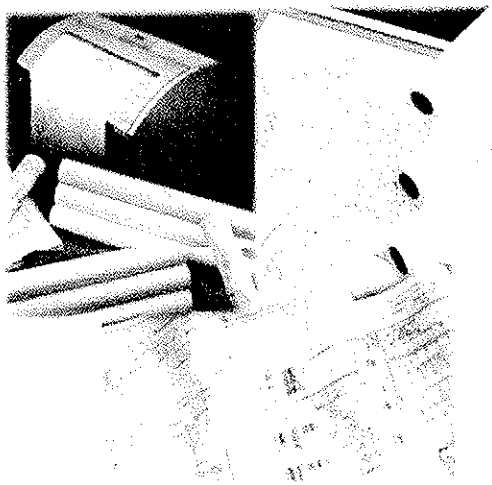
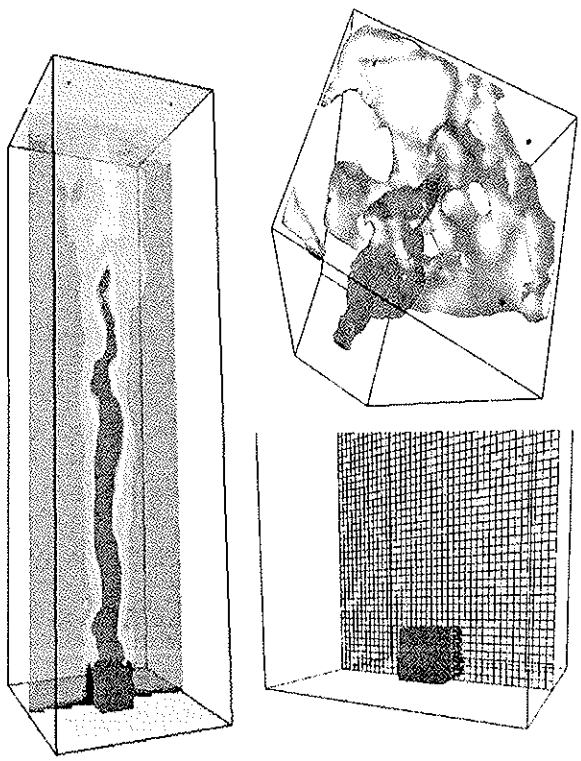
An Introduction to Performance Based Fire Design



EO Edmund Choo

Performance-Based Sytem

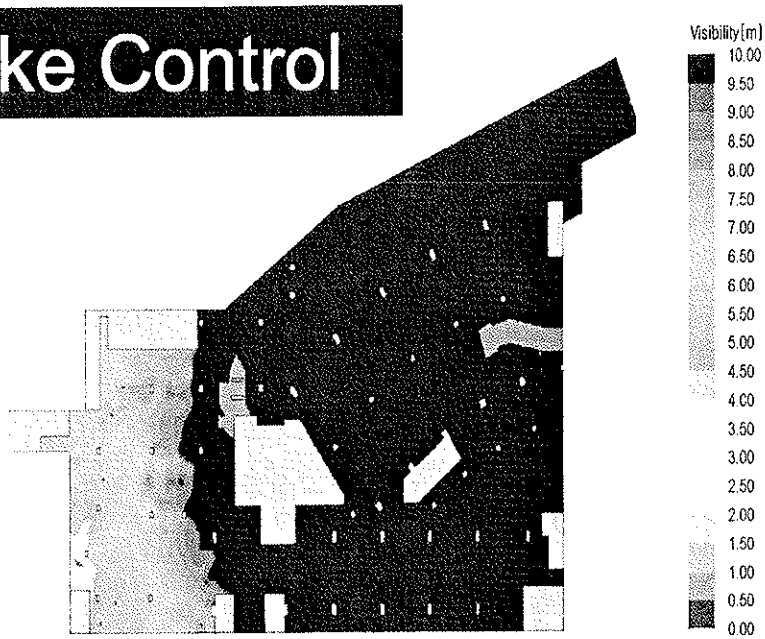
- Introduced in 2004
- Alternative to the prescriptive system



Application to date

- Smoke Control

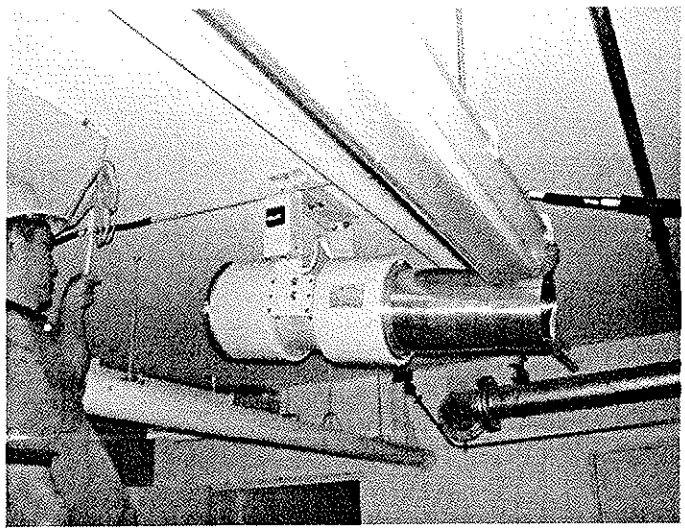
Exceeding of smoke reservoir limits



Application to date

- Smoke Purging (Basement Car Parks)

Duct-Less Fan System



Application to date

• Structural Protection

•Non-protection to appropriate secondary beams



Application to date

• Travel Distance

Exceeding of prescriptive travel distance limits



Application to date

- Exit capacity

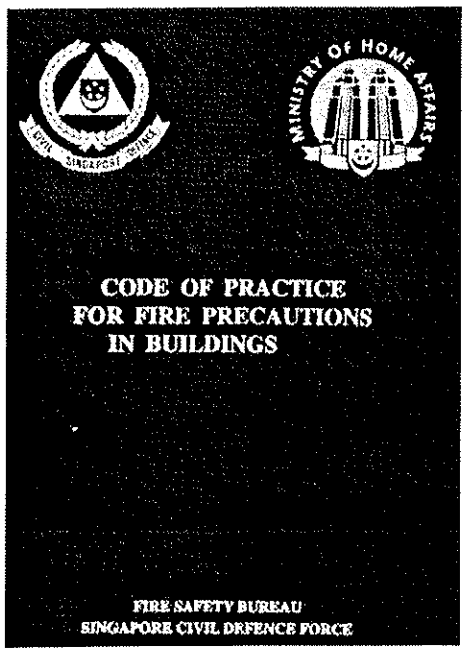
Exceeding of provided capacity for means of escape



Application to date

- Revision to Prescriptive Code

Fire Safety Engineering used to review Fire Code requirements
Eg airwell sizing



Paramount Importance

Life Safety

Pre-Flashover

Life Safety Evaluation

ASET

Available Safe Egress Time

>

RSET

Required Safe Egress Time

ASET

determined by

Fire Modelling

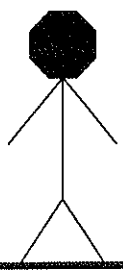
ASET

determined by

Fire Modelling

ZONE MODELLING

Hot Upper Layer



Cold Lower Layer



Room

Zone models solve equations for conservation of

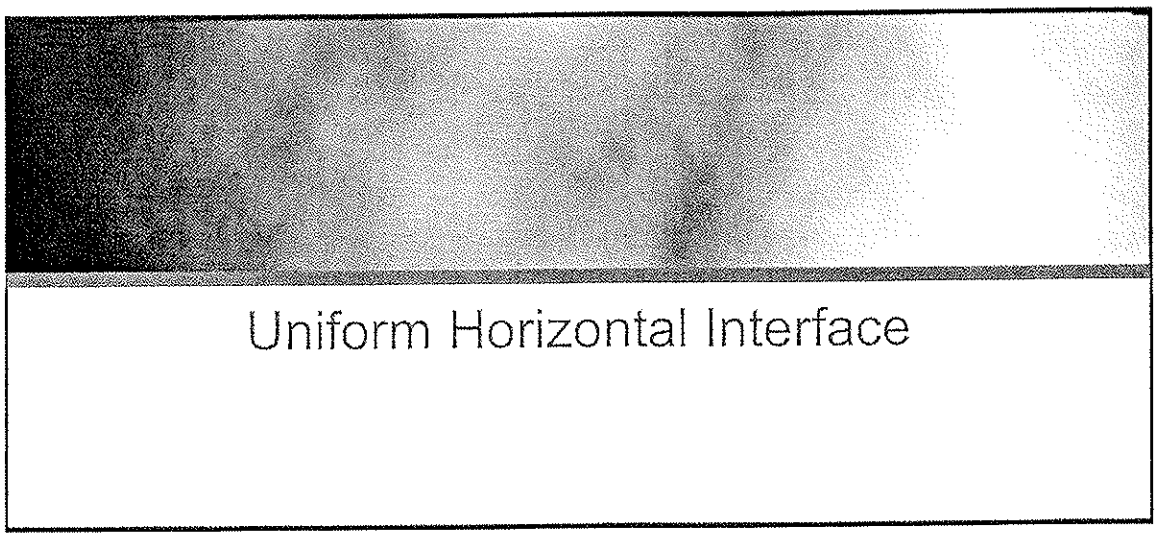
(i) Mass
(ii) Energy
(iii) Momentum
(iv) Ideal gas law

Major Assumptions

(i) Stratification of hot layer with uniform horizontal interface
(ii) Homogeneity across each layer
(iii) Rectilinear compartments
(iv) No transport lag from fire to ceiling and across ceiling

