An example of this was in a tall atrium in Hong Kong where predictions showed that it would be impossible to avoid premature stratification of smoke. The chosen solution was to provide exhaust ventilators at intervals up the height of the atrium and open up the ones within the stratified layer. In order to achieve this smoke detection was required at intervals up the whole height of the atrium to provide the required operation of the smoke control system.

Sprinkler systems and smoke ventilation systems are also closely interactive. Setting aside the perennial problem of which should operate first, a sprinkler system will have a significant effect on fire growth rates and ultimate size and upon the temperature of the smoke in the plume and the smoke layer. This then has a significant effect on the design of the smoke control system, which needs to deal with a lower mass of cooler smoke. Therefore, for design of the smoke control system we need to know not only that a sprinkler system is being installed, but its type, location, RTI, etc to take full account of its effect. For example, in shopping malls in the UK the design fire size in

a shop unit is reduced from 5MW to 2.5MW if fast response sprinklers are specified in place of standard response.

Should sprinkler systems be significantly downgraded or omitted as part of a performance based design the effects on smoke control requirements can also be significant. In a sprinklered room a fire is unlikely to flash over, and the room will only become fully involved if very small (such as an hotel bedroom). Lack of sprinklers makes these effects more likely. Whether they are acceptable or not of course depends entirely upon the overall performance based design, but their occurrence again has a significant effect on the design of the smoke control system.

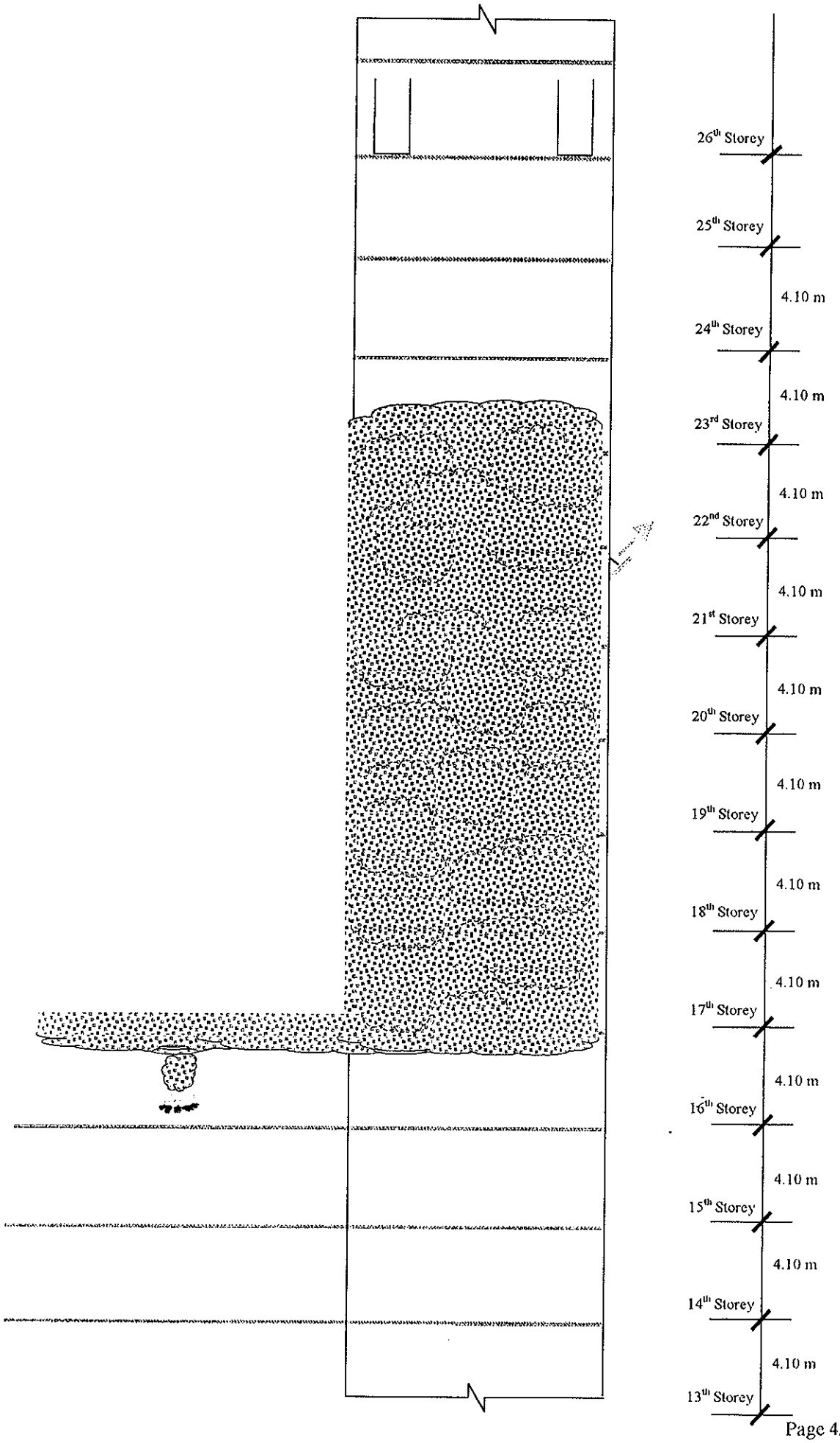
It is also possible to develop a performance based design that does not include a smoke ventilation system, with smoke control being addressed by allowing the atrium to fill with smoke. This 'void filling' design method uses the fact that a large space such as an atrium will take a finite time to fill with smoke, and that if the performance objectives can be met in this time there is no need to provide ventilation. Some ventilation may nevertheless be provided to facilitate smoke clearance after the fire has been extinguished.

Discussion has so far centred on physical fire precautions. Management and fire evacuation strategies also have a significant effect on fire precaution equipment. In tall buildings there has been a tendency to use phased evacuation techniques to minimise space requirements for escape stairs. This strategy may be in some doubt since September 11th as people may no longer be prepared to wait passively to be told to evacuate. However, if it is used, it has a significant effect on the escape period and therefore on the fire resistance of the structure and upon the required performance of active systems.

Atria themselves may also change in design as prescriptive requirements are lifted. The current Singapore Building Code sets a minimum plan area and horizontal dimension. Therefore as well as the trend towards larger and more complex atria there could be a new move to small atria in some smaller buildings. Such atria would require some extra thought in terms of smoke control design as the smoke plume could be restricted by the space dimensions.

CFD analysis or physical modelling will no doubt become more prevalent with performance based design. This is, like so many things in life, both a benefit and a risk. A benefit in that it allows analysis of systems in much greater detail and indeed can model systems that would otherwise be difficult to model with confidence using conventional techniques. A risk in that greater experience and competence is required both in making and assessing the analyses - it is not necessarily easy to tell a faulty analysis from a good one. An example of the benefits of CFD is the tall atrium in Hong Kong. With conventional calculation techniques it would have been impossible to analyse the possible scenarios with sufficient confidence to propose the final adopted solution.

The illustration below shows one of the conditions predicted by the CFD analysis.


26th Storey
25th Storey
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14th Storey
4.10 m
13th Storey

It is clear that performance based design is becoming more prevalent and that pressure will continue for its acceptance by approving authorities as an alternative to prescriptive solutions.

It is also clear that it is still an evolving science, with much research still needed to define fire growth, the effects of sprinklers on both fire growth and smoke flows and temperatures, and other basic data, as well as refining design methods and calculations. An example of this is plugholing, the condition where a ventilator extracts both smoke from the smoke layer and air from below the smoke layer. We know it exists and we can calculate the maximum ventilator size or flow rate that can be used before plugholing commences for any given depth and temperature of smoke layer. What we don't know is how to calculate the smoke flow from a ventilator while it is plugholing, an important issue when we are calculating the effectiveness of ventilation under growing fire conditions. These examples relate to smoke control design, but similar questions and research needs apply to the other disciplines which need to be considered for a full performance based design. These include issues like as the effects of human behaviour on escape periods and, if we want to be able to include fire brigade intervention in our analyses, the effects this may have on the fire.

Performance based design can, and does, go even further. Not only can the fire precautions be analysed, but the risks can be assessed on a probabilistic basis, possibly leading to a situation where the basic performance objectives could change with the assessment of risk. There is a long way to go before the technology matures.

In the mean time, performance based design is with us and it needs to be addressed by regulators and approval authorities. Current prescriptive codes are still valid, and in many cases are doubtless the simplest and most effective means of ensuring fire safety. Nevertheless, performance based design needs to be considered in Building Codes and, if accepted, this is best achieved by setting specific objectives rather than by trying to compare performance based designs with prescriptive measures on a project by project basis.

Speakers Resume

Mr. Dennis J Rose

Mr. Dennis J Rose worked with Colt International Limited from 1972, holding a wide range of positions. Since 1979, he became a part of Colt UK Limited sales force and was responsible for the design and application of fire engineered smoke control systems in the UK. This has meant that he has been involved in virtually every conceivable type and use of building imaginable.

More recently, since 1992, he has worked throughout Asia spending time in Japan, Korea, Singapore and from 1995 until 2002 as Resident Director of Colt Ventilation Malaysia Sdn Bhd. In Malaysia , he has had responsibility for the technical transfer of knowledge to Professional Bodies including Jabatan Bomba. He therefore has over 30 years of experience in this field of work and ten years of experience within Asia.

BR 358 replaced BR 256, which replaced BR 186

A BRIEF REVIEW OF UK AND US AFV STANDARDS (REVISED)

Mr. Dennis Rose

Consultant, International Fire Technology Ltd
Fire and Smoke Control Executive, Colt International Ltd

Since both US and UK standards are mainly arranged by building type, this review will be arranged in the same way. It should be noted however that a new generic standard, BS 9999, is currently being produced to replace the BS 5588 series.

The intention of this review is to point out the major differences between UK and US design practices. For the detail read the standards and codes referenced. The most striking difference is that the US does not accept the principle of the standard design fire size.

US and UK calculation procedures have evolved separately and therefore differ considerably. The results of the calculations however are broadly similar (as they should be). With the increasing use of fire engineering in the UK, the US calculations are being used more and more, where engineers can use them to justify more economic solutions.

The UK now has a fire engineering standard DD240 (soon to be replaced by BS 7974) for design in more complex buildings. This tends towards US practice in designing with growing fires.

In the UK, BR 368 will be largely superceded in 2002 by BS 7346 parts 4 and 5 covering design procedures using steady state and growing fires respectively.

1. Single storey buildings

US Standards: NFPA 204 (1998) A new 2001 edition is soon to be published.

UK standards: BS 5588-11 (1997), SVA guide, BR 368 (1999)

US and UK practices are similar in principle but differ in detail. The main variations are detailed below.

1.1 Fire size

UK practice is to use a steady state design fire size based on occupancy group, with heat output estimated for the specific materials involved. The standard fire sizes are for sprinkler protected buildings.

US practice is to use either a limited growth fire size where this can be quantified or (more usually) a growing T^2 fire. For limited growth fires the design is based upon the maximum heat output (as UK). For growing fires the heat output is defined by the time constant chosen. Standard data is for unsprinklered buildings.

1.2 Vent operation

UK practice is to use ventilators controlled in zones from a fire detection system – all vents in a zone will normally operate together.

US practice has been to use fusible link operated ventilators – each vent operating individually with the spread of heat from the fire. The 1998 edition of 204 mentions the possibility of using smoke detection control if heat build up may be slow and the forthcoming edition takes this further, suggesting the consideration of 'ganged' vent control under any circumstances.

1.3 Smoke reservoirs

UK practice is to compartment the roof space into 2000 m^2 (life safety) or 3000 m^2 (property protection only) reservoirs. Maximum reservoir length is 60 m. Depth of the reservoir is designed on a case by case basis.

US practice is to require draft curtains extending down 20% of the ceiling height and spaced a maximum of 8 times the ceiling height apart. In places that are regarded as specially vulnerable to fire damage curtains should either extend down 40% of ceiling height or be spaced at 2 times ceiling height.

1.4 Mezzanines

The SVA Guide provides design procedures for protection of mezzanines and the areas under them. The principle is to channel smoke flow from under a mezzanine to limit smoke volume.

NFPA 204 does not mention mezzanines.

1.5 Sprinklers

UK smoke control practice is based on the expectation that sprinklers will be provided, with unsprinklered buildings requiring twice the design fire area (up to 100 m^2).

US practice is based on unsprinklered buildings. No specific guidance is provided for sprinklered buildings since the NFPA has still not reached concensus on the results of combining sprinklers and vents. NFPA 204 briefly discusses the existing research and refers the reader to the standard research papers.

1.6 Calculation

Both the UK and US now use calculation techniques rather than tables.

The actual calculation formulae differ but the basic principles are similar.

UK practice is mainly based on steady state calculations while the US mainly uses growing fire calculations. Growing fire calculation is starting to be used in the UK, mainly by consultants striving to minimise fire protection costs.

2. Shopping Malls and Atria

US standards: NFPA 92B (2000)
UK standards: BS 5588 part 7 (1997) and part 10 (199?), BR 368

While the two parts of BS 5588 still treat shopping centres and atria separately, BR 368 has harmonised the calculation procedures for smoke ventilation. In the UK, many atria now only require provision for smoke clearance and atria below 30 m high do not require any smoke control under the Building regulations.

2.1 Fire size

The UK uses standard fire sizes of 10 m^2 (5 MW) for a sprinklered shopping centre or 5 m^2 (2.5 MW) if quick response sprinklers are used. Standard fire sizes are also used for offices, hotel rooms, etc opening onto atria.

The NFPA considers it inappropriate to use a standard design fire size in the USA due to lack of US statistical data. US practice is therefore to consider actual or expected fuel items and their layout. The design fire can be steady state or t^2 growth.

2.2 Vent operation

Zone control from a detection system is normal in both countries. The NFPA also specifies back up from fusible links and sprinkler flow switches.

2.3 Smoke reservoirs

In the UK there are specific maximum reservoir sizes for malls which differ from those for single storey buildings for historic reasons but which are similar in intent. For malls the maximum limit is 1000 m^2 for natural ventilation systems and 1300 m^2 for powered systems, with equal sizes allowed for each shop discharging smoke into the mall. Maximum reservoir length is 60 m. There are no maximum reservoir sizes for atria.

In the US there are no specific reservoir sizes.

2.4 Shop units

UK practice allows choice of extract from each shop unit or allowing spill into the mall for subsequent extract by the mall smoke vent system. The latter solution is most common. Where smoke is exhausted into the mall under a balcony, channelling screens are generally required to limit the plume width.

US options are similar but slot extract is not recognised and channelling screens are not required.

In the US it is possible to allow units above the bottom of the smoke layer to be protected by an outward flow of air through the facia. Substantial flow rates can be required for this, This is not recognised in the UK.

2.5 Sprinklers

UK and US standards allow for both sprinklered and unsprinklered situations, although in the UK sprinklers are necessary in shop units in shopping malls.

2.6 Calculation

In the UK calculation is normally by a zone model based on a steady state fire using formulae from BR 368.

In the US zone modelling is also the norm, but the standards also provide guidance on physical and computer modelling. The calculation formulae differ from the UK and time to fill using a growing design fire is more common. Optical density calculations are included to allow assessment of tenability of smoke logged areas. This is something that is now included in fire engineering standards in the UK but is rarely used and treated with suspicion by approving authorities.

3. Pressurisation

US standards: NFPA 92A (2000), ASHRAE Design of smoke control systems for buildings (1983)
UK standards: BS 5588-4 (1998)

The US standards cover pressurisation of stairwells and building floors or zones of floors. UK recommendations cover lobbies and stair wells only.

3.1 Degree of pressurisation

US standards call for pressurisation between 12 and 45 Pa, depending upon the ceiling height and whether sprinklers are installed. Door opening forces are limited to 133 N. Where specific air velocities are required to hold back smoke the design information is given in ASHRAE.

USA Code model fire growth & decay based on t^2

UK standard is to pressurise to between 50 and 60 Pa (45 Pa in lobbies). Door opening forces are limited to 100 N. In addition, minimum air velocities through open doors to the fire floor are specified.

3.2 Open doors

In the UK the standard specifies pressurisation levels and door air flow rates under set door opening conditions which vary with the type of system.

In the US designers are encouraged to consider how many doors may be open.

3.3 Lifts

In the UK lifts are generally assumed to be closed (except fire fighting lifts) and leakage rates are assessed for crackage only.

In the US the ASME Safety Code for elevators requires lift doors to open and stay open on emergency setting.

Fire Protection measures
- Structural Measures
- means of escape
- Area of refuge
- sprinkler protection - 60dp will be gone after
- Smoke detection & FA system
- Performance based smoke control Sys.

Speakers Resume

Dr. Alex K.H. Lee

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Role of Computational Fluid Dynamics (CFD) For Fire and Smoke Modelling in Atria Designs

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ABSTRACT

The emergence of atrium buildings with large undivided spaces, and the introduction of performance based regulation in an increasing number of countries, has led to a growth in the application of fire safety engineering design concepts. Smoke and heat exhaust ventilation systems are often used in these types of building to provide safe egress of occupants along the escape routes. Fire modelling is one of the design tool that has become increasingly attractive to support design based upon performance based regulatory requirements. There are many such models but perhaps the most influential are those based upon the use of Computational Fluid Dynamics (CFD). This type of model exploits techniques developed for solving general-purpose fluid flow and heat transfer problems. Such tools in expert hands are extremely powerful but that are dangers of misuse if they are used without adequate consideration of both the fire science and of the numerical aspects. This paper gives a very broad overview of the state-of-the-art CFD for fire and smoke simulation, and its important contribution in the design of the smoke exhaust systems.

INTRODUCTION

Social and technical changes have led to changes in building environments which incorporate new (or revived) building forms and the use of innovative construction techniques and new synthetic materials. The buildings adopting these change often have included within their design large spaces or void, often integrated with many of the storeys. These large spaces have been described as malls, atria, arcades and light well. The generic term for the building type tends to be 'atrium' and by their very nature, they can often run contrary to the traditional Building Regulations' approach in terms of horizontal compartmentalization, vertical separation and short escape distance.

Modern atrium buildings tend to contain large quantities of combustible material and often have open-plan layouts increasing the risk of the spread of fire. The populations within such buildings have also increased, hence there has been a substantial increase in the number of people to be protected and evacuated in an emergency.

Modern atrium buildings are usually designed with the atrium as a feature which can be appreciated from within the adjacent rooms. The room/atrium boundary is usually either glazed or completely open. Thus when compared with 'conventional' buildings, this architectural/aesthetic requirement imposes additional problems of life safety, as smoke, hot gases and even flames may travel from one (or more) rooms into the atrium, and hence affect areas which, but for the presence of the atrium, would not be affected.

The adoption of performance based or fire safety engineering principles at an early stage can lead to cost-effective and innovative design, which frees architects and designer from the constraints imposed by the historical prescriptive approach to address fire safety.

SMOKE AND HEAT EXHAUST VENTILATION SYSTEMS

The Concept

Smoke exhaust ventilation is of primary value where occupants and escape routes are in the same undivided space as the fire. This is true, for example, in many modern atrium buildings and shopping malls. Such architectural designs may be acceptable to the authorities provided it can be shown that the occupants can escape safely in the case of a fire of an agreed severity.

In a large undivided space buoyant fire gases will rise to form a layer in a reservoir below the ceiling. In order that a cooler clear layer of sufficient height is maintained for long enough for people to escape, it is necessary in general to vent the smoke from the reservoir using either natural or mechanical means. A Smoke and Heat Exhaust Ventilation System (SHEVS), see Figure 1, should be designed to provide sufficient smoke and heat exhaust capacity to render the building safe, and where necessary provide additional property protection.

A SHEVS will form one component of one the fire safety engineering concept for a building. Additional passive and active protection measures will in general be required. Early fire detection of will reduce the time before fire-fighting operations can take place, and allow automatic fire suppression systems to operate before the fire grows too large. The relationship between the fire load, detection system and active fire suppression measures allows a 'design-fire' to be specified. This design-fire may be transient or steady-state, and will represent an acceptably severe fire scenario against which the overall fire safety engineering design must be shown to satisfy the relevant performance based criteria.

A number of national guides have been produced with provide guidance on the design of smoke control system for atria and shopping malls. Morgan et al have recently reviewed the concept of SHEVS and its application to atrium smoke control, and provide a comprehensive background to the subject.

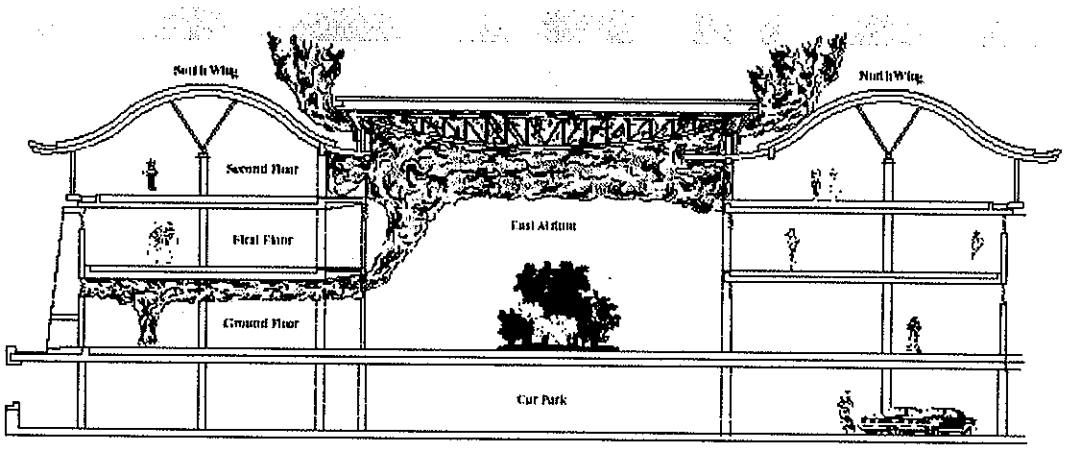


Figure 1 Smoke Exhaust system

Design-Fire Size

Many areas of fire safety engineering require the identification of an appropriate fire size upon which the design can be based. When designing smoke ventilation systems, the calculation of the quantity of smoke and heat produced by a fire requires a knowledge of the size of fire, in terms of area, perimeter and heat flux developed per unit area or from the fire as a whole.

Ideally, the design fire would be based on the materials within an occupancy, suggesting that the choice of a design fire should be straightforward. Unfortunately, this is not the case. While the heat release rates for many materials are known, it is rarely possible to say that a fire will consist of a known quantity of material. Within an occupancy a fire will involve a combination of different materials, so that the heat release rate for that occupancy will be a function of all the materials present. Hence the development of a fire is dependent on a number of factors, including:

- The precise location of the ignition with respect to the fuel,
- The type of material present,
- The quantity of material present,
- The position of the materials relative to each other,
- Possible chemical reactions between material present if their containment is destroyed by fire,
- The position of material relative to walls, ceiling and similar
- The availability of oxygen.

Consequently, there is no method available to calculate the development of a fire in any but the simplest fuel arrays. The likely size of a fire can only be deduced from the analysis of the statistics of fires in the type of occupancy of interest, or from experiments on appropriately similar fuel arrays. The design fire based on statistical analysis are always based on an implied acceptable risk which can differ for various applications, and which is always ultimately related to public opinion.

A design fire can be steady-state fire with constant heat output or a time-dependent growing fire to which the means of escape and evacuation time for the particular building occupancy could be related. Although it is acknowledged that a real fire is not usually 'steady-state', it is relatively simple to assess the maximum size a fire can reasonably be expected to reach during the escape period in a particular scenario, and to design a smoke control system able to cope with that.

The assumption of a steady-state fire allows the smoke control system to cater for all fires up to design size, and by not considering the growth phase of the fire, often introduces a significant margin of safety to the system design.

Morgan (1979) suggests a typical rate of heat release per unit floor area for mercantile occupancies of 500 kW/m^2. Fang and Breese (1980) determined about the same rate of heat release for residential occupancies. Morgan and Hansell (1987) and Law (1982) suggest a heat release rate per unit floor area for office building of 225 kW/m^2. The steady design fire sizes for atria are given in Table 1.

	kW	(Btu/s)
Minimum fire for fuel restricted atrium	2,000	(1,900)
Minimum fire for atrium with combustibles	5,000	(4,700)
Large fire	25,000	(24,000)

Table 1. Steady design fire sizes for atria (c.f. Ref. 1)

Transient fuels must not be over looked when selecting a design fire. The use of growing fire could result in a less onerous design criterion which may result in considerable saving in the implementation of a SHEVS design in a large or complex building. Historically, one reason for not using growing fires for design has been the lack of available data about fire growth rate in various occupancies and scenarios. Research has been carried out in the last few years, at FRS and elsewhere, to determine the likely fire growth rate in some occupancies.

For unsteady fires, fires frequently proceed through an incubation period of slow and uneven growth followed by a period of established growth as illustrated in figure 2 (a). Figure 2(b) shows the established growth is often represented by an idealised parabolic equation (Heskestad 1984).

$$Q = a(t - t_o)^2 \qquad (1)$$

where

Q = heat release rate of fire, kW (Btu/s);
a = fire growth coefficient, kW/s^2 (Btu/s^3);
t = time after ignition, s;
t_o = effective ignition time, s.

It is generally recognised that consideration of the incubation is not necessary for design of atrium smoke control systems, and equation (1) can be expressed as

$$Q = \alpha t^2 \tag{2}$$

where t is the time after effective ignition, and fires following equation (2) are called t-squred fire. Table 2 lists values of α and t_g for some general fire types, and the corresponding fire growths are shown in figure 3.

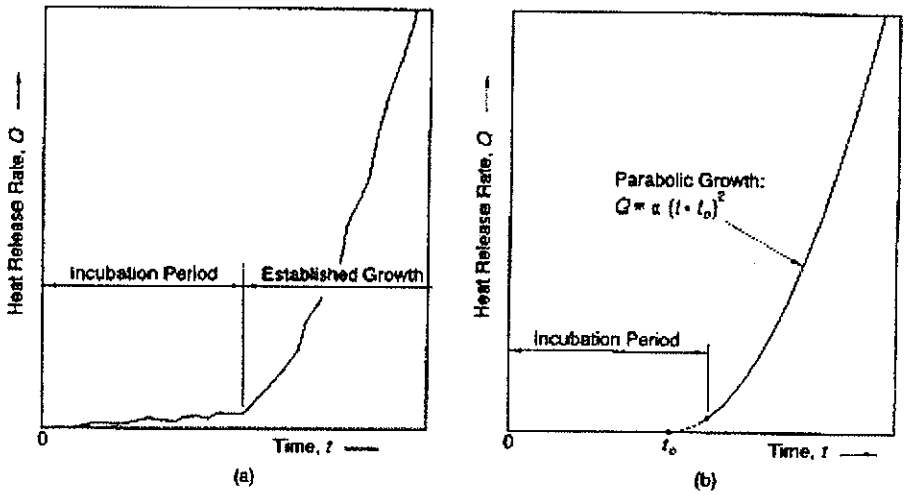


Figure 2 Fire growth (a) typical curve, and (b) idealized parabolic curve

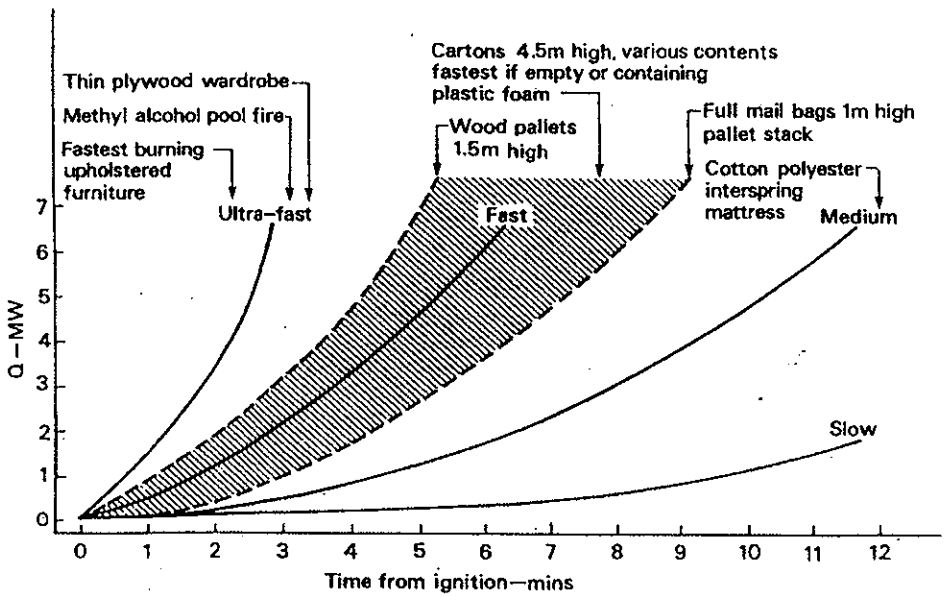


Fig. 3 Some examples of square law fires (adapted from Nelson 1987)

	Growth Constant		*Growth Time*
T-Squared Fires	***a (kW/s^2)***	***a (Btu/s^2)***	***t_g (s)***
Slow	0.002931	0.002778	600
Medium	0.112700	0.111100	300
Fast	0.468900	0.044440	150
Ultra Fast	0.187800	0.177800	75

Table 2 Various t^2 design fires growth rates

The Critical Design Criteria

In a steady state design analysis the main criteria against which the SHEVS is assessed are:

- **The height of the clear layer through which the occupants must escape**

  The boundary between the clear and smoke layers is defined by some visibility distance, typically about 10 m. The required clear layer height will be defined such that the occupants can escape safely, with typical distances being specified in the range of 3.0 to 3.5 m from the floor level. A sufficient clear air height is important form both visibility and a toxically perspective.