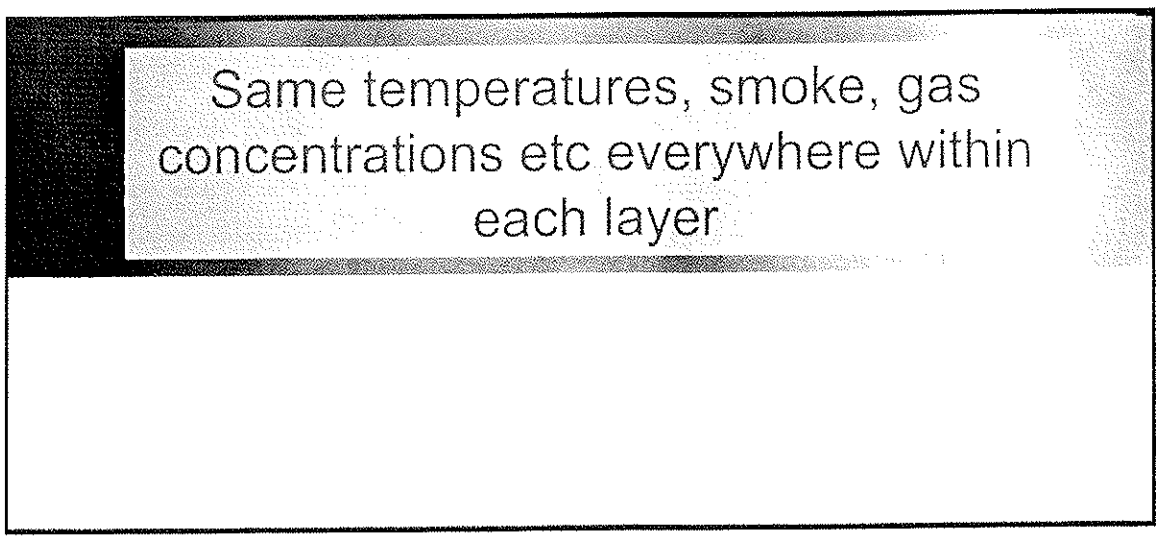
Major Assumptions

(i) Stratification of hot layer with uniform horizontal interface



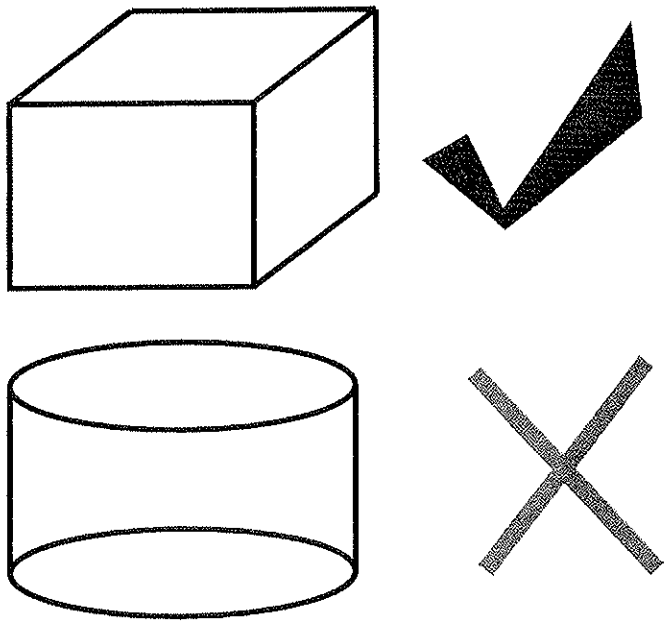
Major Assumptions

(ii) Homogeneity across each layer



Major Assumptions

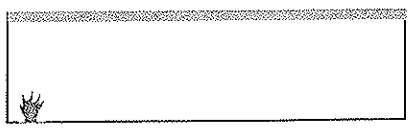
(iii) Rectilinear compartments



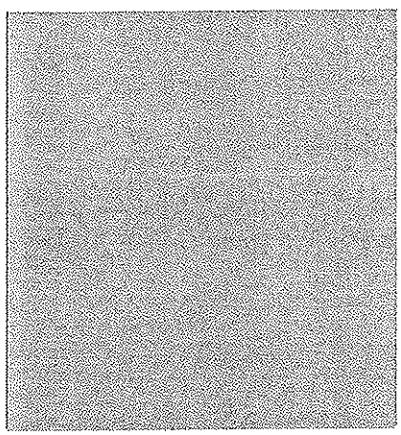
Major Assumptions

(i) No transport lag from fire to ceiling and across ceiling

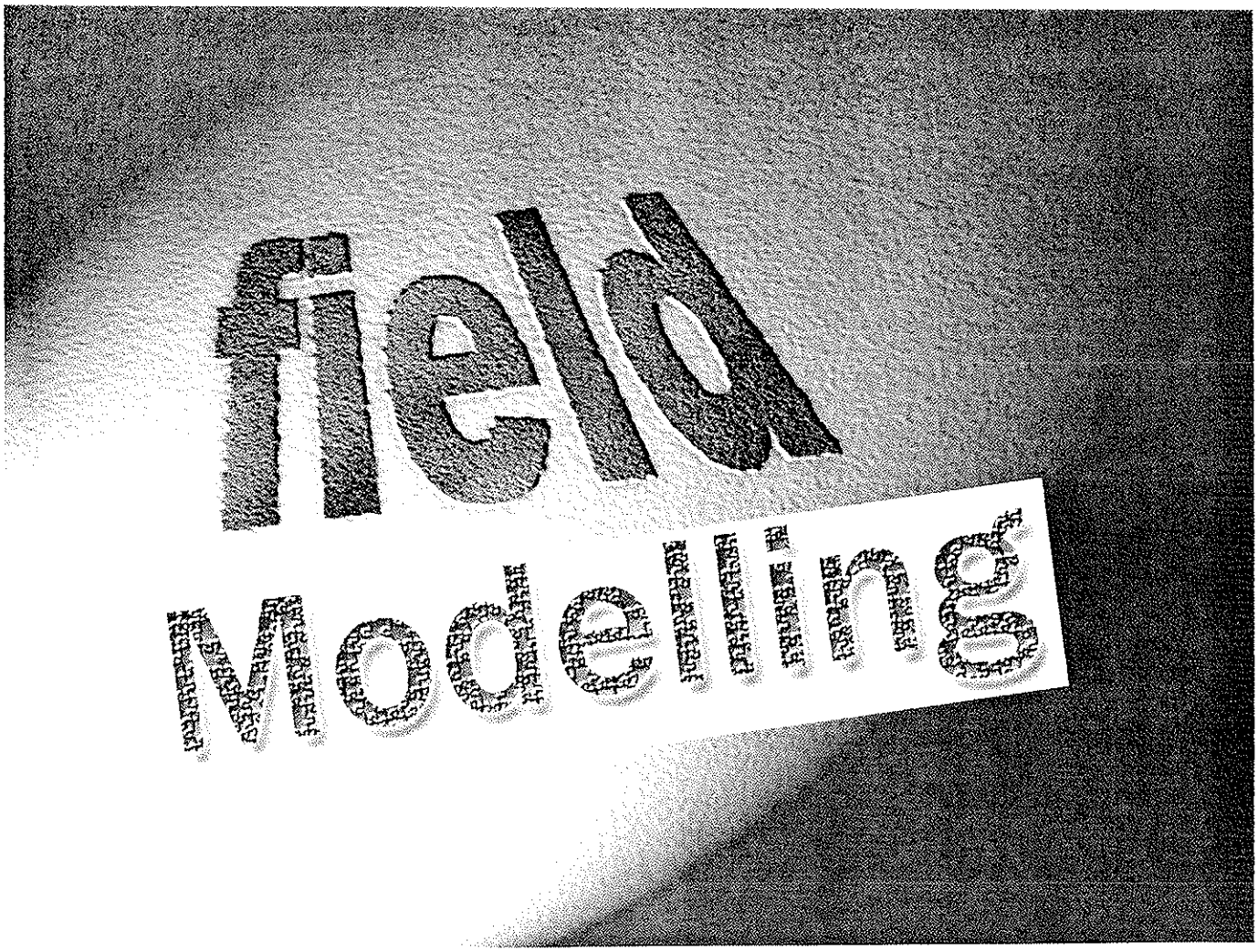
Single Compartment



Elevation View

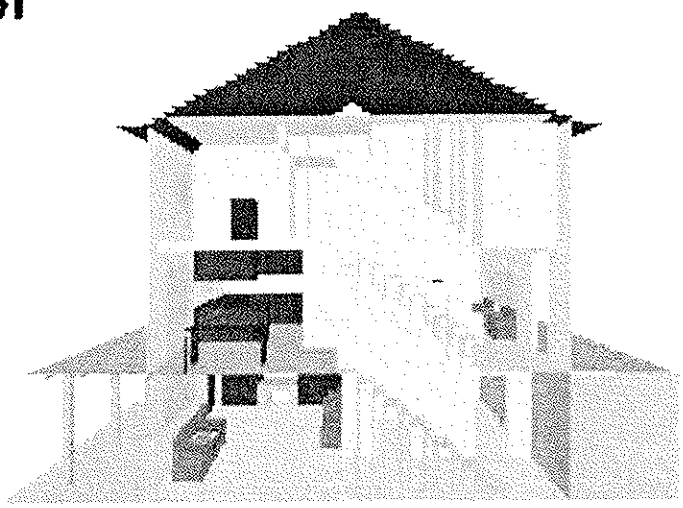


Plan View

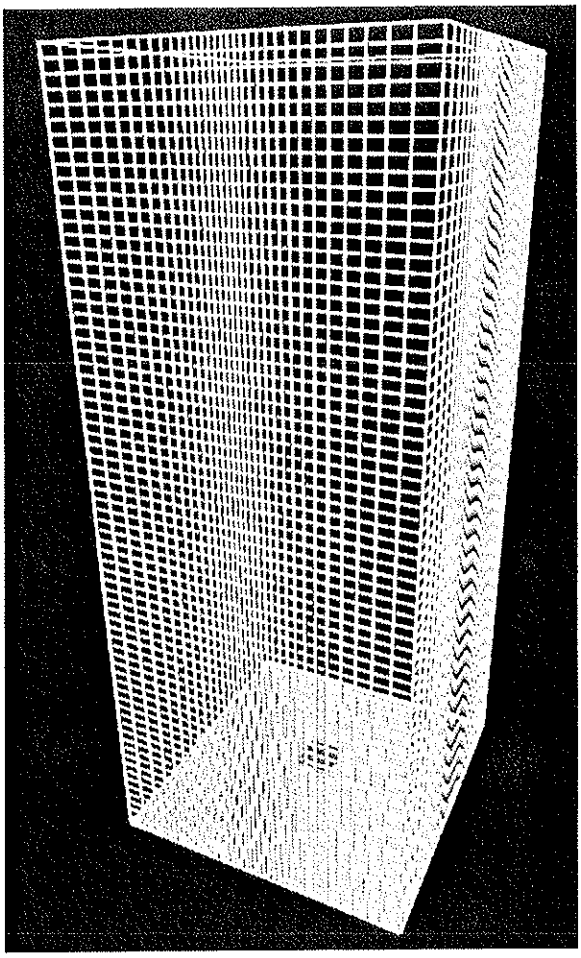


Field Modelling = Computational Fluid Dynamics Modelling

NIST

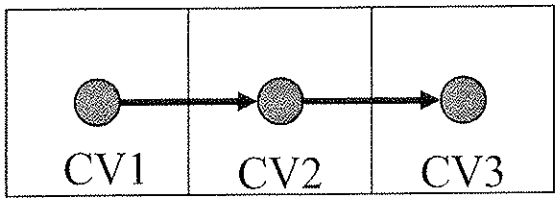


Time: 0.1



Concept

- Space of interest divided into many control volumes



- Iterative solution process

Field Modelling Outputs

(depends on individual software)

- Effects of turbulence
- 3-D temperature profile
- 3-D velocity profile
- 3-D visibility profile
- Soot & species concentration
- Animation sequence (transient runs)



Evacuation Modelling

Evacuation Modelling

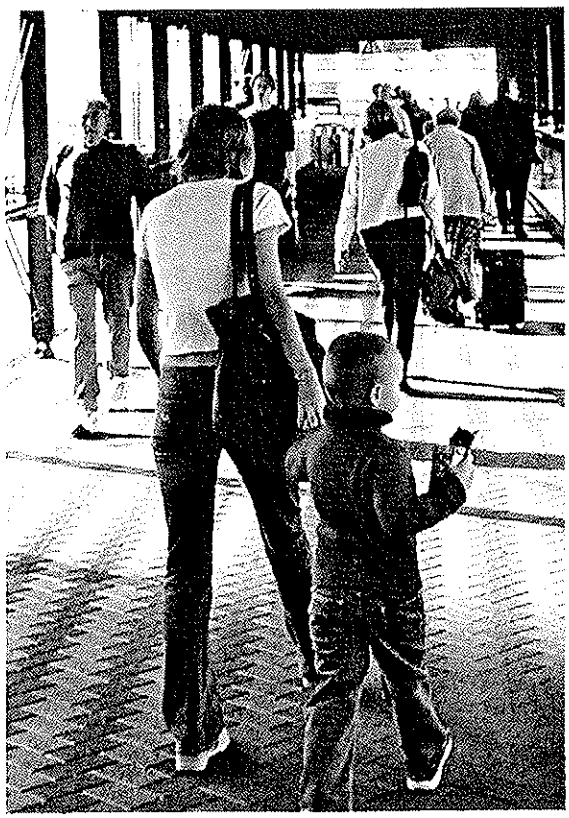
can help FSE ascertain

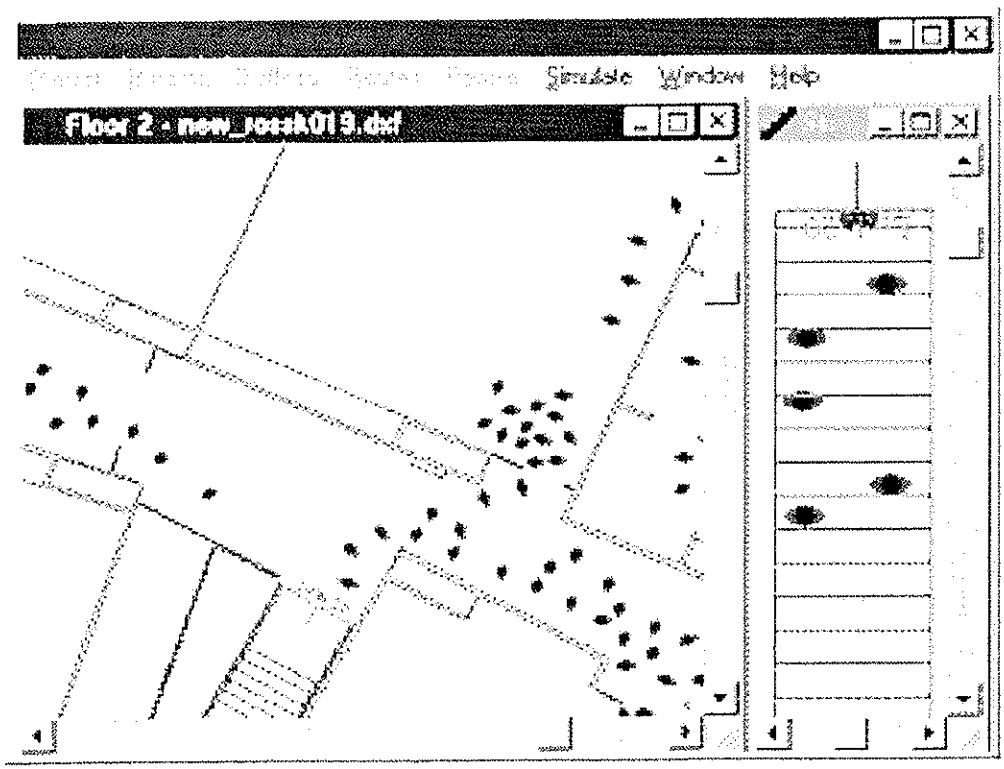
RSET

Required Safe Egress Time

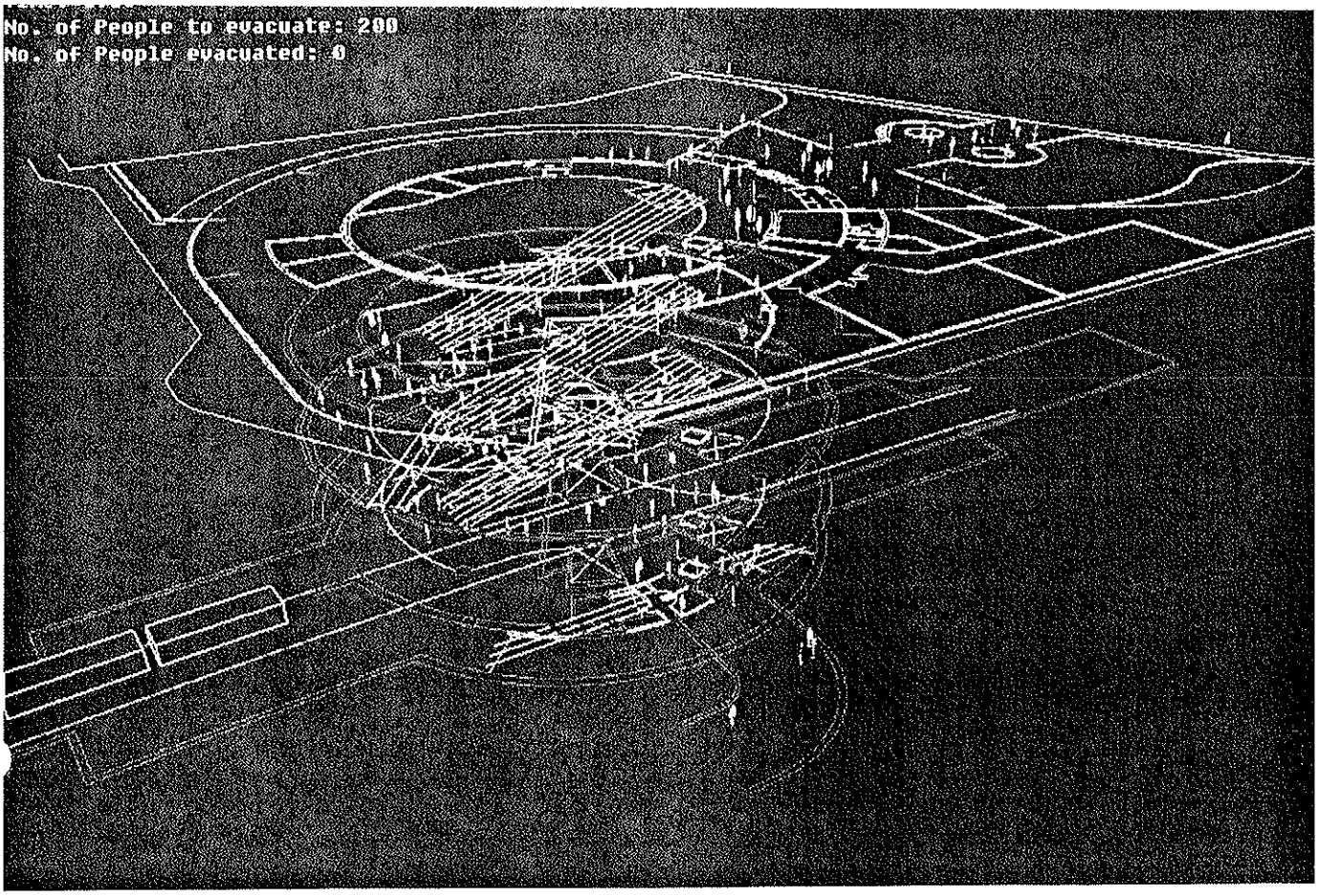
Entity characteristics

- Free walking speed
- Age / fitness
- Familiarity
- Association





Software A – Building Evacuation

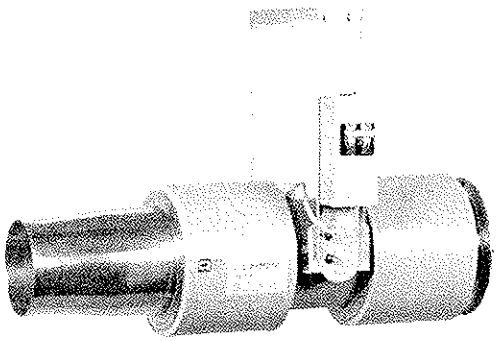


Software B – Train Station Evacuation

Atypical Products and Systems?