- **The temperature of the hot gas layer above the occupants' heads**

  The maximum allowed value is generally about 200°C, so that persons below do not suffer the effects of painful thermal radiation when lightly clad.

For design criteria related to transient design analysis, please refer to Appendix A for details.

CFD FIRE MODELLING

Since the mid-1997s, field modelling has been developed which exploits the new techniques of computational fluid dynamics (CFD) to deduce how, and at what rate, smoked would fill an enclosure. It does this by avoiding resort to experimental correlation, as far as is currently possible, and by returning to first principles to solve the basic laws of fluid flow and thermodynamics. As a consequence, with adequate validation, this type of modelling should have wide application. The use of a computer is necessary since the technique involves the solution of tens of thousands of mathematical equations for every time step forward the simulation makes, and consequently involves relatively long computational times compared with the use of zone models. This makes CFD simulations relatively expensive, particularly when used for buildings with complicated geometry. As the computer become faster and more powerful and the algorithms evolve and improve, CFD is likely to become cheaper and gain more widespread use in Fire Safety Engineering including the smoke control design process.

Users of CFD models should be aware of the importance of:

- Correctly identifying the appropriateness of the sub-models used, for example the heat transfer and radiation model, turbulence model, etc.
- Correctly identifying the boundary conditions appropriate to the precise circumstances of the design,
- Using a small enough grid size so that the converged solution is independent of the grid size.

The CFD methodology is beyond the scope of this paper, but a full description together with a discussion of current limitation is given in, for example in reference [2]. An introductory information about CFD is provided in Appendices B.

ISSUES SURROUNDING THE USE OF CFD FOR FIRE/SMOKE MODELLING

There are two major issues concerning the proper use of CFD for fire/smoke modelling. The first concerning the treatment of the 'fire science' and the second concerning establishment of a 'good' numerical solution.

There is a real danger of mis-use without adequate appreciation of the underlying fire "science" and of the limitation of the numerical method employed. Recently, Kumar [3] has proposed a simple guidance procedure on issues related to the "correct" use of CFD for designing and evaluating active smoke control in buildings. More recently, Cox and Kumar [4] have addressed further considerations of fire science and numerical aspects for the application of CFD modelling to enclosure fires.

An example of the possible misuse of the modelling methodology as a result of an incorrect prescription of the fire itself might be characterise the fire source by a known or prescribed heat release rate but then to associate that heat release rate with an inappropriate fuel area. Close attention needs to be paid, for example, to the relative influences of momentum and buoyancy at the fire source. They are represented by the non-dimensional heat release rate (or source Froude number, Q^*):

$$Q^* = \frac{\dot{Q}}{\rho_\infty C_p T_\infty \sqrt{gD} D^2} \qquad (3)$$

Where Q is the heat release rate of the fire, D is a characteristic fuel dimension (say, diameter of the fuel base), ρ_o , C_p and T_o are respectively the ambient density, specific heat and temperature and g is the acceleration due to gravity. Figure 3 shows a graphical representation of Q^* as a function of non-dimensional flame length (L/D), where L is flame length and the shaded area represents the range of $(0.1 < Q^* < 2.5)$ characteristic of typical buildings fires.

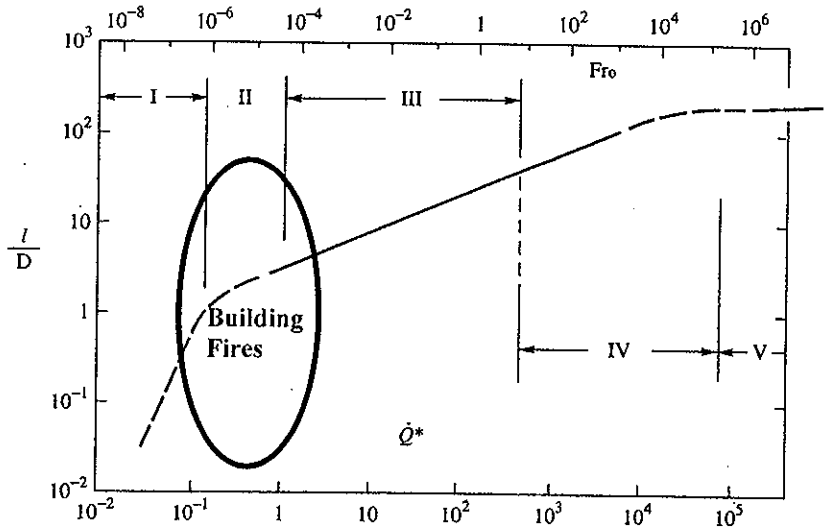


Figure 3 Schematic diagram showing flame length (l) as a function of the fuel flow rate parameters, expressed as Q^* – the extreme right hand-region (V) corresponds to the fully turbulent jet fire, dominated by the momentum of the fuel. Region I and II correspond to buoyancy-driven turbulent diffusion flames. (c.f. Zukoski, 1986)

Another problem can occur when a volumetric heat source is used to describe the fire instead of using a combustion model. Too small a 'pre-determined' volume can yield gas temperatures in the source that are much too high, even higher than the adiabatic flame temperature. Clearly this kind of erroneous source description grossly misrepresents buoyant acceleration and therefore buoyant turbulent mixing at the source. Such errors are easy to avoid with proper attention to the characteristics of buoyant fires.

Measured time-averaged gas temperatures in a fire room seldom exceed around 1300°C. Since the CFD model spatially averages these temperatures over the numerical mesh spacing it is very unlikely that the model should predict temperatures as high as this. Anything above this temperature should therefore be treated with caution and, of course, anything above the adiabatic flame temperature must be incorrect. Other key features that need to be scrutinised closely when studying the numerical solution are the thermal plume above the flame tip, the resulting ceiling jet and upper hot gas layer together with wall and vent flows. Simple calculations can be undertaken to check these components of the overall solution.

Concerning the numerical description of the problem an extremely important requirement is that the 'free' boundary conditions outside a compartment opening, for example, or surrounding an unbounded fire, are far enough away as not to influence the solution in the region of interest. Providing a constant pressure boundary condition across a doorway opening will not, for example, allow the proper inflow and outflow characteristics to be established. Steep pressure gradients near the free-pressure boundary should also be avoided.

It is comparatively easy to produce impressive looking visual images of the fluid flow with modern software but it is essential to demonstrate that the solution is reasonably well converged, by checking for sensitivity to further numerical iteration and further mesh refinement.

A checklist of some of the more important consideration that need to be taken concerning the problem set-up and examination of the solution proposed by Cox and Kumar is listed in Table 4 and Table 5

Considerations of Numerical Aspects

1. *Resist the temptation to undertake two-dimensional simulation. These can be provide physically mislead solutions.*
2. *Ensure that 'free boundary are chosen carefully. A free pressure boundary should be far enough from any ventilation openings not to affect flows through them.*
3. *Ensure that the aspect ratio of cells is not too large – typically not larger than 50.*
4. *Analyse the accuracy of the mesh by a mesh refinement study preferably using at least three grid resolutions-ideally by doubling the grid cells in all directions. For buoyant flows, special attention should be given to the vertical mesh spacing.*
5. *It is likely that a first order numerical differencing scheme will be used at least initially since it is stable, but it is possible as convergence is approached use a second order or higher scheme.*
6. *It is not advisable to change too many relaxation parameters at once, as it then becomes difficult to analyse which of the changes have influenced the solution.*
7. *In transient simulations, be sure that the time-step is adapted to the choice of the grid and check the influence of the time-step on the results. For a rapidly developing fire more iterations per time step are generally needed.*
8. *Normalised mass and momentum continuity errors, and residual errors for all the solved variables should be less than about 0.01, preferably less than 0.001.*
9. *Examine convergence by following data, especially pressure, at critical locations (e.g. in the plume, in the hot gas layer and in ventilation openings). Monitor values should gradually settle down to their converged levels.*
10. *Global mass and heat balance should be about 95% in one or more analysis regions. One of these regions should encompass the entire enclosure or building.*
11. *Explore difficulties in achieving a steady-state solution by utilising transient simulations. There may be no steady solution if physical oscillation is present.*

Table 4 Considerations of Numerical Aspects

Consideration of Fire Science

1. *Use a combustion model to allow a proper coupling between local airflow and distributed heat release.*

2. *Check that Q^* is representative of the fire of concern, for buoyant fires $Q^* < 2.5$.*

3. *It is important to incorporate radiative loss from the flaming region. The fire plume can lose up to 50% of its heat by radiation.*

4. *Ensure that boundary heat losses are accounted for. These can cause ceiling layers to loose their buoyancy and cool wall currents to fall through a buoyant layer.*

5. *For smoke movement problem, a six-flux radiation model, is normally adequate. However, for flame spread predictions, a more sophisticated model such as the discrete transfer method should be considered*

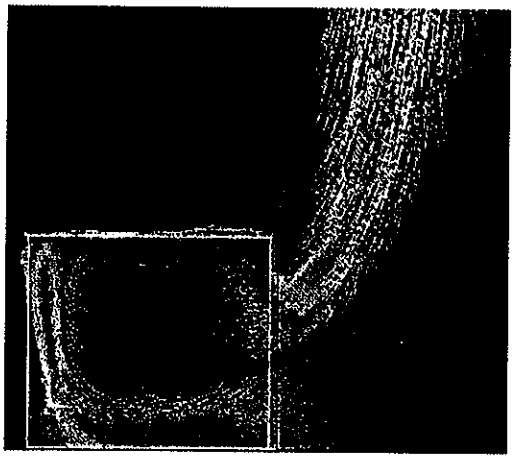
6. *Do the predictions of the fire source make sense? For example, flame temperature should not exceed 1300℃. Anything higher than 2000℃ must be incorrect due to an erroneous source specification – anything higher than 1300℃ should be examined closely.*

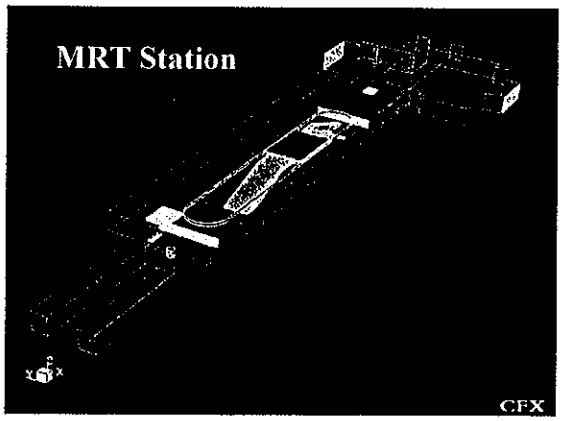
7. *Compare flame temperature, flame height, plume entrainment, upper layer temperature, ceiling jet properties, etc. with empirical correlations.*

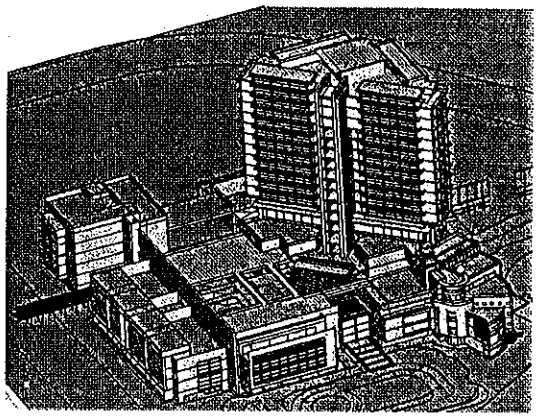
CASE STUDIES

- Steckler Room
- The Esplanade – Theatres On The Bay
- Underground MRT Station
- Jurong General Hospital









CONCLUSION

Smoke and heat exhaust ventilation design forms an integral part of the fire safety engineering concept for many modern atrium buildings, where large undivided spaces require compliance with the appropriate performance based regulations. A smoke ventilation system design may be based on empirical based engineering models, e.g. zone models, in cases where the building geometry is not too demanding. In cases of particularly large volumes or complex architectural features, however, a CFD assessment may be required. This has been illustrated in this paper for a number of cases study involves complicated building geometry.

This paper has also provided guidance and discussion of important issues related to fire science and numerical aspects of CFD that require special consideration for ensuring 'correct' use of CFD for practical fire application.

REFERENCES

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3. Cox G and Kumar S. 2001. Modelling Enclosure Fires using CFD Modelling, SFPE Handbook, 3rd Edition
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Appendix A

TENABLE ENVIRONMENT

The purpose of this appendix is to provide guidelines for the details of the tenable environment.

Some factors that should be considered in maintaining tenable environment for period of short duration can be defined as follows:

a) Air temperature as follows:
Maximum of 60C (140F) for a few second, averaging 49C(120F) or less for the first 6 minutes of the explosure and decreasing thereafter;

b) Air-carbon monoxide content as follows:
Maximum of 2000 ppm (parts per million) for a few seconds, averaging 1500 ppm or less for the first 6 minutes of the exposure, averaging 800 ppm or less for the first 15 minutes of the exposure, averaging 50 ppm or less for the remainder of the exposure.

c) Smoke obscuration levels that are continuously maintained below the point at which a sign illuminated at 80 lux (7.5 foot-candles) is discernible at 30 m. Doors and walls that are discernible at 10 m.

d) Radiation heat flux as follows:
Maximum of 54.4 W/m2 (2000 Btu/(hr-ft2)) for a few seconds, averaging 13.6 W/m2 (500 Btu/(hr-ft2)) for the remainder of the exposure.

e) Replacement Air velocities in the escape route shall not exceed 5.0 m/s to prevent the escapees being hindered by the air flow.