DUCTLESS FAN SYSTEM

- Waiver in Yr 2000/1 to substitute for ducted systems for basement carpark smoke purging



- More and more waivers

DUCTLESS FAN SYSTEM

WHAT IS IT?

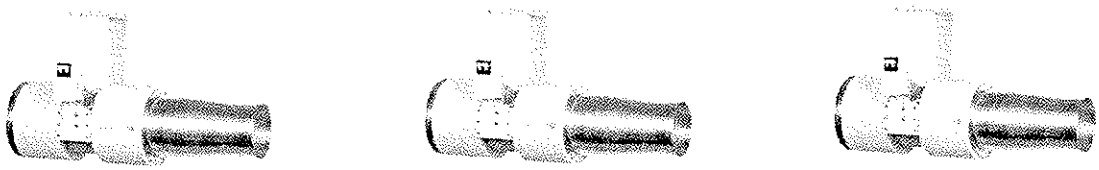
SUPPLY

Relay smoke to next fan

Relay smoke to next fan

Relay smoke to exhaust

EXHAUST



Thought Process

Establish Intent of Fire Code

Smoke Purging System

- Relief heat & smoke from carpark
- Assist fire-fighters to extinguish fire
  - Not life Safety System

Set Parameters

What does SCDF want to see?

- Reliability of fans
- Fan performance

Install Accreditated Lab Testing

- Visibility
- Temperature

Evaluate using CFD

Set CFD Inputs



- Sprinklers?
- Fire Size? Duration?
- Fuel => Soot yield?
- Obstructions to ceiling jet?
- Accuracy of CFD vs actual?

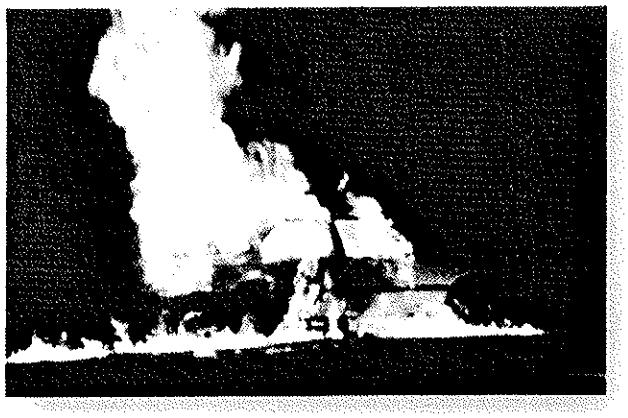
Post Installation

Cannot start fire
to design fire size

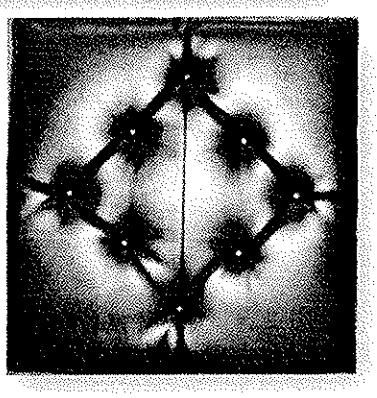
How to determine pass/fail?

FIRE MODELLING

Fire Size



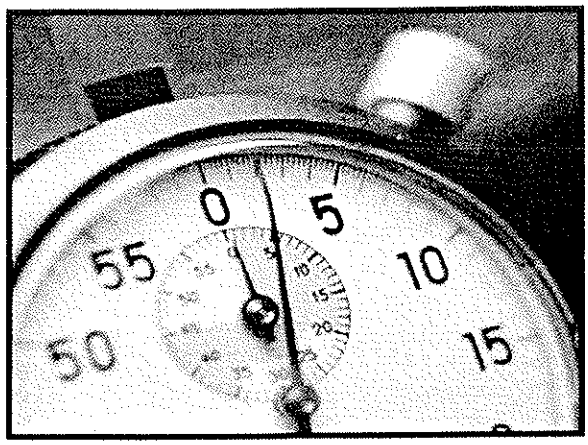
- Average moderate fire of constant 4MW



- Polyurethane fire, corresponding soot yield

FIRE MODELLING

Duration



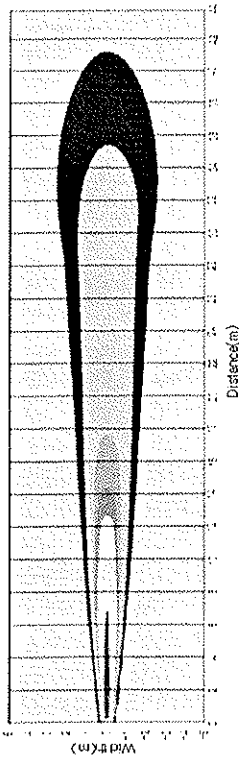
- 20 minutes

20 min adequate time to assess whether smoke is kept within affected zone

---

FIRE MODELLING

Grid Resolution

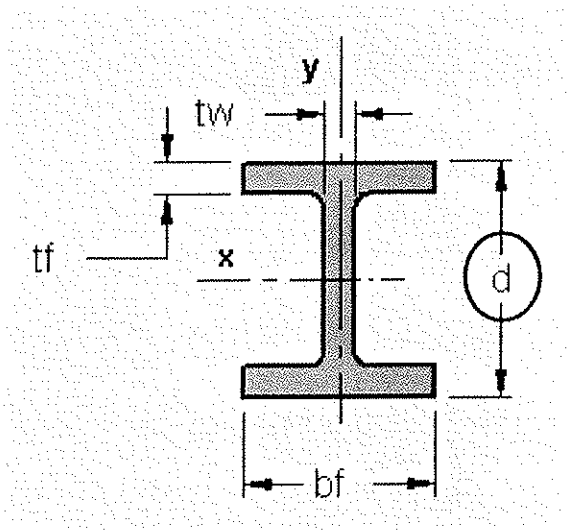


- Dependent on software, turbulence model
- Fire adequately resolved
- Fan to appropriate detail to simulate actual flow
- Geometry accurate, eg vents

FIRE MODELLING

Modelling Deep Beams

Beam depths > 10% carpark floor to ceiling height to be modelled



SCDF

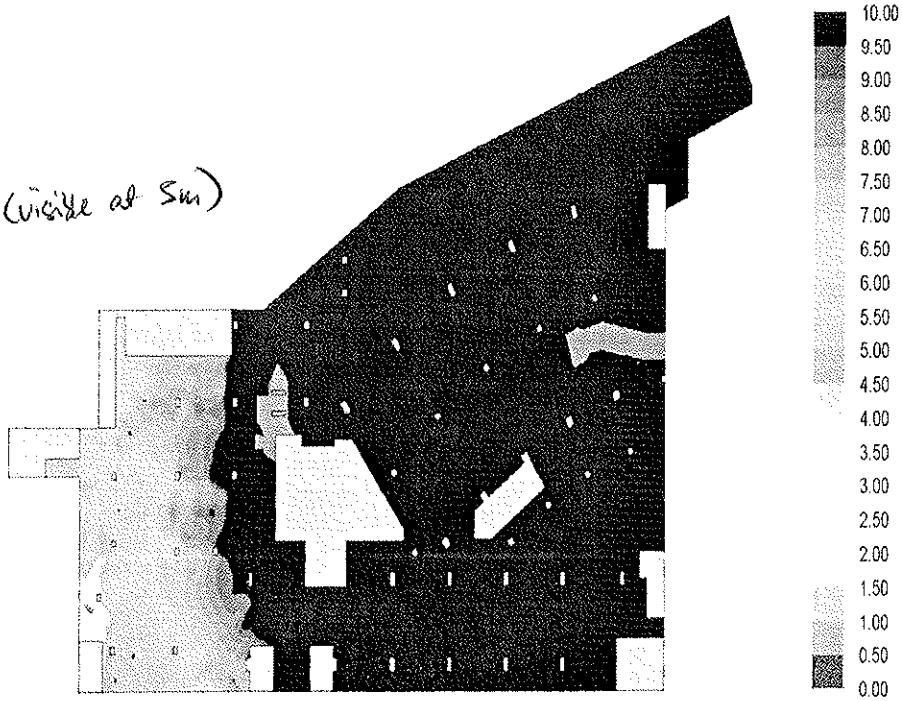
ACCEPTANCE CRITERIA

- Visibility

> $5m^{-1}$ at 1.7m ht

(visible at 5m)

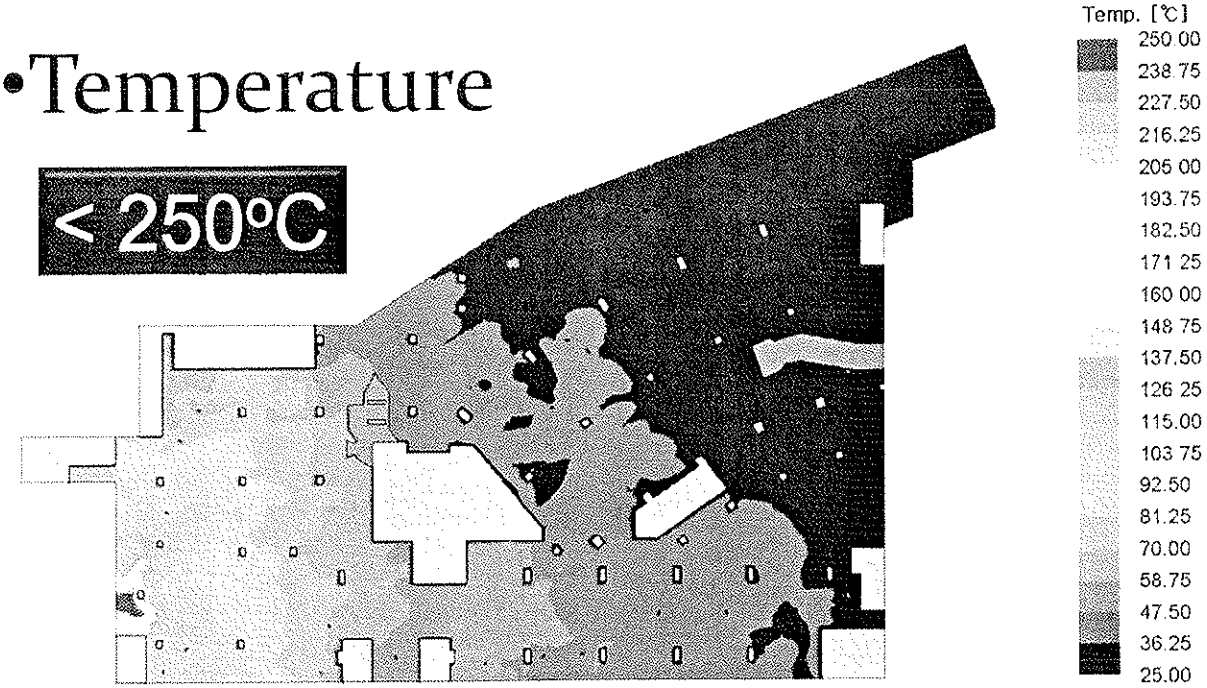
> 50% carpark smoke free



SCDF
ACCEPTANCE CRITERIA

- Temperature

< 250°C

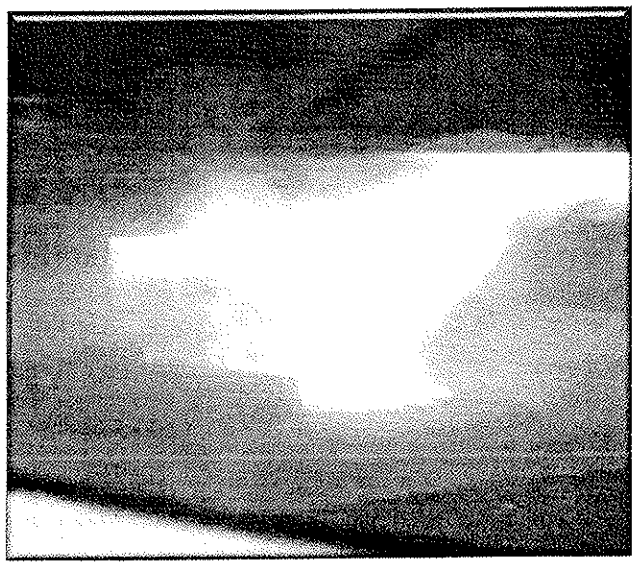


REQUIRED ACCREDITATED LAB TESTING

- Fan furnace test 250°C 2 hrs

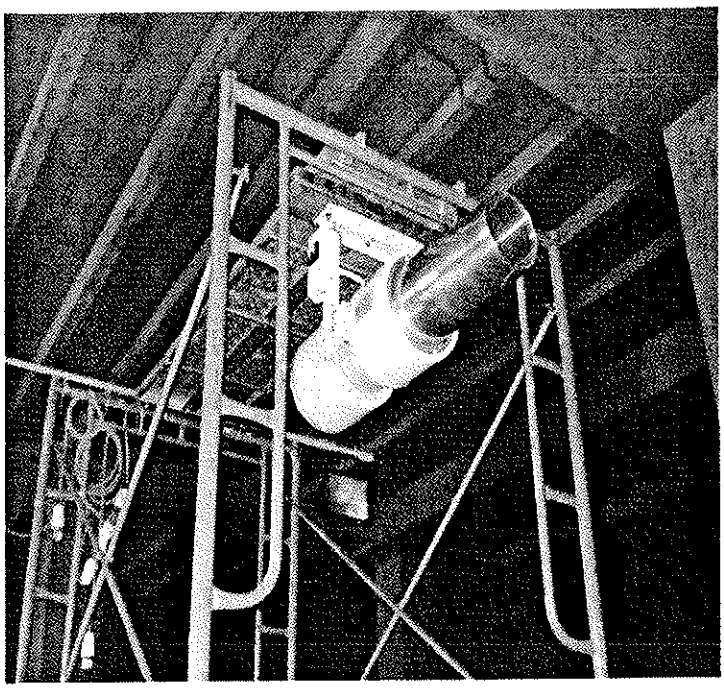
Note

Cabling to fan inclusive

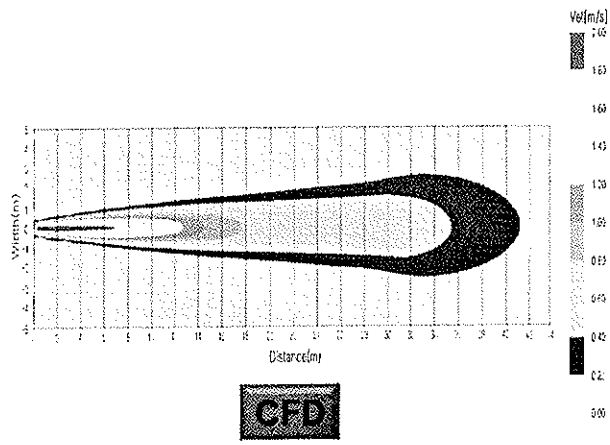


REQUIRED ACCREDITATED LAB TESTING

- Fan velocity flow profiling

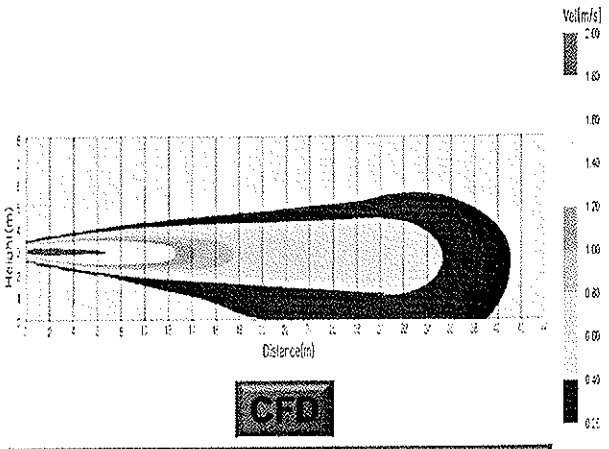


REQUIRED ACCREDITATED LAB TESTING



CFD

HORIZONTAL VELOCITY PROFILE

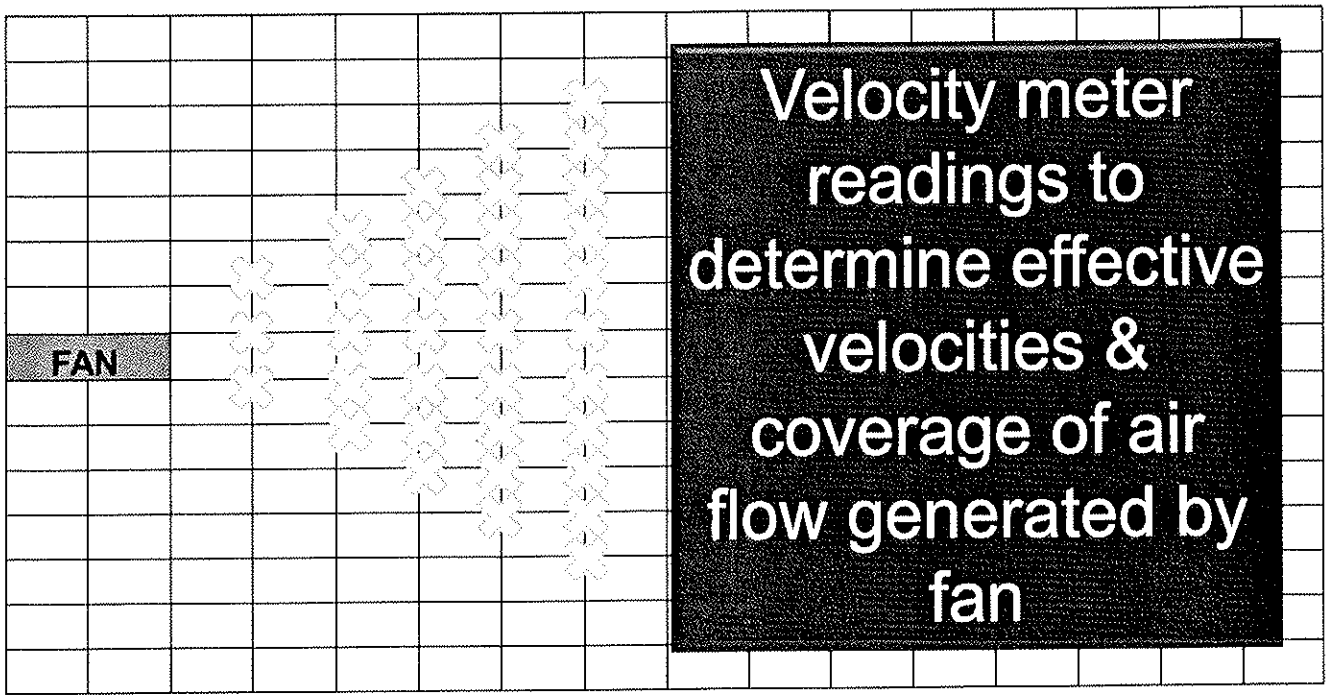


CFD

VERTICAL VELOCITY PROFILE

How well does CFD of single fan compare with actual fan performance?

REQUIRED ACCREDITATED LAB TESTING



REQUIRED ACCREDITATED LAB TESTING

General Guidelines

- Fan mounted horizontal at 3m ht
- Horizontal & vertical profiles required
- Space must be large enough to carry out test without influencing fan flow profile, eg no interference from columns, wind, mechanical ventilation etc

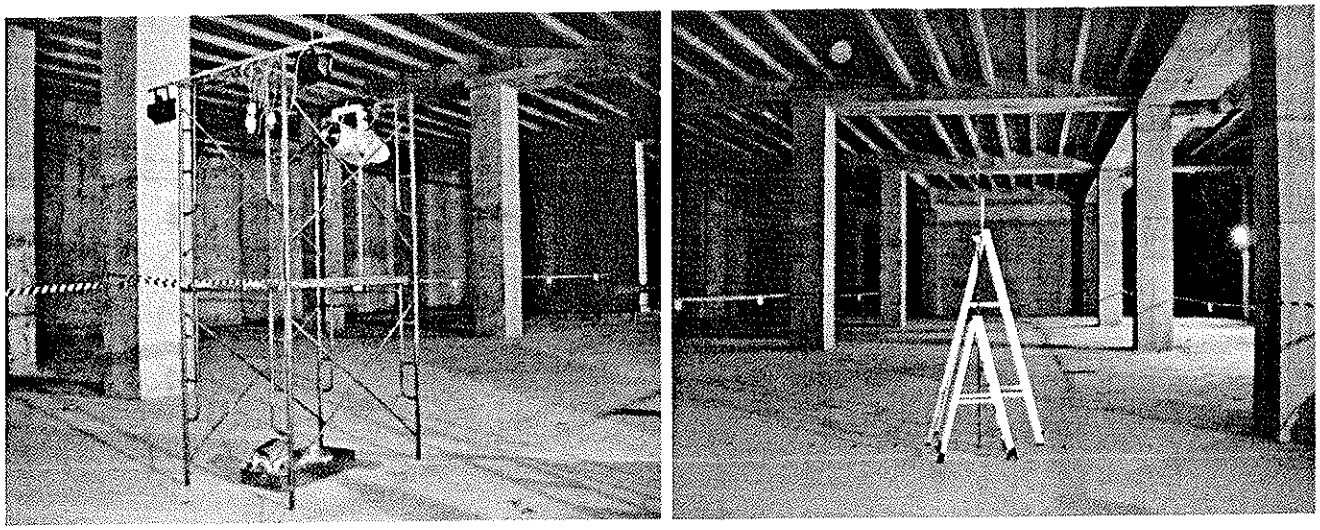
REQUIRED ACCREDITATED LAB TESTING

General Guidelines

- Lab to provide assessment of deviation of CFD from actual recorded test values
- Input file of CFD software for single fan modelled shall be included in report

⇨ **Same level of detail expected for fans in car park CFD model**

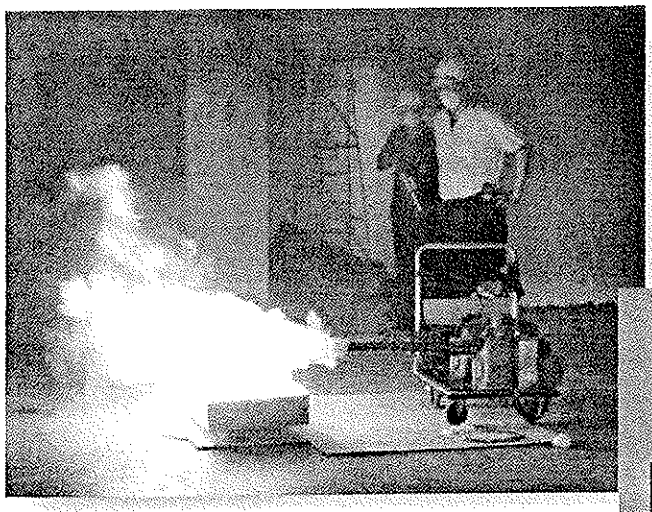
REQUIRED ACCREDITATED LAB TESTING



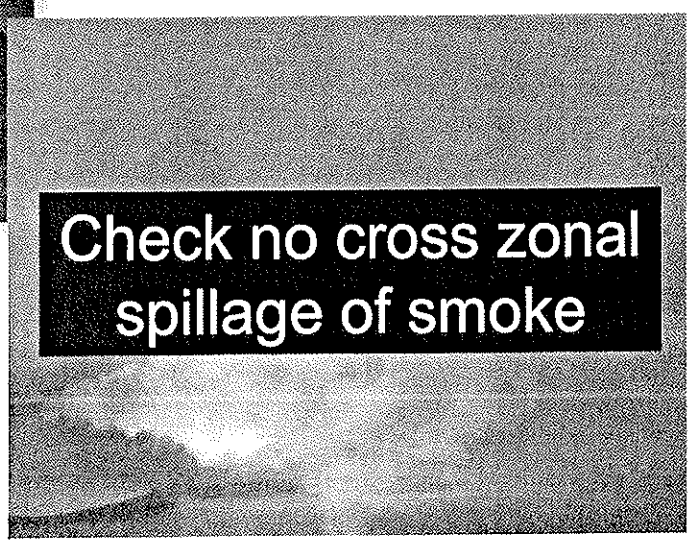
REQUIRED ACCREDITATED LAB TESTING



HOT SMOKE TEST FOR TFP/FSC



Registered Inspector to Note



Check no cross zonal spillage of smoke

CONCLUSION

Performance-Based Fire Design

- SCDF is open to possibilities
- We are prepared to work hand in hand with you
- SCDF expects systematic & thorough substantiation of idea/product

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Thank You!

Recent Fire Research and its implications for fire safety engineering

bre

Fire safety engineering developments and processes

Prof David Charters, PhD, CEng, FIFireE, MIMechE

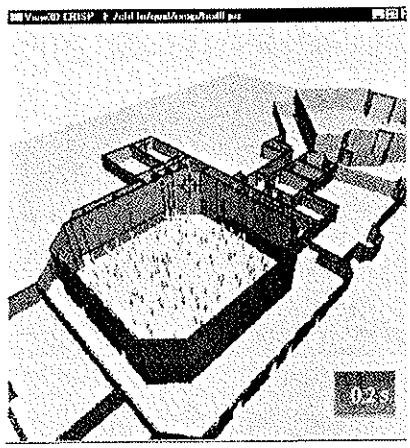
Director of Fire Engineering

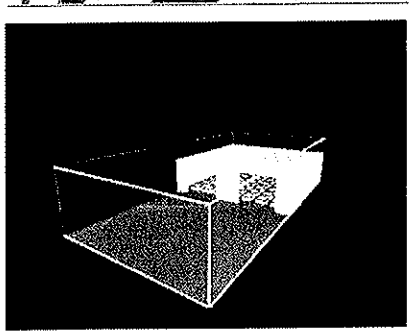
Visiting Professor of Fire Risk Analysis at the University of Ulster

Immediate Past International President of the Institution of Fire Engineers

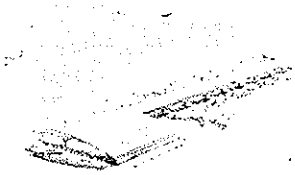
Overview

1. Introduction
2. Fire safety engineering
3. Review and improvement
4. Specific developments
5. Future opportunities/challenges

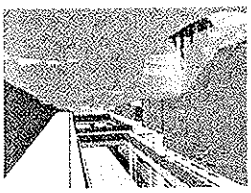




A unique perspective



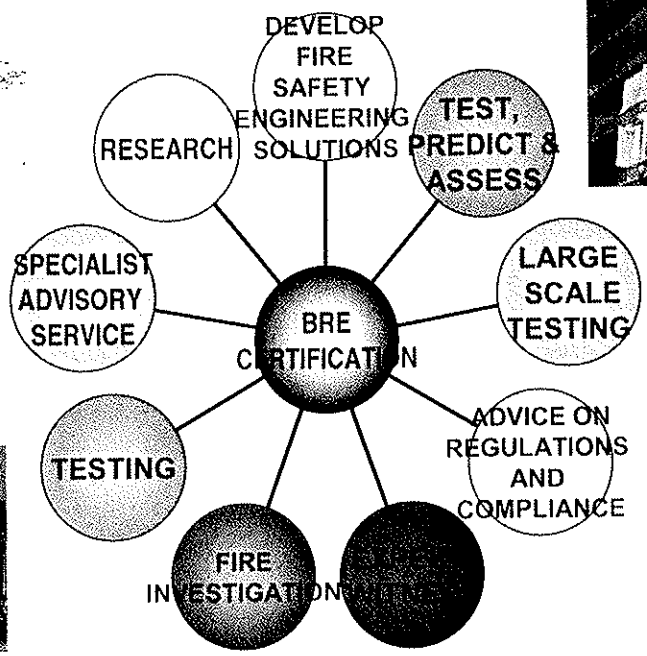








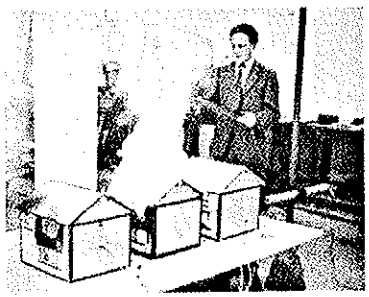




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Ingredients of an engineering discipline

- A robust body of research
  - Ongoing need/changing hazards
- An education system
  - Not just for fire engineers designers, but for all stakeholders
- A body of practitioners with a code of practice/ethics
- Codes and standards
  - Not just for fire engineers designers



bre

Institution of Fire Engineers

The International qualifying body and learned body for fire engineering and fire safety professionals.