Appendix B

Computational Fluid Dynamics

Computational fluid dynamics (CFD) consists of dividing a space into a large number of spaces, and obtaining approximate solutions to the fundamental equations of fluid dynamics for each space. CFD is sometimes called field modeling. Many computer CFD programs has been developed that are capable of simulation of fire induced flows. Several of these are general purpose codes that are commercially available. The development of computer work stations that are capable of running meaningful simulations has lead to an increased use of CFD in many areas of engineering, and fire protection is no exception.

This appendix is an outline of the topic with the intent of providing some understanding of the capabilities and limitations of CFD with respect to smoke flow in atria. Because this appendix is intended for practicing engieers, it was written so that readers need only the basic knowledge of undergraduate fluid dynamics. The equations in this appendix are intended to describe CFD modeling and not be used for calculations. Acoordingly, units are not give for variables of this section. However, all of these equations are valid for SI units or any other dimensionally homogeneous unit system.

Readers should be aware that a thorough knowledge of CFD requires extensive understanding of graduate level fluid dynamics. For more inforamtion on this topic readers are referred to Anderson, Tannehill and Pletcher (1984), Abbot and Basco (1989), Hoffman (1989; 1990), Kumar (1983), and Markatos (1986).

A-1. Fundamental Equations

This section lists the fundamental equations of fluid dynamics with the intent of giving readers an appreciation of the level of complexity of this topic. However, it is not expected that readers would have a significant understanding these equations without study of fluid dynamics at the graduate level. In Cartesian corrdinates, the velocity vector is expressed as

$$\vec{V} = u\,\vec{i} + v\,\vec{j} + w\,\vec{k}$$

Where u, v and w are velocity components in the x, y and z directions respectively. For unsteady compressible, viscous flow, the conservation equations are written below.

Conservation of Mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \vec{V} = 0$$

Conservation of Momentum:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[\mu\left(2\frac{\partial u}{\partial x}-\frac{2}{3}\nabla\cdot\vec{V}\right)\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right]+B_x$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\frac{\partial}{\partial y}\left[\mu\left(2\frac{\partial v}{\partial y}-\frac{2}{3}\nabla\cdot\vec{V}\right)\right]+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+B_y$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\frac{\partial}{\partial z}\left[\mu\left(2\frac{\partial w}{\partial z}-\frac{2}{3}\nabla\cdot\vec{V}\right)\right]+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+B_z$$

Conservation of Energy:

$$\rho\left(\frac{\partial E}{\partial t}+u\frac{\partial E}{\partial x}+v\frac{\partial E}{\partial y}+w\frac{\partial E}{\partial z}\right)=\nabla\cdot(k\nabla T)-\nabla\cdot p\vec{V}+\dot{Q}_v+\dot{Q}_g$$

Equations of state:

In additional to the conservation quations, an equation relating pressure, temperature and density is needed. Such equations are called equations of state. The perfect gas law is frequently used in CFD applications:

$$\rho=\rho(P,T)$$

Where R is the gas constant.

The conservation of momentum equations are often called the Navier-Stokes (NS) equations, but the term NS equation is also used in a broader sense to mean all the conservation equations plus the equation of state, and this paper the broader meaning is used. It is not possible here to discuss all of the assumptions involved in the derivation of NS equations. However, two of the more important ones are the continuum assumption and the stress-strain relations for a Newtonian fluid. For an exhaustive derivation of the NS equation reader are referred to Aris (1962).

At the level of generally presented above, it is beyond the state of technology to solve the NS equations exactly. Even with the simplifying assumptions of incompressibility or of Boussineq flow, it is still not possible to solve the three dimensional NS equations exactly. Exact solutions have been obtained for a laminar flow in simple geometries, and the most notable application of inexact solutions are to boundary layer flows. Exact and inexact solutions are discussed in several texts (White 1974;

Sherman 1990; Schlichting 1960; Schetz 1993). By expermerimental verification of these solutions, the NS equations have themselves been verified for laminar flows. There is no such verification for turbulent flow. However, CFD simulations of turbulent flow based on NS equations as discussed below often corresponds well with experimental data.

A-2. Turbulence Modeling

Most CFD models use an approach called large eddy simulation which uses the NS equation to simulate the evolution of large eddies and models the effects of the small eddies. Before modelling of small eddies is discussed, it should be mentioned that large eddy simulation is based on the conversion of the NS equation to an averaged form of equations. All of the parameters in the government equations are separated into average and fluctuating components. An assumption of this approach is that these fluctuations are random.

The quantity, $\bar{f}$, averaged over time, Δt, is defined as

$$\bar{f} = \frac{1}{\Delta t} \int_{t}^{t+\Delta t} f \, dt$$

The quantity, f, can be separated into averaged, $\bar{f}$, and fluctuating, f', components ($f = \bar{f} + f'$). Separation of u is illustrated in figure A-1.

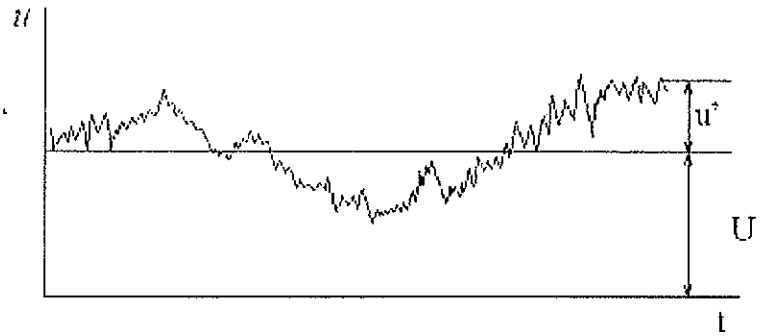


Figure A-1 Time averaging approach of Reynolds

In Reynolds decomposition, the fluctuating terms of the NS equations become

$$u = \bar{u} + u'; \quad v = \bar{v} + v'; \quad w = \bar{w} + w';$$
$$\rho = \bar{\rho} + \rho'; \quad p = \bar{p} + p'; \quad T = \bar{T} + T',$$

Substituting these into the NS equation results in the Reynolds averaged NS equation with additional terms that are related to the averaged flow variables by *turbulent models*. These turbulence models approximate the effect of small eddies, and some of

the common ones are the Prandtl algebraic model, the κ-ε model and the Reynolds stress model.

Because the κ-ε model is extensively implemented in CFD codes, a few details of it are given. This model was developed by analogy to incompressible boundary layer flow (Harlow and Nakayama 1968; Launder and Spalding 1974), and it consists of adding two partial differential equations to the averaged NS equation. The term κ is the kinetic energy of turbulence, and it is

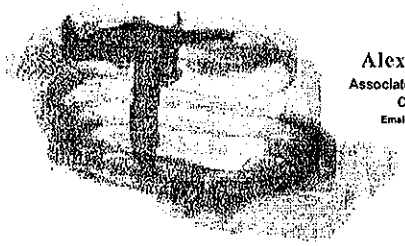
$$\varepsilon = \frac{C(k)^{3/2}}{l_\varepsilon}$$

Where

l_g = dissipation
C = constant

In addition to the above constant, there are several others, and the values in the 1974 paper by Launder and Spalding are almost the same ones used for most applications today. For a discussion about extension of the κ-ε model to compressible flow and a general presentation about CFD to fire application, the reader is referred to Kumar (1983).

Role of Computational Fluid Dynamics (CFD) For Fire and Smoke Modelling in Atria Designs



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Contents

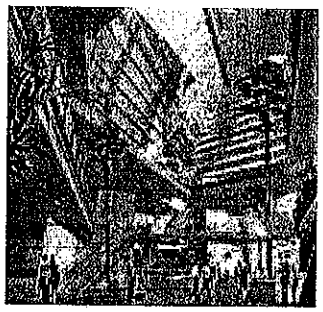
- The Atrium – Description and Behaviour in Fire
- Smoke and heat exhaust design philosophies
- Behaviour and Dynamics of Fire Development & Smoke Spread
- Fire Field Models – What are they?
- Issues Surrounding the use of CFD for Fire Modelling
  - Mesh Refinement
  - Fire Source
  - Convergence
- Some Application Examples
  - *MRT Station,*
  - *Concert Hall/Theatre*
  - High Rise Building
- Concluding Remarks

The Atrium



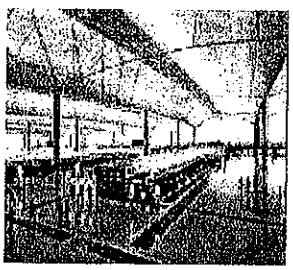
- Social and technical changes have led to changes in building environments which incorporate new (or revived) building forms and the use of innovative construction techniques;
- 'atrium' type of building can often run contrary to the traditional Building Regulations' approach in terms of horizontal compartmentalization, vertical separation and short escape distance.

The Atrium



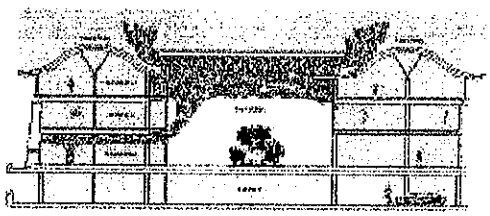
- contain large quantities of combustible material;
- have open-plan layouts increasing the risk of the spread of fire;
- has a substantial increase in the number of people to be protected and evacuated in an emergency.

The Atrium



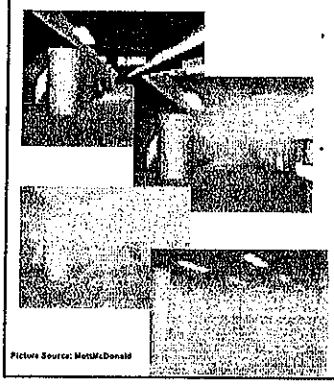
- The room/atrium boundary is usually either glazed or completely open;
- Architectural/aesthetic requirement of atrium imposes additional problems of life safety, as smoke, hot gases and even flames may travel from one (or more) rooms into the atrium.

The Atrium



- Experience of fires in atrium buildings in the USA has shown that the problem of flame travel internally through the atrium to be minor in comparison with the problem of hot and toxic gases accumulating and filling the atrium; spreading throughout the building; and affecting escape routes.

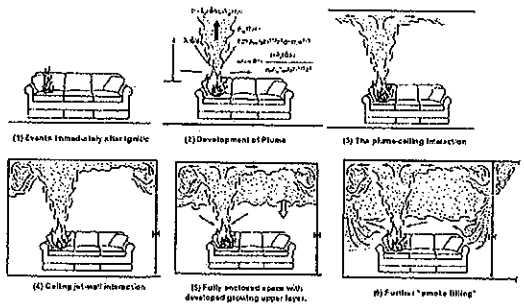
When Is Smoke Extraction Necessary



- **Life Safety**
  The system is to be designed to maintain tenable conditions on escape routes and in other areas throughout the period they are likely to be in use by occupants of the building.
- **Fire-Fighter access/Property Protection**
  The system is to be designed to increase visibility for, and reduce heat exposure to, trained fire fighters. This allows earlier and less hazardous attack on the fire.
- **Smoke Purging**
  The system is to be designed to enable smoke to be cleared from a building after the fire has been brought under control.

Picture Source: Hott/McDonald

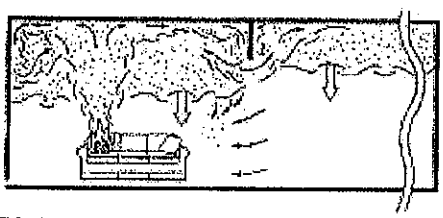
Behaviour and Dynamics of Fire Development & Smoke Spread



(1) Events immediately after ignition (2) Development of Plume (3) The plume-ceiling interaction

(4) Ceiling jet-wall interaction (5) Fully enclosed space with developed growing upper layer. (6) Further "smoke filling"

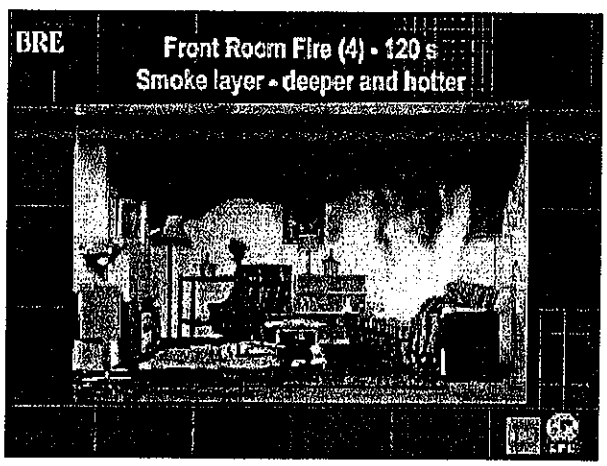
Behaviour and Dynamics of Fire Development & Smoke Spread



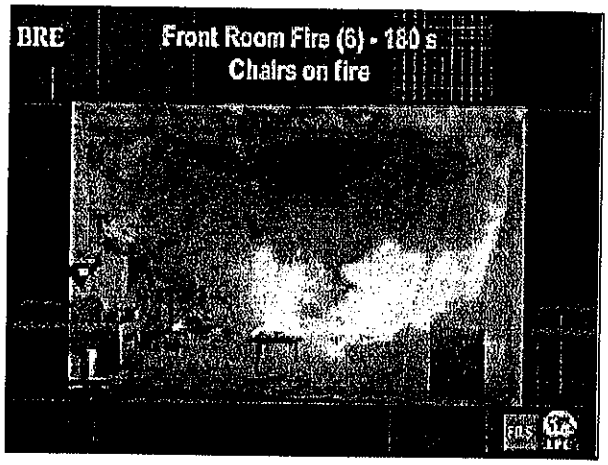
(7) Smoke and fresh air exchange between a room of fire involvement and an adjacent space











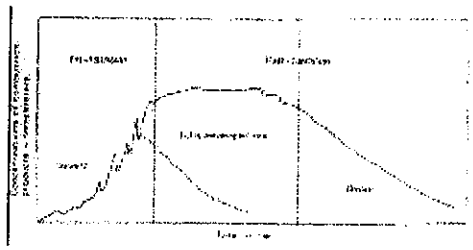




Behaviour and Dynamics of Fire Development & Smoke Spread

- No two fires are alike. Fact or fiction?
- Given sufficient fuel and oxygen, a fire will go through 5 stages of development:
  - Ignition
  - Smouldering phase
  - Growth stage
  - Fully developed period and
  - Decay phase
- Differentiation between fires due to time scales associated with each phase.
- These in turn are controlled by
  - The chemical and physical nature of the fuel load,
  - The size of the enclosure
  - The degree of ventilation and
  - Type of fire initiation

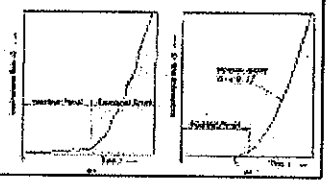
Behaviour and Dynamics of Fire Development & Smoke Spread



The Design Fire and Heat Release Rate

- The design fire has a board impact on the estimation of hazard in smoke management in large spaces.
- Design fires can be steady or unsteady,
- The size of the fire is expressed in terms of the rate of heat release,
- Fire growth is expressed in terms of the rate of change of the heat release rate or as a time constant that identifies the time required for the fire to attain a particular magnitude of the rate of heat release.

$$Q = \alpha(t - t_0)^2$$

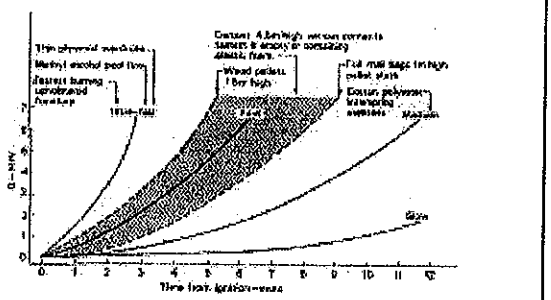


The Design Fire and Heat Release Rate

	Growth Constant		Growth Time To reach 1000 kW
T-Squared Fires	α (kW/s²)	α (Btu/s²)	t_g (s)
Slow	0.002931	0.002778	600
Medium	0.112700	0.111100	300
Fast	0.468900	0.044440	150
Ultra Fast	0.187800	0.177800	75

Table Various t^2 design fires growth rates

The Design Fire and Heat Release Rate



How Big is the Fire?

The development of a fire is dependent on a number of factors, including:

- The precise location of the ignition with respect to the fuel,
- The type of material present,
- The quantity of material present,
- The position of the materials relative to each other,
- Possible chemical reactions between material present if their containment is destroyed by fire,
- The position of material relative to walls, ceiling and similar
- The availability of oxygen.

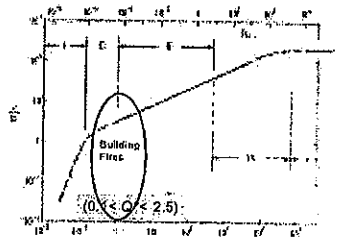
Typical Design Fire Size

- Designers have used different values of heat release rate for different type of buildings in the past. Typical values used in past projects are:
  - Airport and train terminal hall: up to 7 MW,
  - Shopping mall: 5 MW
  - Atrium: up to 7 MW
  - Train compartment: 1 MW

Fire Source (Non-dimensional HRR, Q*)

$$Q^* = \frac{Q}{\rho_\infty C_p T_\infty \sqrt{g} D^{5/2}}$$

Where :
Q is the heat release rate of the fire,
D is a characteristic fuel dimension
ρ_∞, Cp and To are respectively the ambient density, specific heat and temperature and g is the acceleration due to gravity



Fire Modelling Objectives

- What we want from fire modelling?
  - Is it for improving our understanding of fires?
  - It is for assessing the hazard & risk of fire
    - to the safety of life?
    - To the protection of property?
    - To examine its impact on the environment and heritage?
- What type of fire model do we want?
  - Is qualitative assessment sufficient for meeting one or more of the above objectives, or
  - Do we want full quantitative assessment involving full hazard and risk analysis of fire and its effects?
  - Are we looking for relative assessment of alternative design strategies?
  - Is it for evaluating trade-off between active and passive fire protection measures?

Fire Modelling Tools

- Simple calculation methods — Deterministic
  - ASKFRS, FPE Tools, Design guides
- Zone Models
  - Roofvent, CFAST, HAZARD
- CFD Models
  - CFX, Fluent, JASMINE, SOFIE, SMARTFIRE, STAR-CD, etc
- Risk Models — Probabilistic
  - CRISP, METHOD
- Evacuation Models
  - CRISP, SIMULEX, EXODUS, Gridflow, EXITT

Fire Safety Science and Engineering:
Reasons for Fire Modelling

- An important research tool in Fire Safety Science.
- Avoid full scale fire test.
  - Full scale fire test is very expensive
  - Sometimes, even full scale test is impossible, e.g.In the early design stage of buildings.
- Help fire safety designers and architects.
  - From concept design to the detail design
  - Evaluating and optimising engineering design
- Increase the flexibility and reliability of fire codes.
  - *World trends of fire codes: from "prescriptive approach" to "engineering performance based fire codes"*
- Help in fire accident investigation.

Fire Safety Science and Engineering:
Current Models for Fire Simulation

Chemical reaction model
(Combustion Model)
- -- Finite rate
- -- Eddy Break Up Model
- -- Eddy Dissipation Model
- √ Accurate, Comprehensive (fire ignition and extinction)
- × Lacking of burning material parameters

Simplified heat and mass release sources model
(Volumetric Heat/Mass Source Model)
- -- Using experimental and standard test data source
- √ Simpler and easier, less computer sources needed
- √ Using standard test data (Calorimeter) for materials
- × Limited to smoke movement simulation

Fire Safety Science and Engineering:
Fire and Smoke Modelling for Buildings

- Solving the basic conservation equations of mass, energy, and species.
  - *mass: combustion products generation*
  - *energy: heat release in fire*
  - *species: Soot, toxic products*
- Turbulence model
  - *k-ε two equation,*
  - *Large-Eddy Simulation*
- Fire sub-models
  - *Source term for mass, energy and species*
  - *Combustion model*
- Boundary conditions

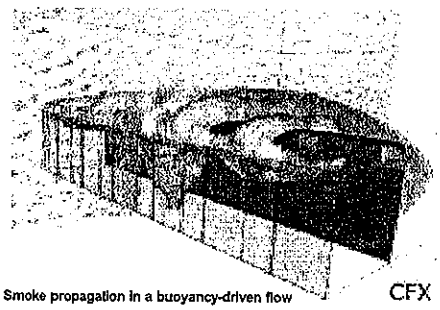
Fire Safety Science and Engineering:
Fire Safety Design Approaches

- Prescriptive fire safety design
  - --- *simple and easy*
  - × *only good for standard shaped room fire safety design*
  - × *depending upon experimental data source*
  - × *steady state calculation based*
  - √ *initial design*
- Performance based fire safety design
  - --- *using computer simulation as tools*
  - --- *non-standard shaped room space, e.g. multi-storey atrium*
  - --- *considering transient fire scenarios.*

Fire Safety Science and Engineering:
Engineering Performance Based Fire Safety Design

- Requirements
  - *hardware:*
    - *super computers: large memory*
    - *high computing speed*
  - *software:*
    - *well validated CFD software package.*
    - *validated fire sub-model.*
    - *expertise in Fire Safety Science and Engineering.*
  - *Knowledge of CFD is important.*

CFD Fire Modelling



Smoke propagation in a buoyancy-driven flow

CFX

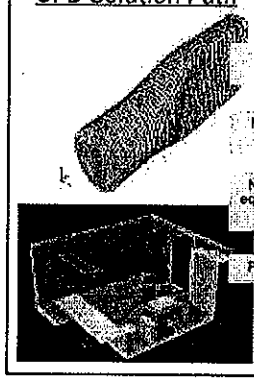
What is CFD?

- Computational Fluid Dynamics (CFD)
  - Numerical solution of the governing equations of heat and mass transfer; i.e., Computer Simulation

$$\frac{\partial}{\partial t}\iiint Q\,dV + \iint \left|\vec{F} - \vec{G}\right| \cdot d\vec{A} = 0$$

  - Conservation of Mass, Momentum, Energy

CFD Solution Path



Generate Problem Geometry

↓

Mesh (discretize) the Geometry

↓

Numerically solve the equations in an iterative process

↓

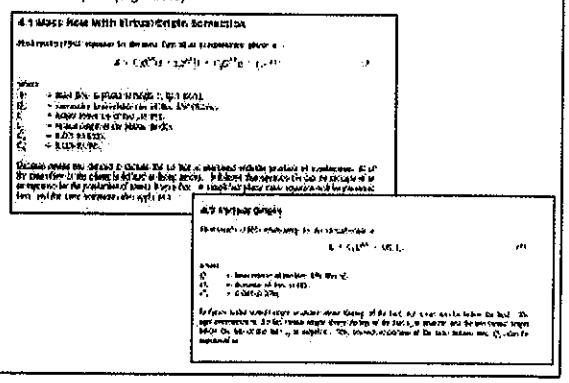
Post-Process Results



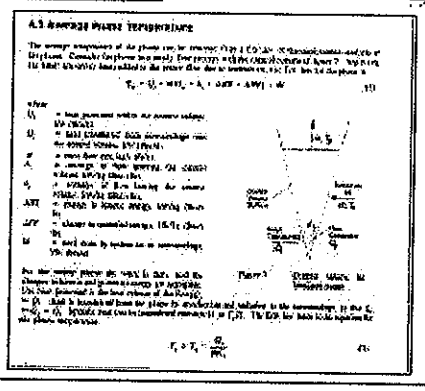
CFD Solution Path

- Set up the physics
  - Fluid and solid properties
  - Conjugate Heat Transfer
  - Turbulence, buoyancy.....
- Set the boundary conditions
- Initial conditions
- Solver controls
  - convergence criteria
  - 1st or 2nd order
  - parallel / serial / adaptation

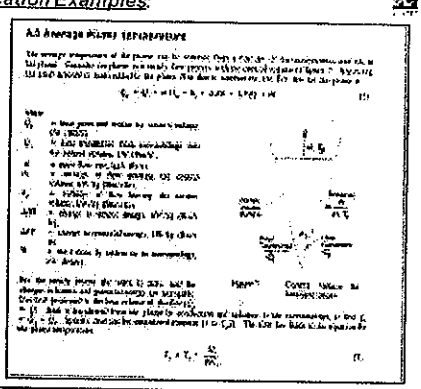
Application Examples:
Basic Principles (e.g Klote)



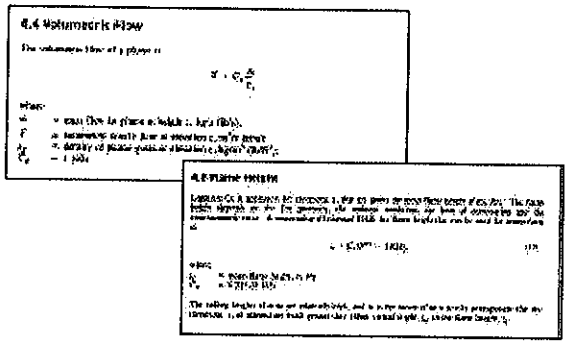
Application Examples:



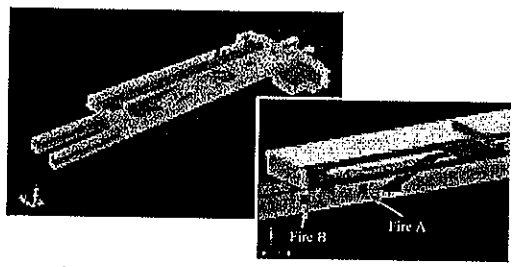
Application Examples:



Application Examples:

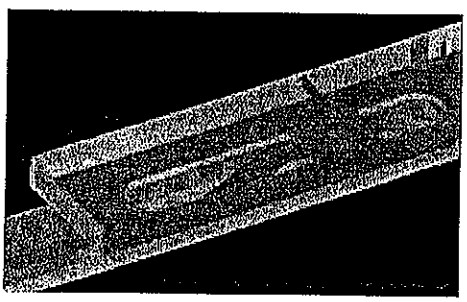


Application Examples:
Smoke Simulation for A MRT Station



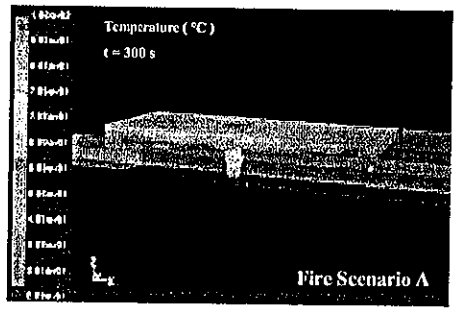
Geometry configuration of the MRT station

Application Examples:
Smoke simulation for A MRT Station



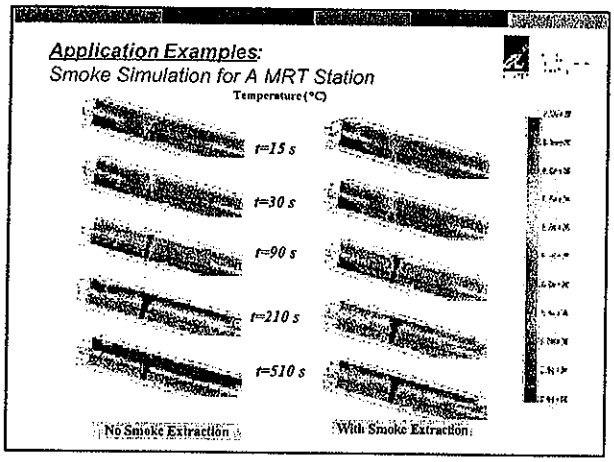
Unstructured meshing scheme for the MRT station

Application Examples:
Smoke Simulation for A MRT Station

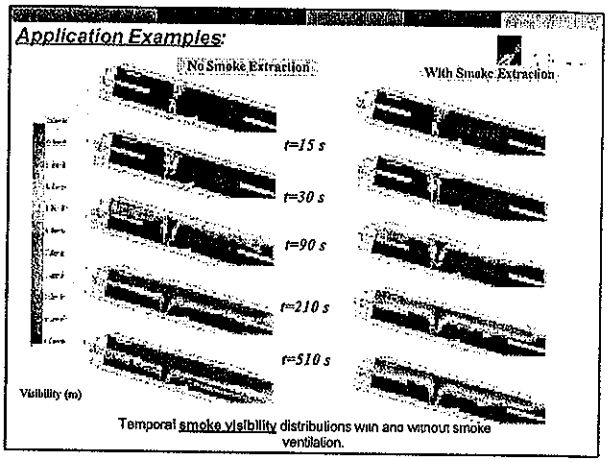


Smoke temperature distribution at t=300s for fire scenario A.