Advancing the discipline for the benefit of society and supporting the professional development of members.

- Inclusive of all fire professionals
- Sets professional Standards
- Value and opportunity for members
- Global learning network
- Tech, Reg. & Social influence
- Independent voice for profession



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www.ife.org.uk

Fire Safety Engineering

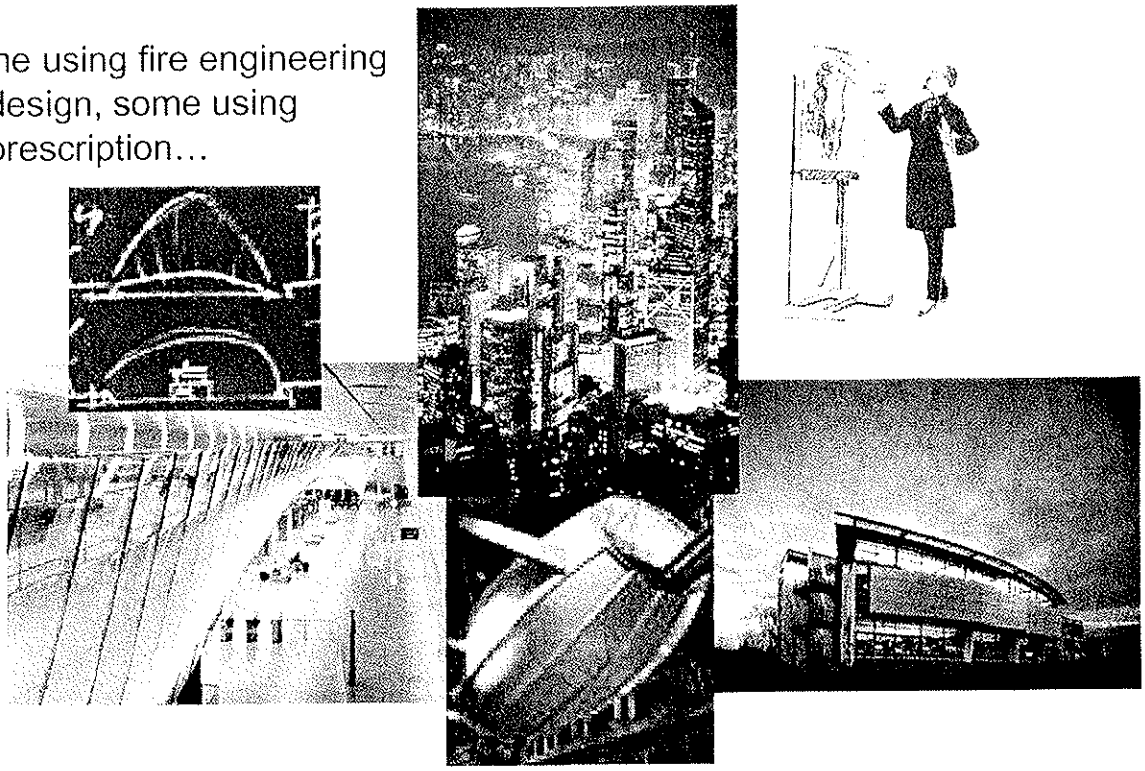
- The application of:
  - scientific and engineering principles;
  - rules (codes); and
  - and expert judgement,
- based on an understanding of:
  - the phenomena and effects of fire; and
  - the reaction and behaviour of people to fire,
- to protect:
  - people;
  - property; and
  - the environment

  from the destructive effects of fire

bre

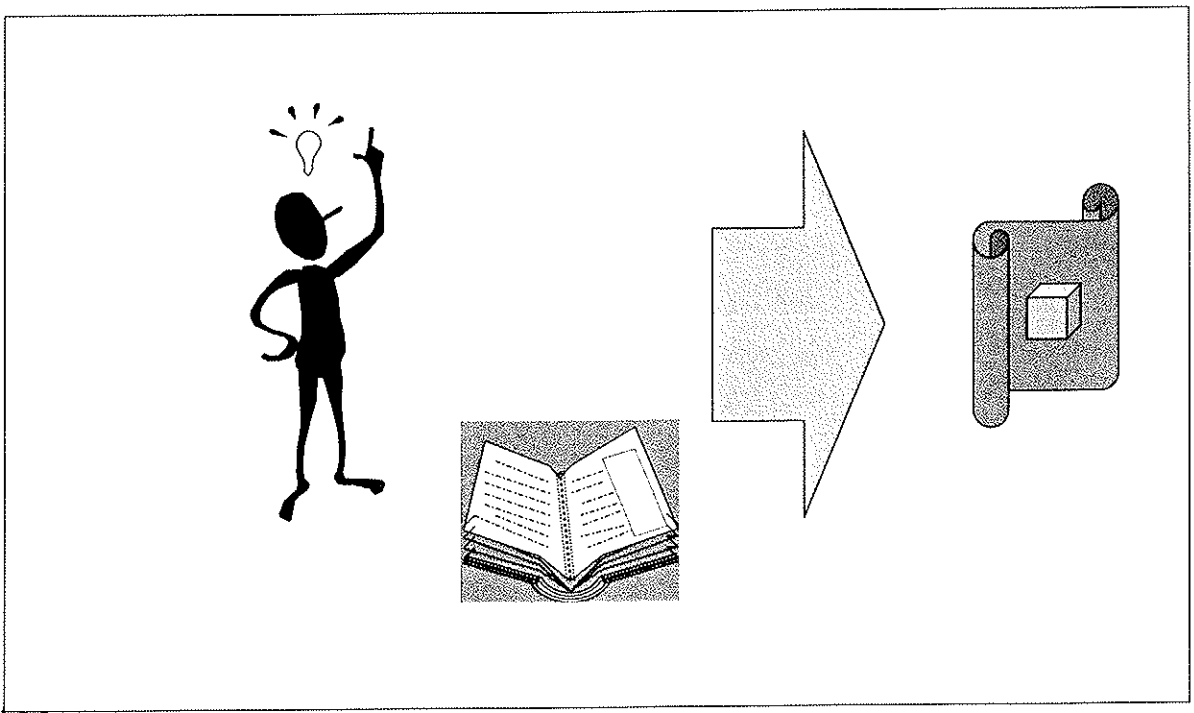
Grand designs…Architectural prize winners

Some using fire engineering design, some using prescription…



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The "Old" process



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Sources of science

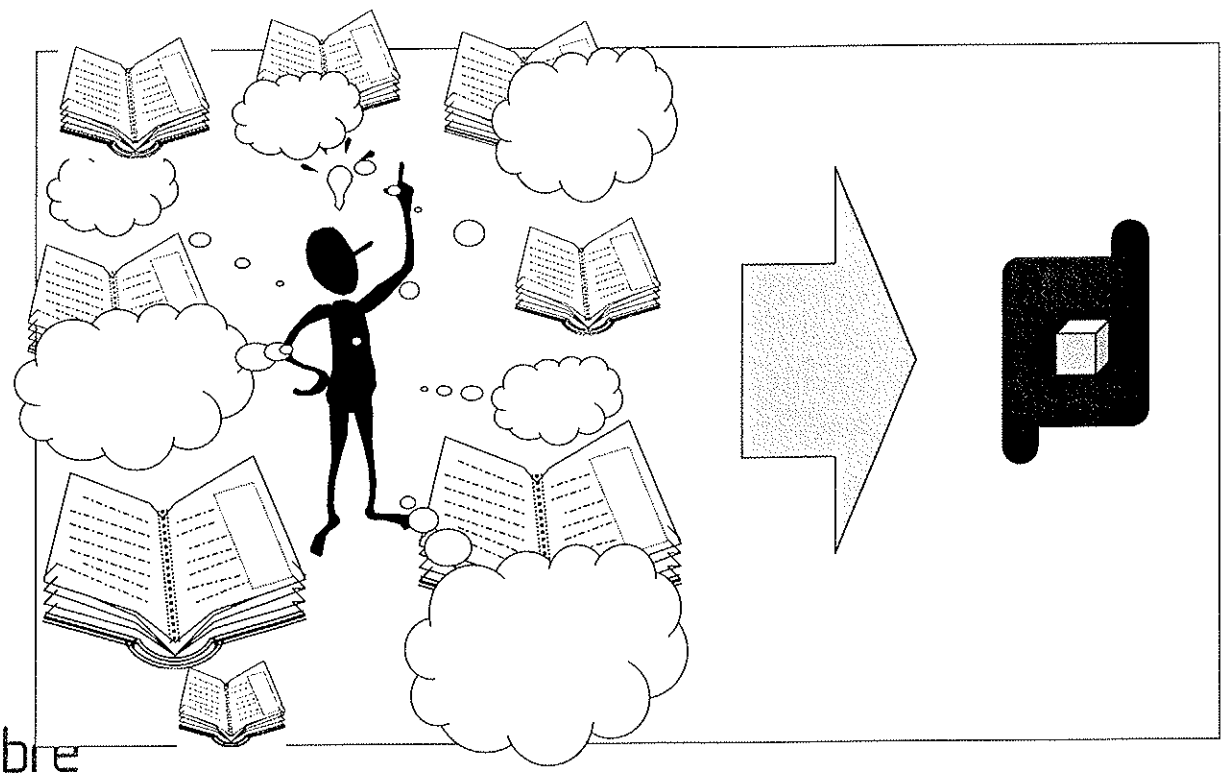
- Peer Review Journals:
  - Fire Safety Journal
  - Fire Technology
  - Fire Safety Technology and Management
  - ...etc
- Conferences and symposia:
  - International Symposia for Fire Safety Science
  - Interflam
  - Fire and Explosion Hazards...etc
- Government research bodies:
  - NIST
  - BRE
  - Tan Jin...etc
- Universities:
  - City University Hong Kong
  - Hong Kong Polytechnic University
  - University of Central Lancashire
  - University of Leeds
  - University of Maryland
  - Victoria University of Technology...etc
- Manufacturers and designers:
  - Building contents
  - Construction products
  - Detection and suppression systems
  - Firefighting systems

"Researchers have already cast much darkness on this subject and if they continue their investigations we shall soon know nothing at all."

Mark Twain

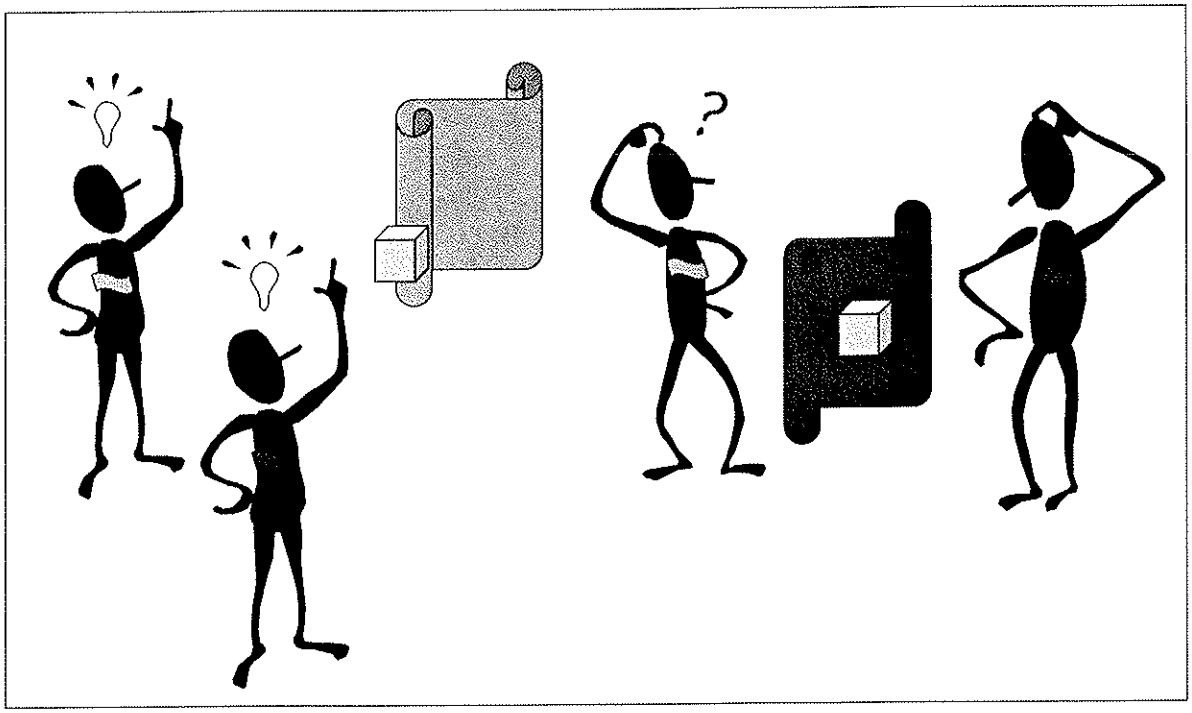
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The "New" process



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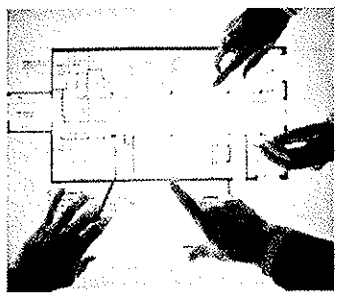
Approvals



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Reviews of fire engineering (UK, US, Sweden)

- Fire Safety Engineering is:
  - different from other disciplines
  - not yet a mature discipline
- Shortage of qualified engineers
- What qualifications do we need?
- Undeclared assumptions
- Reliability of source documentation



- The need to trust computer models and modellers
- Poor Documentation
- Designs that cannot be built
- Difficult to test systems
- Is Fire Safety Management do-able?