Application Examples:
Smoke Simulation for A MRT Station

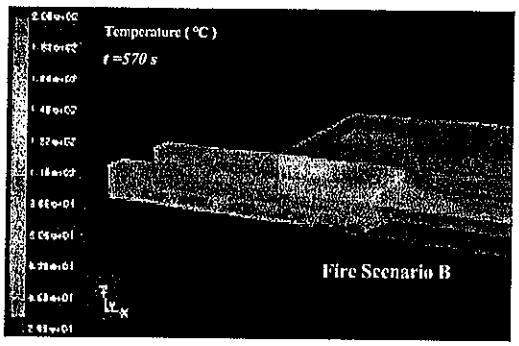


Application Examples:

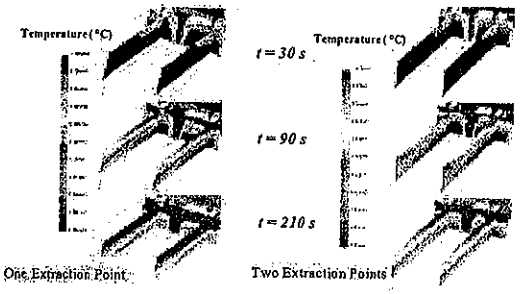


Temporal smoke visibility distributions with and without smoke ventilation.

Application Examples:
Smoke Simulation for A MRT Station

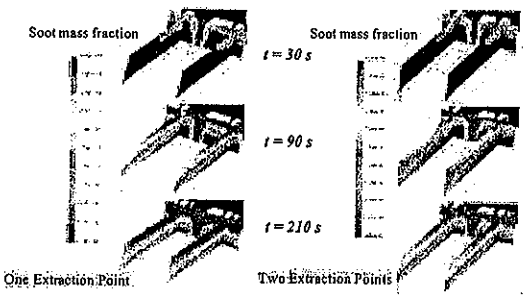


Application Examples:
Smoke simulation for a MRT station



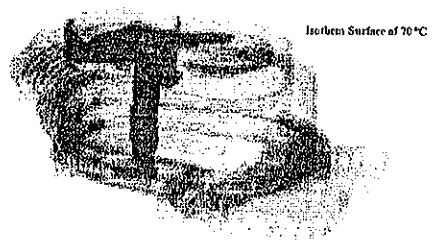
Temporal temperature distributions with one or two extraction points .

Application Examples:
Smoke simulation for a MRT Station



Temporal soot mass fraction distributions with one or two extraction points

Application Examples:
Smoke Simulation



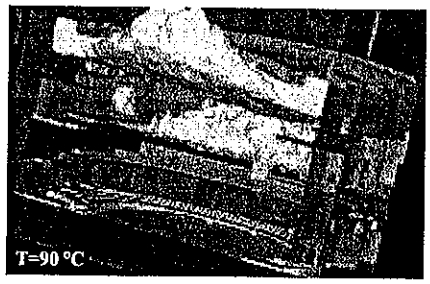
Stall room fire simulation for the Concert Hall Auditorium

Application Examples:
Smoke Simulation



Stall room fire simulation for Lyric Theatre Auditorium

Application Examples:
Smoke Simulation



First tire fire simulation for Lyric Theatre Auditorium

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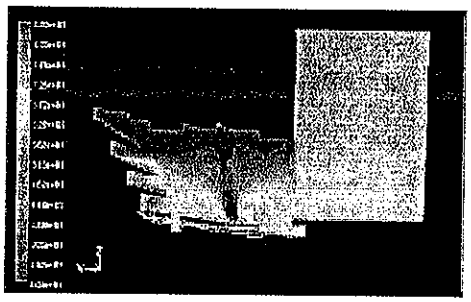
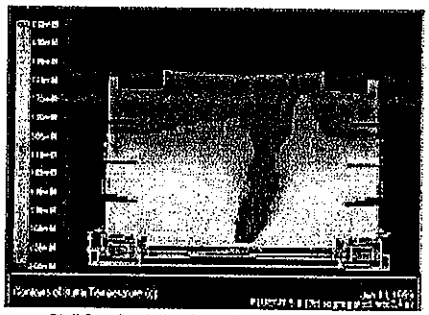
Application Examples:
Smoke Simulation



Stall fire simulation for Lyric Theatre Auditorium

Application Examples:
Smoke Simulation



Stall fire simulation for Lyric Theatre Auditorium

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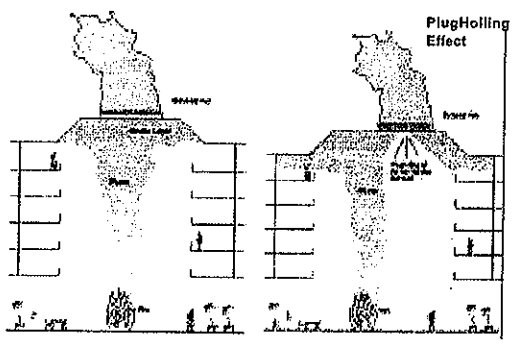
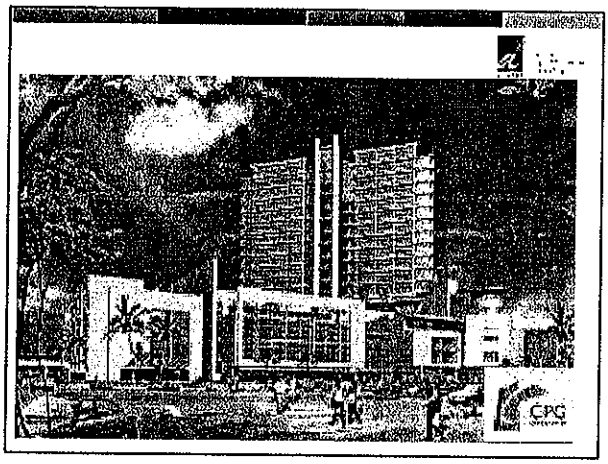
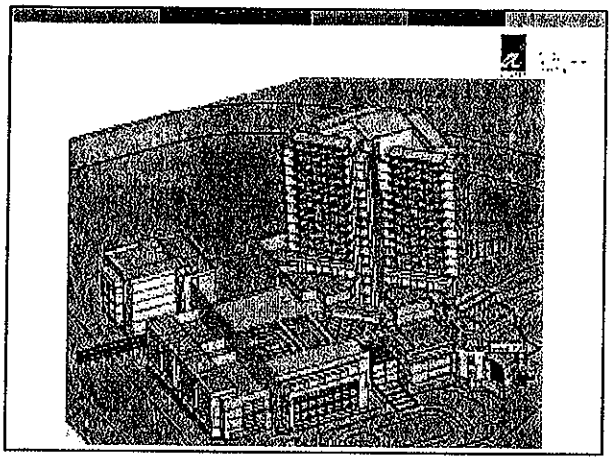
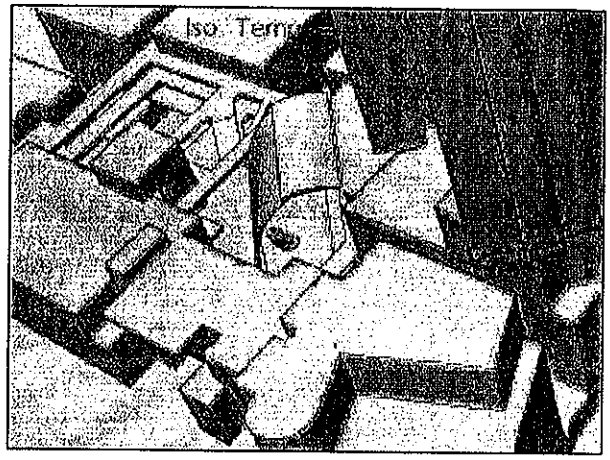
Application Examples:
High Rise Building/Atrim





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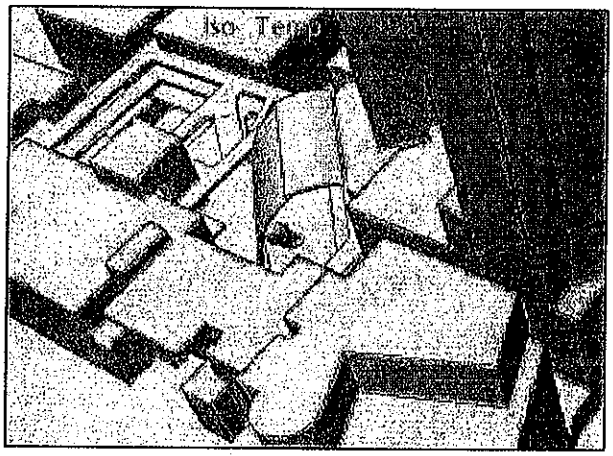
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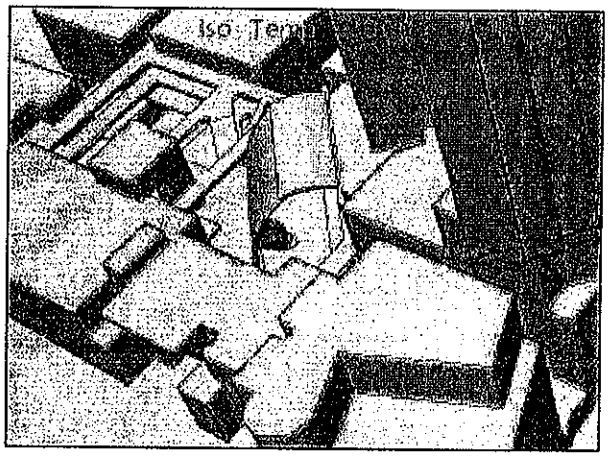
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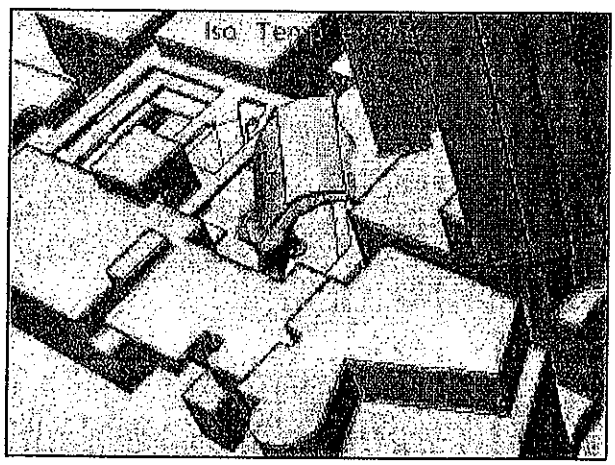
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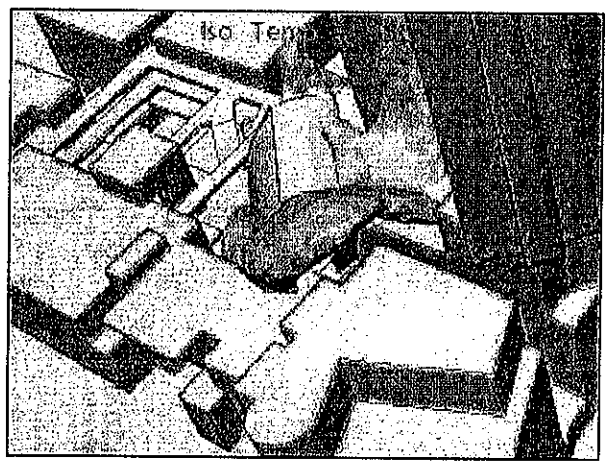
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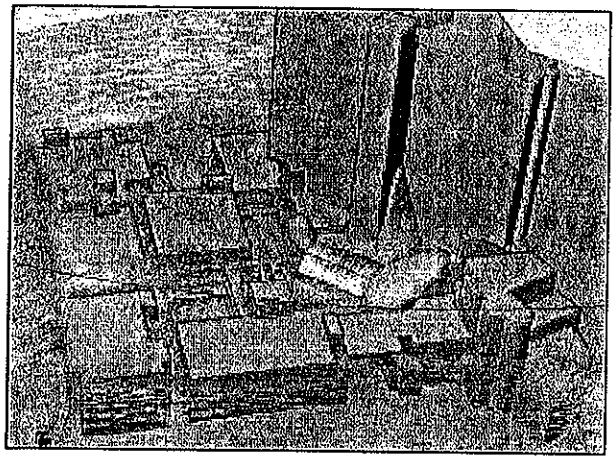
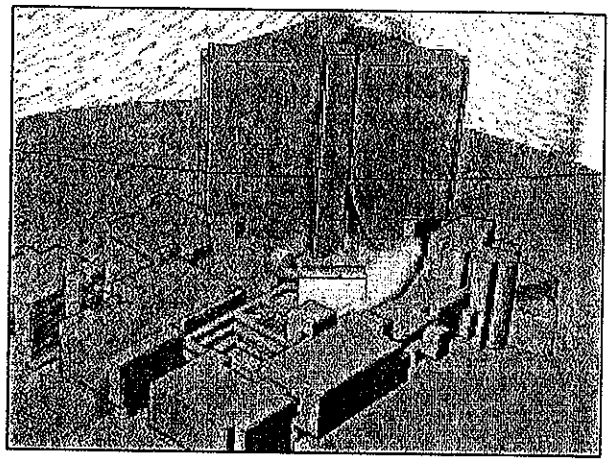
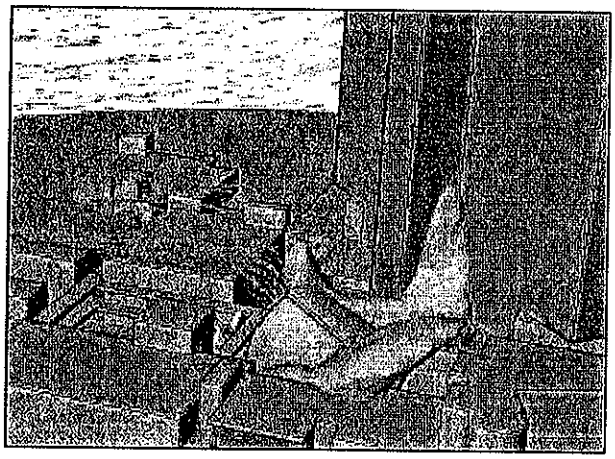
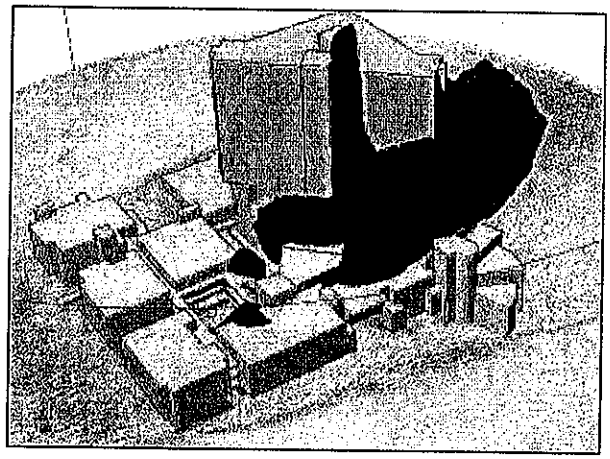