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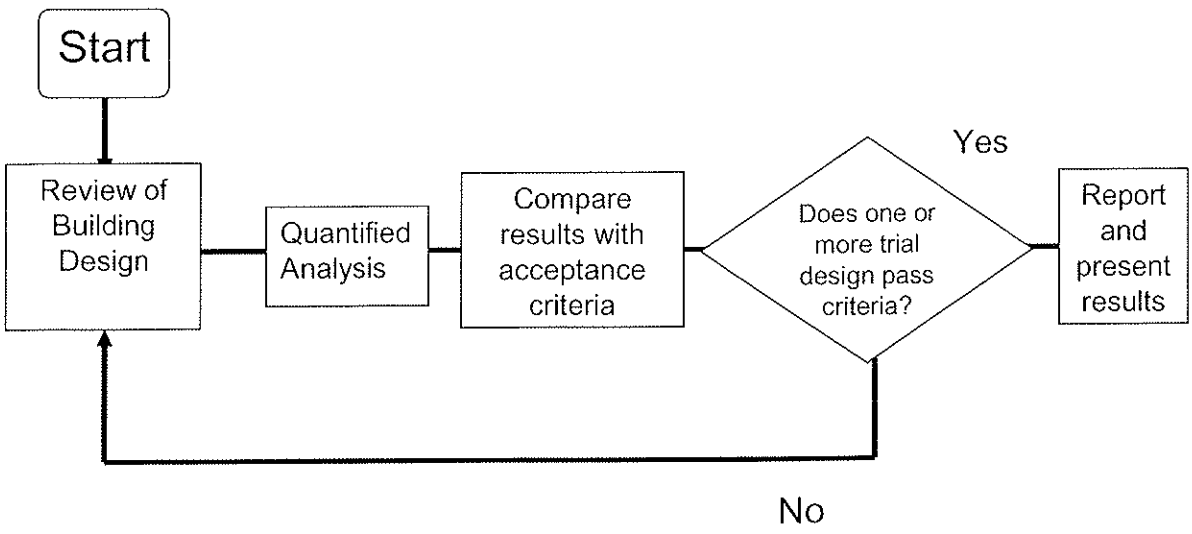
Critical Success Factors for Fire Safety Engineering

1. Integration of fire safety with other safety issues
2. Comprehensive documentation covering all aspects of fire safety design - not just "engineered parts"
3. Qualifications and experience of designers & approvers
4. Explicit assumptions
5. Clear communications
6. Consultation and co-ordination between Building Control and Fire Authorities
7. Properly arranged and documented commissioning tests
8. Audit trail for documentation - fire safety manager to maintain documentation
9. Continuity during management changes
10. Clear & comprehensive lines of responsibility



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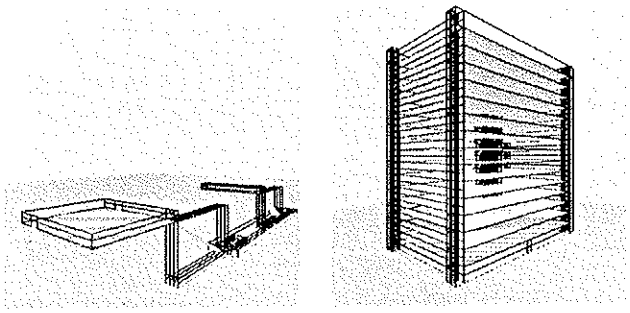
Fire Engineering Process



bre

Review of building design

1. Layout and structural design of building
2. Fire safety objectives
3. Fire hazards & consequences
4. Trial fire safety designs
5. Acceptance criteria & method of analysis
6. Fire scenarios for analysis



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New designs, new solutions and new methods

New designs:

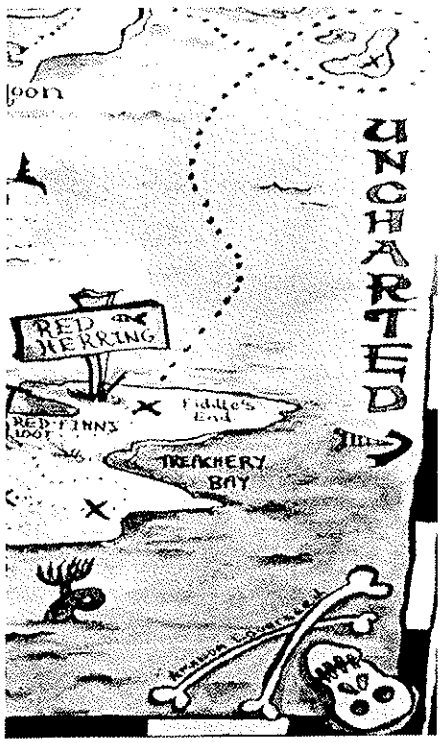
- Large
- Complex
- Open plan
- Atria

New solutions:

- Different solutions
- Reduced protection

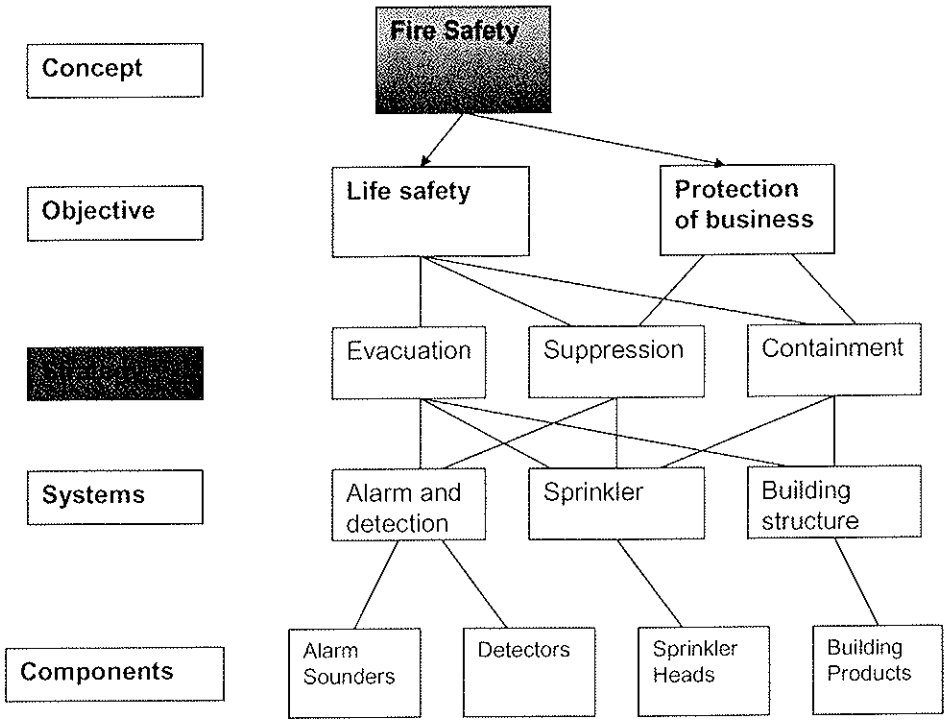
New methods:

- Empiricism
- CFD/FEA/Discrete Evacuation



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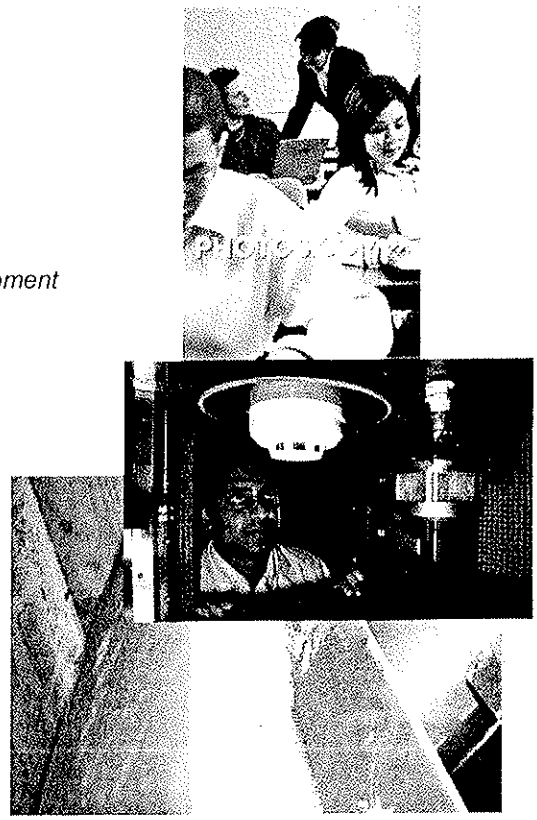
Fire safety – hierarchical approach (Shields et al)



bre

Fire strategy

- Prevention
  - Fire safety management
    - *Control of ignition sources*
    - *Control of combustibles*
    - *Maintenance of electrical equipment*
    - *Smoking policy…etc*
- Escape
  - Fire alarm systems
  - Fire detection systems
  - Escape routes
  - Fire safety management…etc
- Containment
  - Compartmentation
  - Structure
  - Separation
  - Fire safety management…etc
- Suppression
  - First aid fire-fighting
  - Automatic suppression
  - Fire & Rescue Service facilities
  - Fire safety management…etc



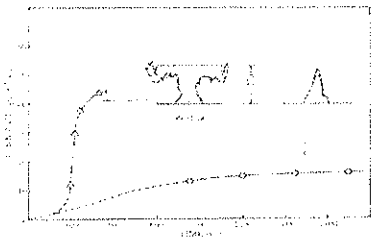
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Scientific knowledge…

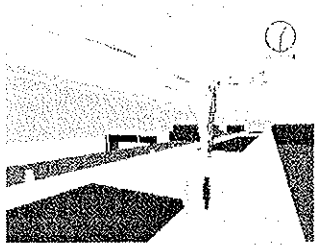
- Observation
  - Qualitative understanding



- Measurement
  - Quantitative understanding



- Theory
  - Fundamental understanding



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Fire safety management

Management factor	Management level		
	Level 1	Level 2	Level 3
Ownership	Known	Limited	Not known
Manager's role	Single responsible person	Known responsible persons	Not known
Resources/authority	Good	Average	Minimal/none
Staffing level (staff-occupant ratio)	High	Medium	Low/none
Fire training	Good	Average	Minimal/not known
Security	Good	Medium	Minimal
Work control (e.g. repairs to structure)	Good	Average	Minimal/none
Communications procedures	Good	Average	Minimal
Maintenance/testing of fire safety systems	Frequent	Occasional	Minimal
Liaison with fire & rescue services	Good	Average	Minimal
Contingency planning	Good	Adequate	None
Degraded systems planning	Good	Adequate	None
Abnormal occupancy planning	Good	Adequate	None
Testing/auditing of management system	Fully independent	In-house	Minimal/none
Risk management	Good	Poor	None
Fire load management (contents control)	Good	Poor	None

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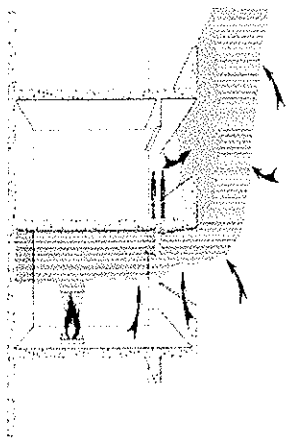
Scientific basis…future development

- Observation
  - Human behaviour in fire
  - Fire safety management
- Measurement
  - Fire growth
  - Plume modelling
  - Movement of people
  - Time equivalence
- Theory
  - Computational Fluid Dynamics
  - Finite Element Analysis

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Quantitative analysis

- Initiation and development of fire
- Smoke movement beyond the room of origin
- Response of structure to fire
- Activation of detection and suppression systems
- Fire service intervention
- Human response and evacuation
- Probabilistic risk assessment

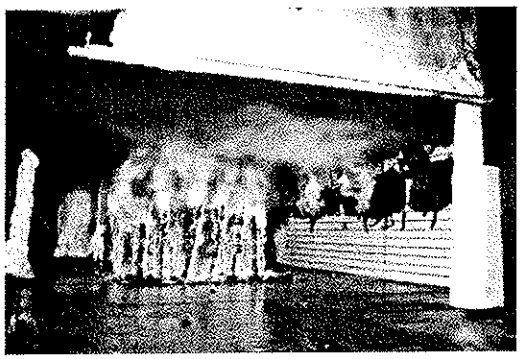


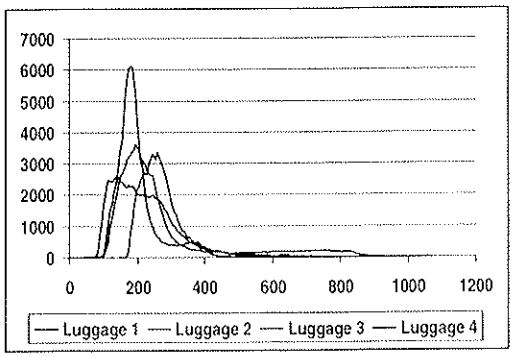
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Ignition and fire growth

Fire scenarios:

- Ignition – where and when?
- Fire growth rate?
- Peak rate of heat release?
- Duration?





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The 5MW design fire

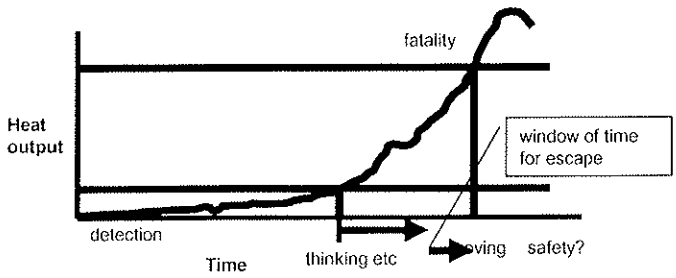
- Based on FRS "Shopping Mall Experiments, 1975"
  - Unsprinklered display stand
    - *$3m^2$, Heat release rate 3.2MW Q/A ~ $1MW/m^2$*
  - Compare sprinklered and non sprinklered kerosene fires (canopy over fire)
    - *Convective heat from fire compartment halved with sprinklers*
  - Assume "design fire" controlled by sprinkler in a 3m by 3m grid
    - *Fire area = 3 x 3 = $9m^2$*
    - *Heat release rate = 9x 0.5 MW = 4.5MW ~ 5MW*
- OR
  - Sprinklered crib fires Q/A ~ $0.5MW/m^2$
  - Area as above giving heat release rate 5MW

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Design Fires

Why do we need design fires?

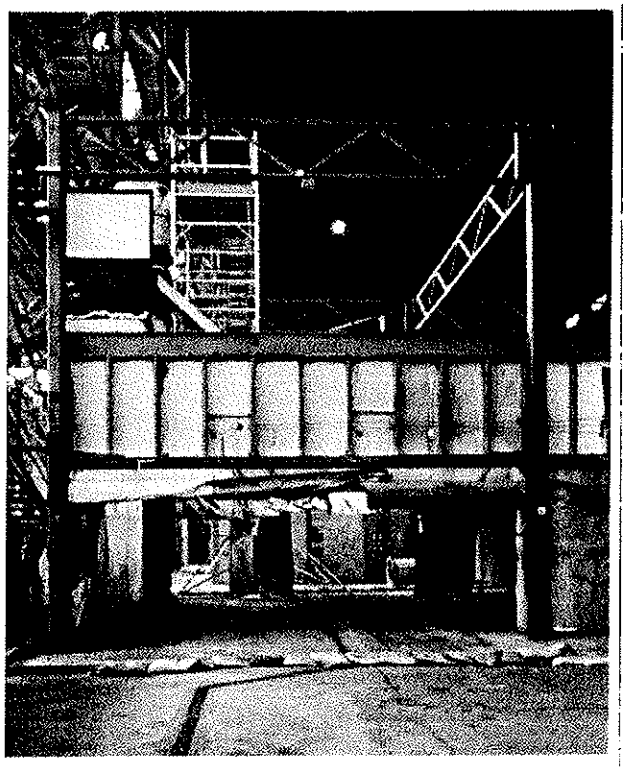
- Fundamental assumption underlying the design of fire protection and life safety systems in buildings.
- Easy to identify the fire load, but rarely is there firm evidence on which to base the fire's characteristics.
- Characteristics of common or representative fires reduces the uncertainties in the specification of a design fire.