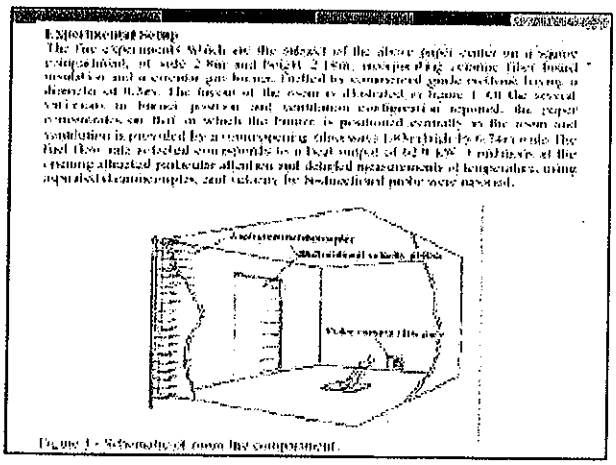
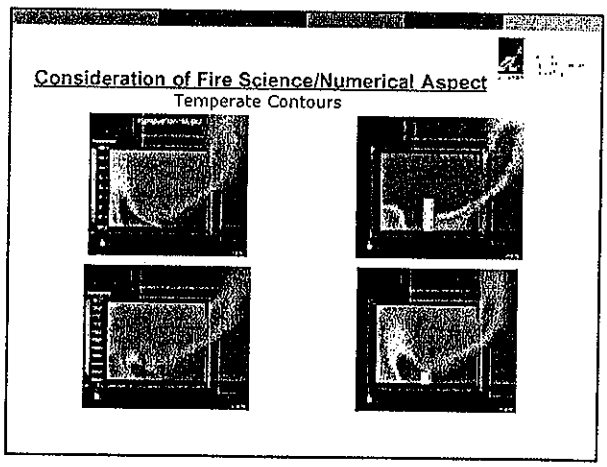
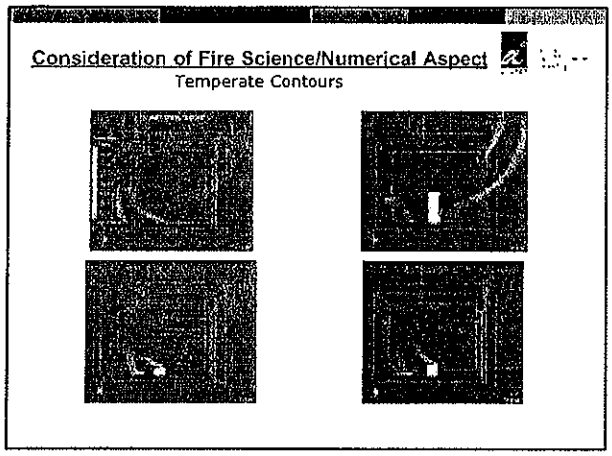
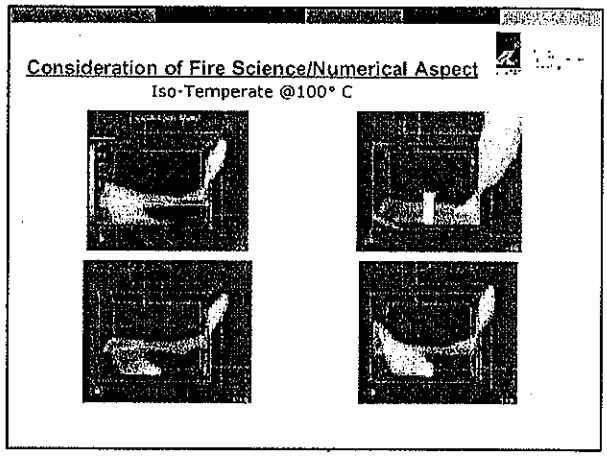
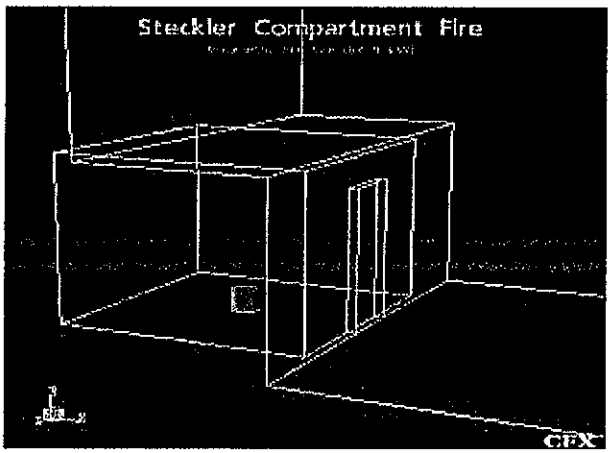


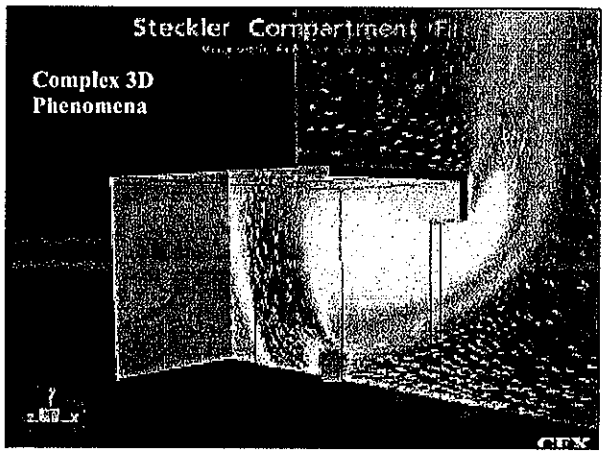
Figure 1 - Schematic of room fire compartment.

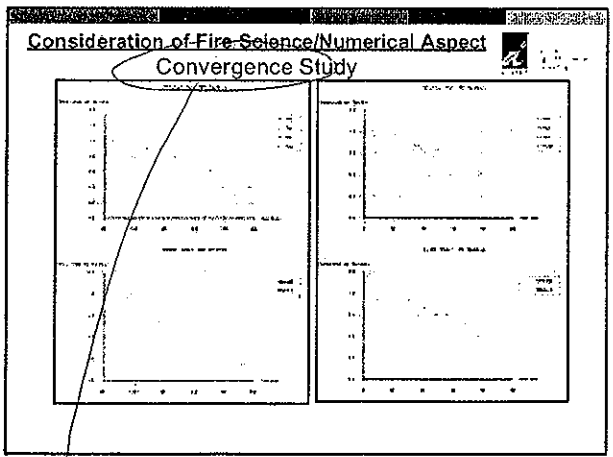


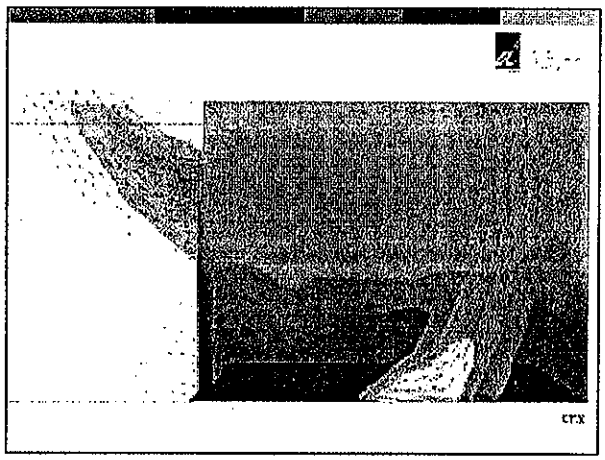








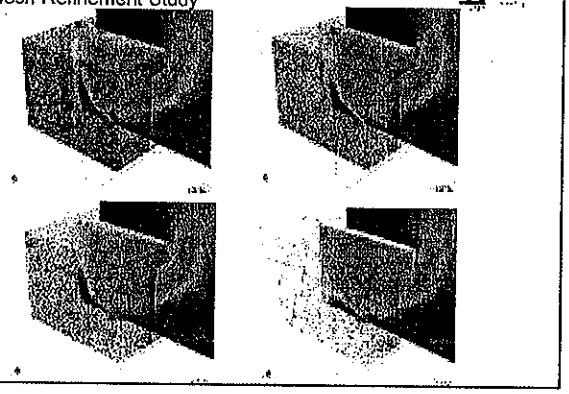




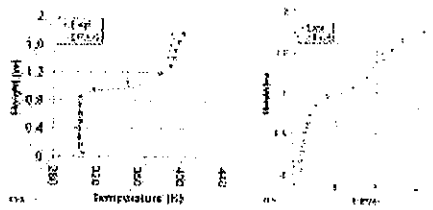
very important - look at the heat & mass pattern
Do not trust only the simulator.

Consideration of Fire Science/Numerical Aspect

Mesh Refinement Study



Numerical Results vs Experimental Measurements



Conclusions

- Smoke and heat exhaust ventilation design forms an integral part of the fire safety engineering concept for many modern atrium buildings, where large undivided spaces require compliance with the appropriate performance based regulations.
- A smoke ventilation system design may be based on empirical based engineering models, e.g. zone models, in cases where the building geometry is not too demanding. In cases of particularly large volumes or complex architectural features, however, a CFD assessment may be required. This has been illustrated in this paper for a number of cases study involves complicated building geometry.
- This paper has also provided guidance and discussion of important issues related to fire science and numerical aspects of CFD that require special consideration for ensuring 'correct' use of CFD for practical fire application.

ATRIA

EXTRACT FROM FIRE CODE 2002

A) EXTRACT FROM FIRE CODE 2002

1) CHAPTER 3 - STRUCTURAL FIRE PRECAUTIONS

Provision for atrium spaces

(a) The minimum plan area of the Atrium void shall be not less than 93 m^2 and no horizontal dimension between opposite edges of the floor opening is less than 6 m wide; and

(b) Occupancy within the floor space of the Atrium meets with the specification for low or ordinary hazard content; and

(c) The atrium is open and unobstructed in a manner such that it may be assumed that a fire in any part of the space will be readily obvious to the occupants before it becomes a hazard; and

(d) The building is fitted throughout with an automatic sprinkler system to comply with the requirements in Chapter 6; and

(e) The building is fitted with an engineered smoke control system in accordance with cl.7.6; and

(f) Provision of openings and enclosures, and the planning of means of escape shall be subject to the approval of the Relevant Authority.

2) CHAPTER 7 - MECHANICAL VENTILATION AND SMOKE CONTROL SYSTEMS

7.6.8 For cases where smoke is removed from the circulation space or atrium space the smoke reservoir size for a smoke ventilation system shall not exceed :

Removal of smoke from circulation or atrium spaces

(a) 1000 sq m for natural smoke ventilation system.

(b) 1300 sq m for mechanical smoke ventilation system.

7.6.9 For cases where smoke is removed from the circulation space or atrium space, the rooms discharging smoke into the circulation space/atrium spaces shall either:

Discharge of smoke into circulation/

(a) have a floor area of not exceeding 1000 sq m (for natural ventilation system) or 1300 sq m (for mechanical ventilation system) or atrium spaces

(b) be subdivided such that smoke is vented to the circulation space or atrium only from part of the room with floor area not exceeding 1000 sq m (for natural ventilation system) or 1300 sq m (for mechanical ventilation system) that are adjacent to the circulation space or atrium. However, the remainder of the room needs to be provided with an independent smoke ventilation system(s).

7.6.10 The maximum length of the smoke reservoir shall not exceed 60 m.

Length of smoke reservoir

7.6.11 Adequate arrangement(s) shall be made in each smoke reservoir for the removal of smoke in a way that will prevent the formation of stagnant regions.

Stagnant regions

7.6.12 Owing to practical limitation, a smoke ventilation system shall have:

(a) a maximum mass flow not exceeding 175 kg/s; and

(b) a minimum smoke layer temperature of 18°C above ambient.

7.6.13 Replacement air shall be by natural means drawing air directly from the external.

(a) The design replacement air discharge velocity shall not exceed 5.0 m/s to prevent the escapees being hindered by the air flow.

Replacement air velocity

(b) Replacement air intake shall be sited at least 5 m away from any exhaust air discharge.

Distance from exhaust air discharge

(c) Replacement air shall be discharged at a low level, at least 1.5 m beneath the designed smoke layer, to prevent "fogging" of the lower clear zone.

Replacement discharge position

(d) Where the inlet cannot be sited at least 1.5 m below the smoke layer, a smoke curtain or a barrier shall be used to prevent replacement air distorting the smoke layer.

Siting of inlets

(e) Where replacement air is taken through inlet air ventilators or doorways, devices shall be incorporated to automatically open such inlet ventilators and doors to admit replacement air upon activation of the smoke ventilation system.

7.6.14 For cases where the smoke reservoir is above the false ceiling, the ceiling shall be of perforated type with at least 25% opening.

Perforated ceiling

7.6.15 The smoke ventilation system shall be provided with secondary source of power supply.

Emergency power supply

7.6.16 The smoke ventilation system shall be activated by smoke detectors located in the smoke control zone. Use of smoke detectors for activation must be carefully
designed so that accidental or premature activation of smoke detectors on a non-fire zone due to smoke spills or spread from other areas must be avoided.

Mode of activation

7.6.17 Provision of activating smoke detectors shall comply with CP 10.

7.6.18 A remote manual activation and control switches as well as visual indication of the operation status of the smoke ventilation system shall also be provided at the fire command centre and where there is no fire command centre, at main fire indicator board.

Manual activation

7.6.19 Except for ventilation systems in Cl. 5.2.1 (g) and (h), all other air-conditioning and ventilation systems within the areas served shall be shut down automatically upon activation of the smoke ventilation system.

Shut down of other air conditioning & ventilation systems

7.6.20 Either a standby fan or multiple fans with excess capacity shall be provided for each mechanical smoke ventilation system such that in the event the duty fan or the largest capacity fan fails, the designed smoke extraction rate will still be met. The standby fan shall be automatically activated in the event the duty fan fails.

Standby fans or multiple fans

7.6.21 Fans shall be capable of operating at 250°C for 2 hours.

7.6.22 The fans and associated smoke control equipment shall be wired in protected circuits designed to ensure continued operation in the event of the fire.

Protected circuits

7.6.23 The electrical supply to the fans shall, in each case, be connected to a sub-main circuit exclusive thereto after the main isolator of the building. The cables shall be of at least 1-hour fire resistance in accordance with SS CP 299.

Electrical supply

7.6.24 Smoke ventilation ducts (both exhaust and replacement air ducts) shall be of at least 1 hour fire resistance. Where a duct passes through other fire compartment of higher rating, the duct shall be constructed to have the rating as that of the compartment. The rating shall apply to fire exposure from both internal and external of the duct or structure and the duct shall also comply with subcl.7.1.1(j).

7.6.25 Fire damper shall not be fitted in the smoke ventilation system.

7.6.26 The time taken for the smoke ventilation system within a smoke zone to be fully operational shall not exceed 60 seconds from system activation.

7.6.27 For natural smoke ventilation system the natural ventilators shall be :

Fail-safe system

(a) in the "open" position in the event of power/system failure; and

(b) positioned such that they will not be adversely affected by positive wind pressure.

7.6.28 Natural exhaust ventilation shall not be used together with powered smoke exhaust ventilation.

7.6.29 All smoke curtains where required, unless permanently fixed in position, shall be brought into position automatically to provide adequate smoke-tightness and effective depth.

Smoke curtain

7.6.30 Smoke curtain or other smoke barrier at any access route forming part of or leading to a means of escape shall not in their operational position obstruct the escape of people through such route.

Obstruction to means of escape

7.6.31 Where glass walls or panels are being used as smoke screens to form a smoke reservoir or as channeling screens, they shall be able to withstand the design highest temperature.

Smoke or chanelling screens

7.6.32 All smoke control equipment (including smoke curtains) shall be supplied and installed in accordance with the accepted standards eg BS 7346.

3.2 PROVISION OF COMPARTMENT WALLS AND COMPARTMENT FLOORS

3.2.1 Any building other than a building of Purpose Group I which has – Compartment size – floor area & (a) Any storey the floor area of which exceeds that specified as relevant to a building of that height in column (2) of Table 3.2A, or cubical extent (b) A cubic capacity which exceeds that specified as relevant in column (3) of Table 3.2A, shall be divided into compartments by means of compartment walls and compartment floors so that –

(i) no such compartment has any storey the floor area of which exceeds the area specified as relevant to the building in column (2) of the Table, and

(ii) no such compartment has a cubic capacity which exceeds that specified as relevant in column (3) of the Table.

3.2.2 In computing the cubical extent of compartments in shops, similar premises and in single storey factory buildings, a height of 4m may be used where the actual height exceeds that figure, provided that this rule for measurement shall not be applied when a compartment comprises more than one storey or contains mezzanine, galleries or lofts. Cubical extent for compartment exceeding 4m in height

3.2.3 Where however, the Relevant Authority is satisfied that additional floor area and cubical extent are necessary for any such building or compartment or part thereof, as aforesaid, he may consent to such additional floor area and cubical extent, provided :

Relevant authority may consent to greater sizes

(a) Such building or compartment thereof is fitted throughout with an automatic sprinkler system, which complies with the requirements in Chapter 6,

(b) There is proper accessibility of site to fire fighting appliances, in compliance with the requirements in Chapter 4,

(c) All other measures have been or will be taken and maintained for lessening so far as is reasonably practicable, any danger from fire. Such consent shall continue in force only while such building or compartment is used for the purposes in respect of which such consent was given.

(ii)All doors to the lobby shall each have fire resistance of not less than half an hour and fitted with automatic self-closing device.

Tenancy unit

3.2.6 The Relevant Authority may consent to modify the requirements under Cl. 3.2.1 and 3.2.4(a) and (b) of this Code for the design of 'Atrium spaces' in a building
provided the following conditions are complied with :

Provision for atrium spaces

(a) The minimum plan area of the Atrium void shall be not less than 93 m^2 and no horizontal dimension between opposite edges of the floor opening is less than 6 m wide; and

(b) Occupancy within the floor space of the Atrium meets with the specification for low or ordinary hazard content; and

(c) The atrium is open and unobstructed in a manner such that it may be assumed that a fire in any part of the space will be readily obvious to the occupants before it becomes a hazard; and

(d) The building is fitted throughout with an automatic sprinkler system to comply with the requirements in Chapter 6; and

(e) The building is fitted with an engineered smoke control system in accordance with cl.7.6; and

(f) Provision of openings and enclosures, and the planning of means of escape shall be subject to the approval of the Relevant Authority.

3.2.7 Buildings of High Hazard Occupancy

(a) The compartment of buildings of high hazard Buildings of occupancy shall not exceed one half of the sizes given in Table 3.2A and each compartment shall comprise one storey only; and high hazard occupancy

(b) No storey of a building, the habitable height of which is more than 24 m, shall be used for the bulk storage of goods or substances of highly combustible nature unless the building is provided with a sprinkler system to comply with Chapter 6; and

(c) The type of storage materials or substances shall not include the following:

(i) materials that will flame up by themselves without the presence of any fire source below the ignition temperature of 200°C; and

(ii) combustible/highly flammable materials which include those highlighted in sub-clauses (a), (b), (c) and (d) of cl.1.2.39.

3.2.8 The requirements of Cl.3.2.1 may be exempted under the following circumstances:

(a) Buildings used solely for the sale, storage, processing and packaging of goods and substances of a non-combustible nature, provided that any other parts of the buildings used otherwise as described shall be separated by compartment walls and compartment floors in compliance with the requirements of the relevant provisions for compartment walls and compartment floors, and Exemption from Cl. 3.2.1 on size limitation of compartment

(b) Single storey buildings of Purpose Group VI, provided that the buildings are used solely for the sale, storage, processing & packaging of goods & substances of a non-combustible nature, and (c) Open sided car parking decks having not less than 50% of the sides permanently open and such openings being evenly distributed as to provide cross ventilation to all 7.5

SMOKE CONTROL SYSTEM

7.5.1 A smoke control system specified in Cl.7.6 shall be provided where:

Smoke control system

(i) The requirements for compartmentation specified in Cl. 3.2.1 and 3.2.4(a) and (b) are relaxed under the conditions in Cl. 3.2.6 for `Atrium spaces' in a building; and

(ii) The total floor area of any compartment in a building or part of a building exceeds 5000 sq.m.

7.6 **ENGINEERED SMOKE CONTROL SYSTEM**

7.6.1 The engineered smoke control system shall be in the form of a smoke ventilation system by natural or mechanical extraction designed in accordance with:

Acceptable design guidance

(a) BR 186 - Design principles for smoke ventilation in enclosed shopping centres; and

(b) BR 258 - Design approaches for smoke control in atrium buildings; or

(c) Other acceptable standards.

(Note: BR 186 and 258 are reports published by the Fire Research Station, Building Research Establishment, Borehamwood, Herts WD62BL).

7.6.2 The building to be provided with smoke ventilation system shall be sprinkler protected.

Sprinkler system

7.6.3 Capacity of the smoke ventilation system shall be calculated based on the incidence of a likely maximum fire size for a sprinkler controlled fire as recommended in the following table:

Occupancy (sprinklered)	Fire Size	
	Heat Output (MW)	Perimeter of Fire (m)
Shops	5	12
Offices	1	14
Hotel Guest Room	0.5	6
Hotel Public Areas	2.5	12
Assembly Occupancy with fixed seating	2.5	12

7.6.4 The capacity of a smoke ventilation system shall be capable of handling the largest demand for smoke exhaust from the worst case scenario.

Capacity of smoke ventilation system

7.6.5 The design smoke layer base shall be above the heads of people escaping beneath it. The minimum height shall be 2.5 m.

Clear layer

7.6.6 Smoke reservoirs to prevent the lateral spread of smoke, and to collect smoke for removal shall be of noncombustible construction capable of withstanding smoke temperatures.

Smoke reservoir

7.6.7 For cases where smoke is removed from the room of origin the smoke reservoir size for a smoke ventilation system shall not exceed:

Smoke reservoir size

(a) 2000 sq m for natural smoke ventilation system.
(b) 2600 sq m for mechanical smoke ventilation system.

7.6.8 For cases where smoke is removed from the circulation space or atrium space the smoke reservoir size for a smoke ventilation system shall not exceed :

Removal of smoke from circulation or atrium spaces

(a) 1000 sq m for natural smoke ventilation system.
(b) 1300 sq m for mechanical smoke ventilation system.

7.6.9 For cases where smoke is removed from the circulation space or atrium space, the rooms discharging smoke into the circulation space/atrium spaces shall either:

Discharge of smoke into circulation/

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(b) be subdivided such that smoke is vented to the circulation space or atrium only from part of the room with floor area not exceeding 1000 sq m (for natural ventilation system) or 1300 sq m (for mechanical ventilation system) that are adjacent to the circulation space or atrium. However, the remainder of the room needs to be provided with an independent smoke ventilation system(s).

7.6.10 The maximum length of the smoke reservoir shall not exceed 60 m.

Length of smoke reservoir

7.6.11 Adequate arrangement(s) shall be made in each smoke reservoir for the removal of smoke in a way that will prevent the formation of stagnant regions.

Stagnant regions

7.6.12 Owing to practical limitation, a smoke ventilation system shall have:

(a) a maximum mass flow not exceeding 175 kg/s; and

(b) a minimum smoke layer temperature of 18oC above ambient.

7.6.13 Replacement air shall be by natural means drawing air directly from the external.

(a) The design replacement air discharge velocity shall not exceed 5.0 m/s to prevent the escapees being hindered by the air flow.

Replacement air velocity

(b) Replacement air intake shall be sited at least 5 m away from any exhaust air discharge.

Distance from exhaust air discharge

(c) Replacement air shall be discharged at a low level, at least 1.5 m beneath the designed smoke layer, to prevent "fogging" of the lower clear zone.

Replacement discharge position

(d) Where the inlet cannot be sited at least 1.5 m below the smoke layer, a smoke curtain or a barrier shall be used to prevent replacement air distorting the smoke layer.

Siting of inlets

(e) Where replacement air is taken through inlet air ventilators or doorways, devices shall be incorporated to automatically open such inlet ventilators and doors to admit replacement air upon activation of the smoke ventilation system.

7.6.14 For cases where the smoke reservoir is above the false ceiling, the ceiling shall be of perforated type with at least 25% opening.

Perforated ceiling

7.6.15 The smoke ventilation system shall be provided with secondary source of power supply.

Emergency power supply

7.6.16 The smoke ventilation system shall be activated by smoke detectors located in the smoke control zone. Use of smoke detectors for activation must be carefully designed so that accidental or premature activation of smoke detectors on a non-fire zone due to smoke spills or spread from other areas must be avoided.

Mode of activation

7.6.17 Provision of activating smoke detectors shall comply with CP 10.

7.6.18 A remote manual activation and control switches as well as visual indication of the operation status of the smoke ventilation system shall also be provided at the fire command centre and where there is no fire command centre, at main fire indicator board.

Manual activation

7.6.19 Except for ventilation systems in Cl. 5.2.1 (g) and (h), all other air-conditioning and ventilation systems within the areas served shall be shut down automatically upon activation of the smoke ventilation system.

Shut down of other air-conditioning & ventilation systems

7.6.20 Either a standby fan or multiple fans with excess capacity shall be provided for each mechanical smoke ventilation system such that in the event the duty fan or the largest capacity fan fails, the designed smoke extraction rate will still be met. The standby fan shall be automatically activated in the event the duty fan fails.

Standby fans or multiple-fans

7.6.21 Fans shall be capable of operating at 250°C for 2 hours.

7.6.22 The fans and associated smoke control equipment shall be wired in protected circuits designed to ensure continued operation in the event of the fire.

Protected circuits

7.6.23 The electrical supply to the fans shall, in each case, be connected to a sub-main circuit exclusive thereto after the main isolator of the building. The cables shall be of at least 1-hour fire resistance in accordance with SS CP 299.

Electrical supply

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7.6.26 The time taken for the smoke ventilation system within a smoke zone to be fully operational shall not exceed 60 seconds from system activation.

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Fail-safe system

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Smoke curtain

7.6.30 Smoke curtain or other smoke barrier at any access route forming part of or leading to a means of escape shall not in their operational position obstruct the escape of people through such route. Obstruction to means of escape

7.6.31 Where glass walls or panels are being used as smoke screens to form a smoke reservoir or as channeling screens, they shall be able to withstand the design highest temperature. Smoke or channeling screens

7.6.32 All smoke control equipment (including smoke curtains) shall be supplied and installed in accordance with the accepted standards e.g. BS 7346. parts of the car parking areas.

9.4 BRIEF EXPLANATORY NOTES FOR OUTLINE REPORT ON FIRE PROTECTION AND LIFE SAFETY FEATURES

B Fire Safety Design Concept

This would include the safety design concept incorporated in the project such as the application of design and provision of areas of refuge, smoke barriers, additional compartment walls/ doors in sectionalizing the **large atrium floors etc** and other added fire safety features provided over and above the intent of the Code of Practice for Fire Precautions in Buildings 2002.

ASHRAE

ASHRAE SINGAPORE CHAPTER

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. SINGAPORE CHAPTER
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