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The Characterisation of Fires for Design Purposes

- concentrations of:
  - *oxygen,*
  - *carbon dioxide and*
  - *carbon monoxide*
- mass flow of gases
- gas temperature
- smoke density (by obscuration of a light source)
- concentrations of:
  - *hydrogen cyanide,*
  - *hydrogen chloride,*
  - *Acrolein.*



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The Characterisation of Fires for Design Purposes

Fire loads tested:

- Array of wooden pallets
- Array of stacked cardboard boxes
- Soft toy mountain
- Retail luggage displays
- Retail clothing displays
- Retail handcarts displays.
- Open plan Office
- Retail carpet display
- Soft Play Area
- Night Club /Theme Bar
- Office Reception area

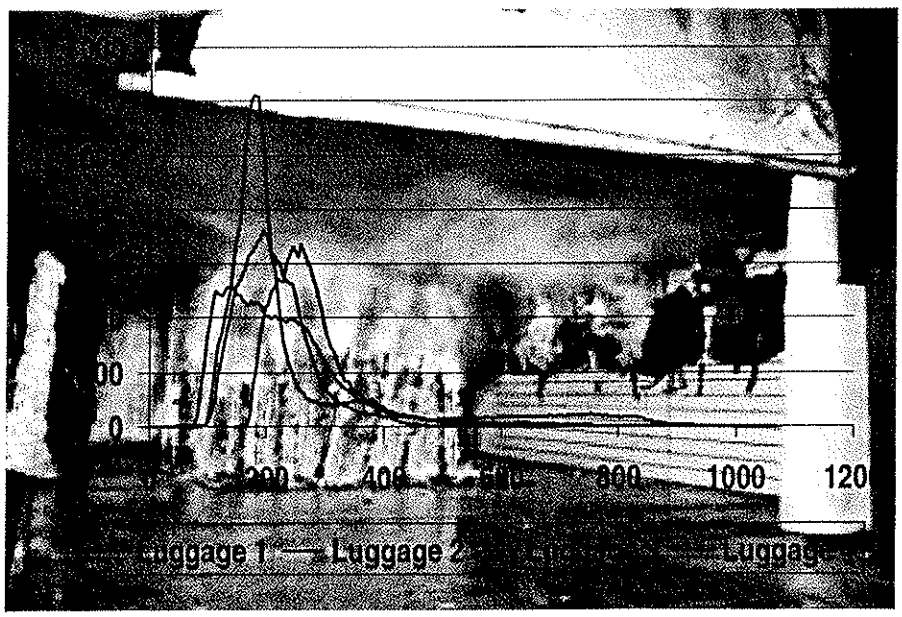




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Design Fires

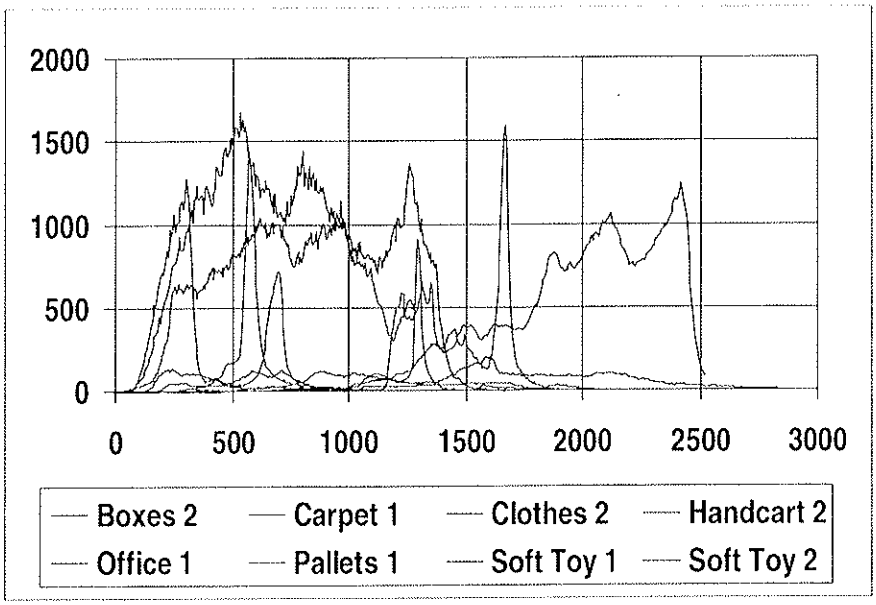
- Luggage display, unsprinklered fire just before peak fire size



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Design Fires

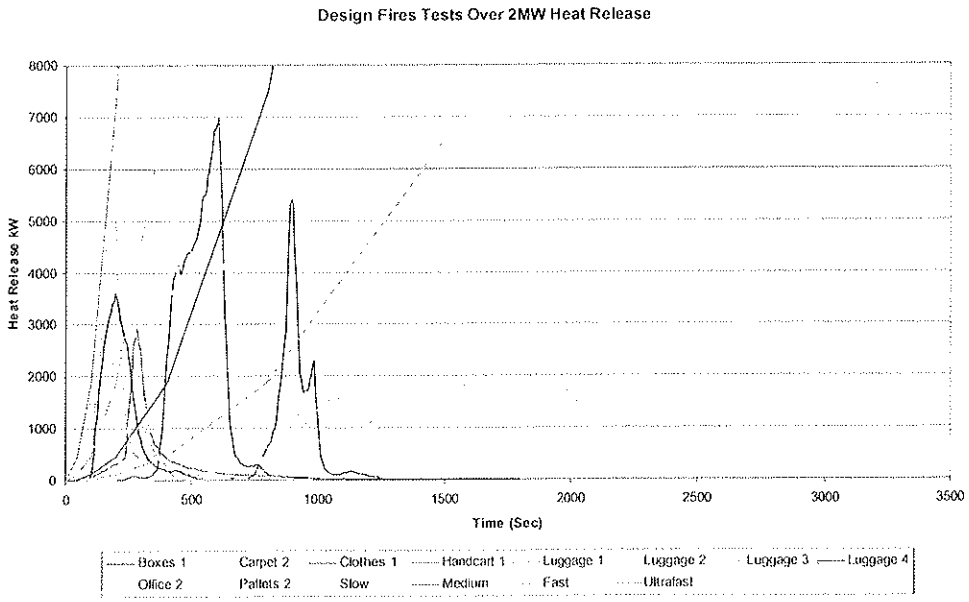
- Design Fires under 2MW Heat Release.



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Design Fires

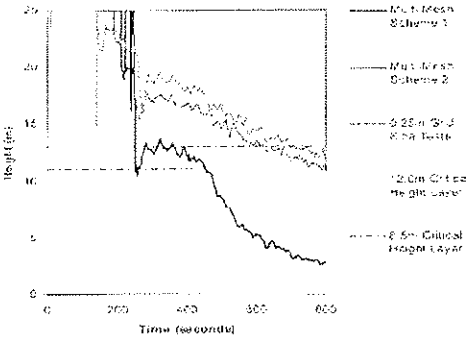
- Design Fires Over 2MW Heat Release.

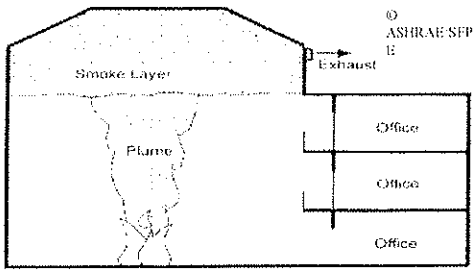


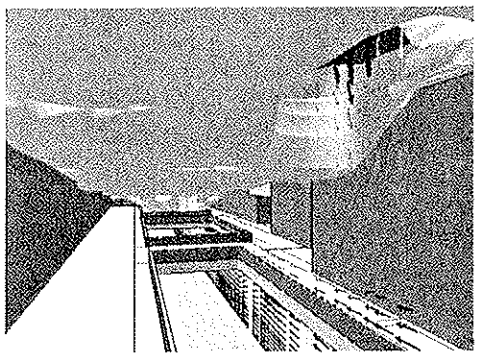
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Smoke movement

- Temperature?
- Depth?
- Toxicity?
- Visibility?
- Radiation?





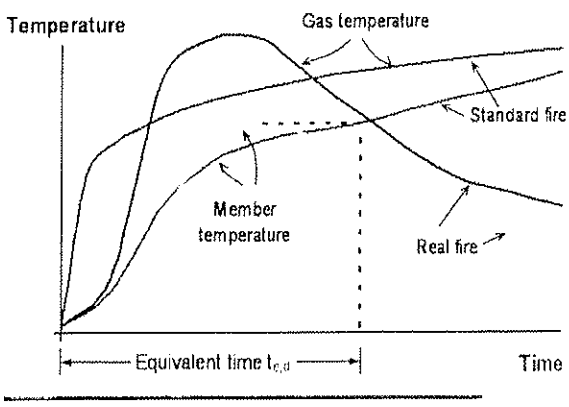


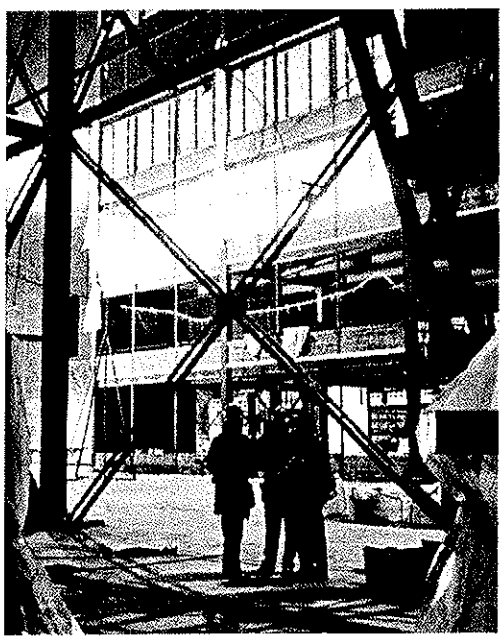
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Structural response

Fire resistance:

- Fire severity?
- Time and mode of failure?

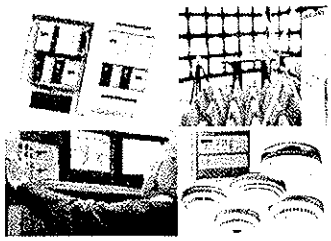


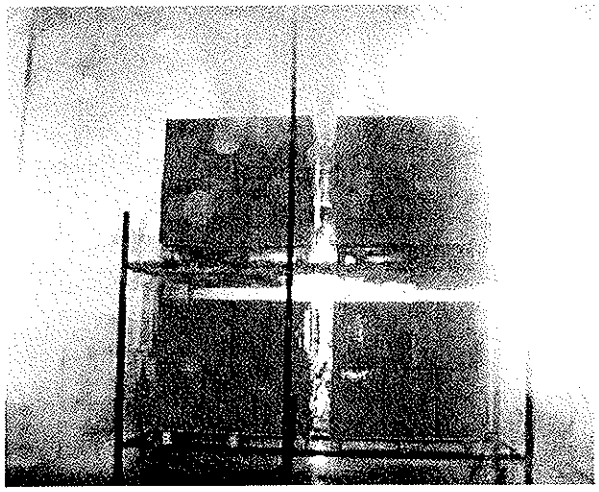


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Activation of fire detection and suppression systems

- Time of activation?
- Effect?
  - Evacuation
  - Suppression
  - ...etc





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Fire service intervention

- Time of arrival?
- Deployment time?
- Means and time of fighting the fire?
- Rescue?

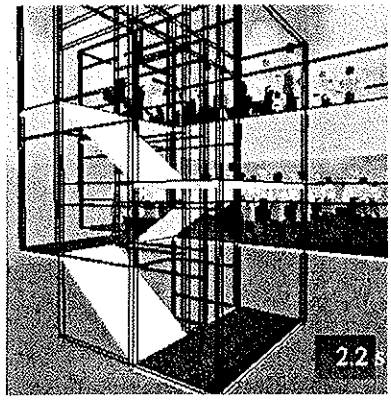




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Evacuation and human behaviour

- Recognition time?
- Pre-travel activities and duration?
- Travel time?
- Tenability?





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Fire risk assessment

- How often will fires occur?
- How bad will they be?
- What is the level of risk?
- Is the risk acceptable?





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Comparison with acceptance criteria

		Type of acceptance criteria	
		Comparative (Compare to code)	Absolute (Safe enough?)
Type of analysis	Deterministic (Physical)	Many	Many
	Probabilistic (Risk)	Some	Major hazard industry only

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Independent 3rd Party Review



- Qualified
- Experienced
- Technical excellence
- Independent
- Impartial
- Constructive

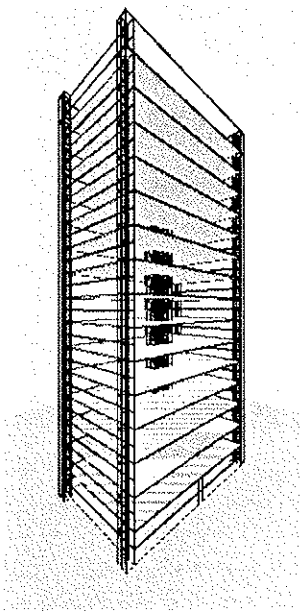
"…demonstrate that a building, as designed, presents no greater ***risk*** to occupants than a similar type of building designed in accordance with well established codes."



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High rise office/hotel/residential

- 5 Storey office podium
- Steel structure
- Code solution – 1 hr fire protection
- Alternative solution:
  - No fire structural fire protection
  - Water mist system
- Monte-Carlo risk analysis
- Did not demonstrate equivalency
- Result: 30 minutes fire protection added



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Application of Government Research Projects

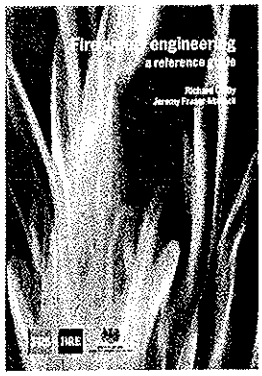
Evaluate the need for sprinklers in schools:

- Fire load surveys
- Analysis of fire report data
- Model fire growth and smoke movement
- Full scale sprinkler tests
- Quantify benefits of sprinkler systems
- Review the reliability of sprinkler systems
- Evaluate potential hazards from sprinkler systems
- Quantify costs of sprinkler systems
- Regulatory Impact Assessment (RIA)



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Government fire safety projects



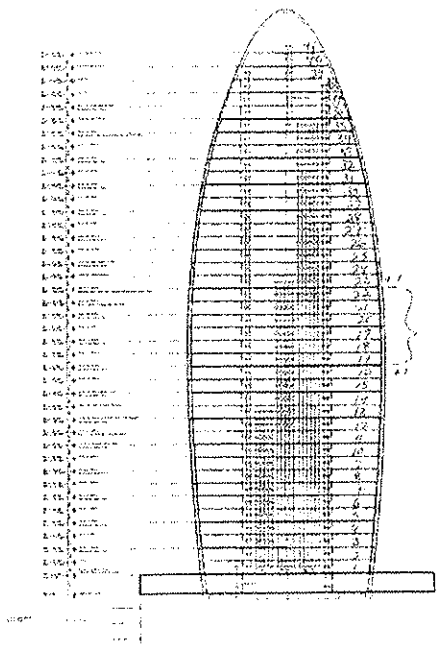
- Development of new guidance;
  - Cavity barriers
  - Smoke and burning droplets
  - Ducts and dampers
  - Compartmentation
  - Sprinkler effectiveness in care homes
- Current projects to resolve fire safety issues
  - Investigation of real fires
  - Emergency use of lifts or escalators for evacuation and fire and rescue service operations
  - Residential sprinkler installation practice and functionality
  - Fire spread in car parks
  - Representation of CLG interests at National, European and International Standard and Code Fora,
  - Secondment to CLG and Provision of Expert Advice

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Case Study - Office
(Swiss Re - Gherkin)

- Office, 39 stories with dome on top
- Glass façade – radiation calculation
- Compartmentation – reduced - employed Eurocodes
- Smoke clearance – novel design using natural vents, light domes, ≤6 floors zones, BRE smoke shaft report
- Sprinklers - yes
- Evacuation – phased evacuation, employed calculation

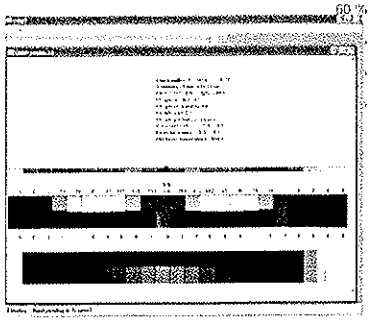


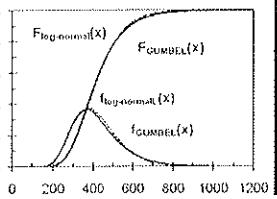
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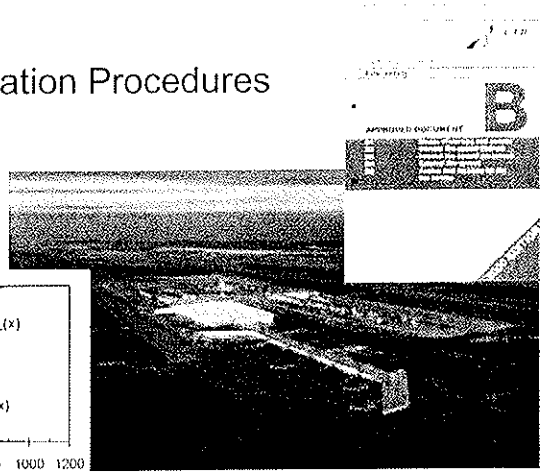
Regulatory Impact Assessment

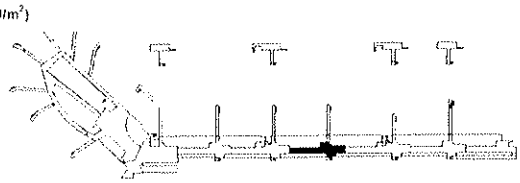
CRISP is ...

- Computation of Risk Indices by Simulation Procedures
- Simulation of the entire fire 'system'
- Monte-Carlo method









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Investigation into the WTC collapse

- One event
- A-typical

- Unprecedented investigation
- New insight into qualitative processes
- Significant new data
- Opportunity for model refinement
- Professional duty of care/moral imperative



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Flow rates down stairs

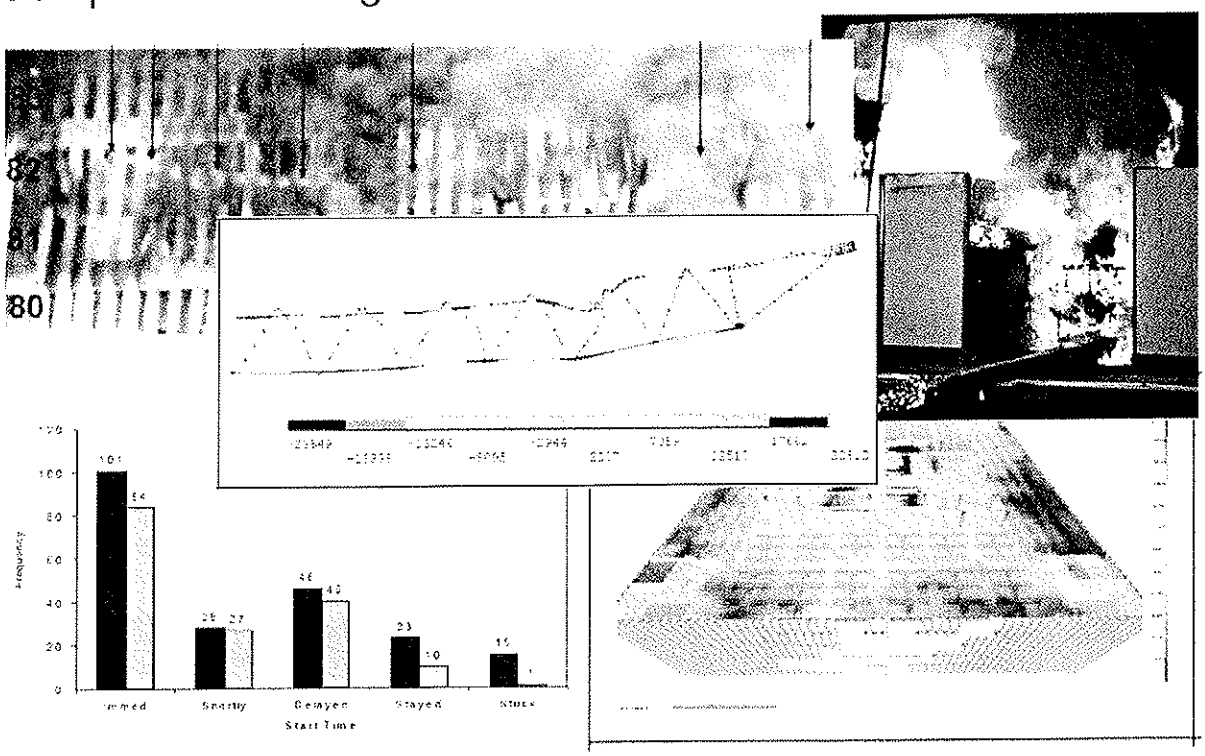
Table 40: Summary of descent speeds

		Reliable estimated average (ms)	Less reliable estimated average (m/s)	Unreliable Estimated average (m/s)	Estimated average (m/s) using all data	Estimated average (m/s) excluding unreliable data
WTC1	Min	[0.25] (0.28)	[0.08] (0.13)	[0.18] (0.22)	[0.08] (0.13)	[0.08] (0.13)
	Max	[0.41] (0.41)	[0.31] (0.83)	[0.32] (0.39)	[0.41] (0.83)	[0.41] (0.83)
	Mean	[0.29] (0.33)	[0.19] (0.34)	[0.27] (0.32)	[0.24] (0.33)	[0.22] (0.34)
	Data points	[5] (5)	[10] (10)	[5] (5)	[20] (20)	[15] (15)
WTC2	Min	[0.2] (0.37)	[0.15] (0.17)	[0.16] (0.16)	[0.15] (0.16)	[0.15] (0.17)
	Max	[0.56] (0.71)	[0.26] (0.57)	[0.39] (0.47)	[0.56] (0.71)	[0.56] (0.71)
	Mean	[0.33] (0.49)	[0.21] (0.34)	[0.26] (0.3)	[0.27] (0.39)	[0.27] (0.42)
	Data points	[6] (7)	[6] (6)	[5] (5)	[17] (18)	[12] (13)

[ ] = conservative estimate, ( ) = optimistic estimate

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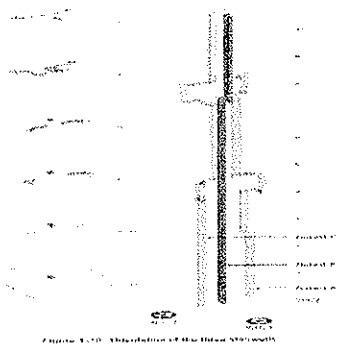
Computational integration



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Other Projects/Topics

- Modelling/predicting building collapse
- CBRN attacks
- Physiology of fire-fighters
- Design of fire fighting equipment for high rise
- Passive Fire Protection for extreme loading/events
- Use of lifts in emergencies
- Simultaneous Evacuation?



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Conclusions – Fire Engineering

Advantages

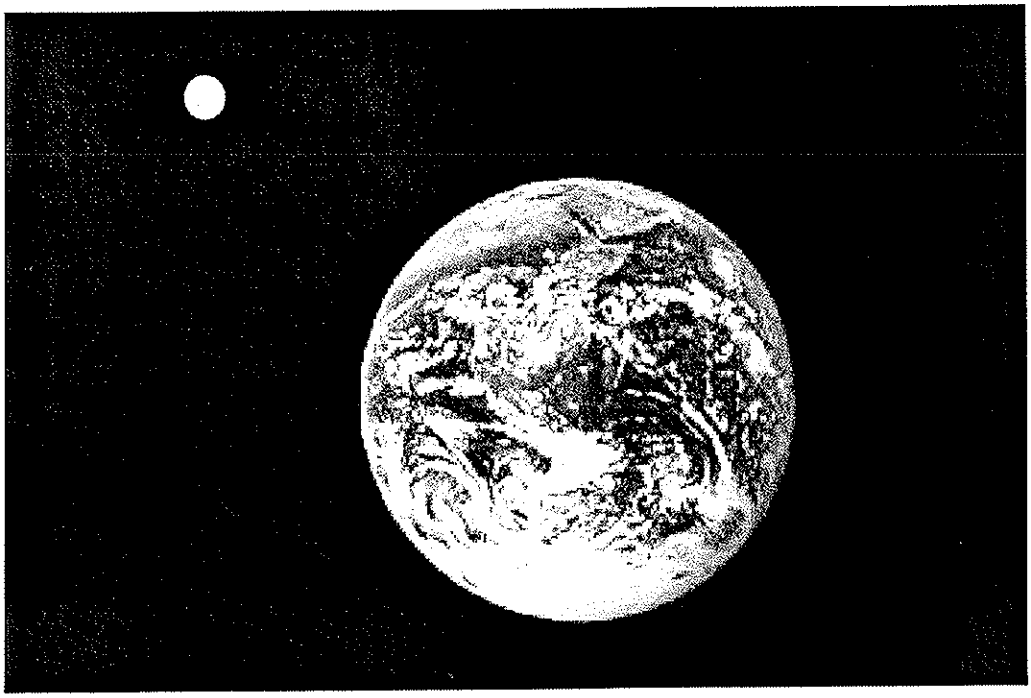
- **Fire safety measures tailored**
- **Allows innovation**
- **Can minimise costs**
- **Uses recent research**
- **Improves operation**
- **Design team consider fire safety**
- **Equivalent fire safety**

Disadvantages

- **Higher qualified and experienced people**
- **Data is lacking in some areas**
- **May restrict future flexibility**

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Would you like to take part in the largest fire safety experiment in the world?



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Thank you

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Recent Fire Research and its implications for fire safety engineering

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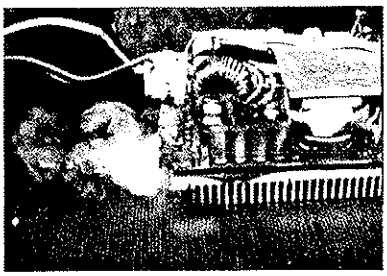
Fire Detection Systems

Mr Nigel Smithies
BRE Associate
Visiting Professor of Fire Risk Analysis at the University of Ulster

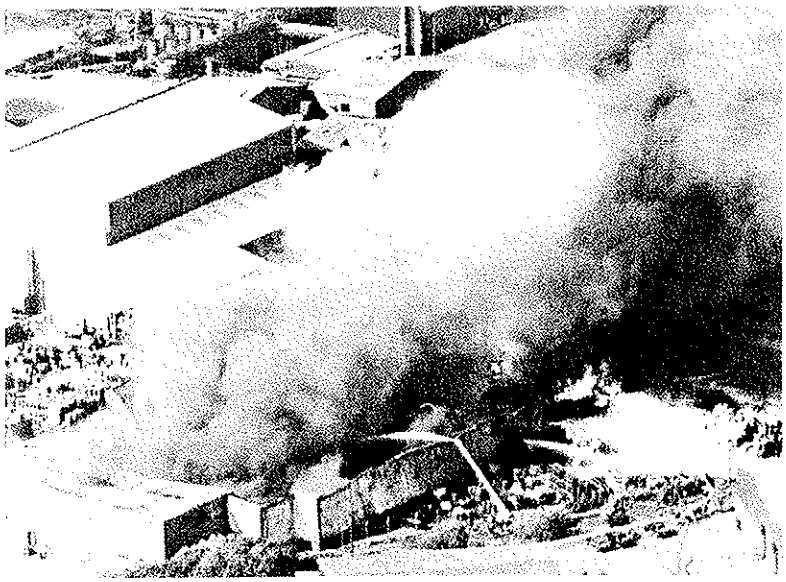
Introduction

- Detection/Alarm (FDAS, AFDAS)
- Developments + Research
- Technology, Standards, Codes/Guidelines, Regulations
- Certification

Why fit AFDAS – timely intervention?



Stop fires at an early stage?



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Why fit AFDAS?

- Alert the occupants
- Alert the Fire and Rescue Service
- Alert the owners/manager
- Protect the building – trigger other systems
- Protect the contents
- AFD 'protected' areas
- Comply with Codes and Regulations

bre

Introduction - why are AFDAS's specified?

- Regulatory – Means of warning and escape (FDAS)
- Insurers +owners - Property/asset/business protection (AFD(A)S)
- Enforcers - Compensatory features MoE, Compartmentation (AFDAS)
- Fire Safety Engineers Fire engineered solution including control of other systems (AFDAS)

bre

Regulatory Requirement

'the building should be provided with a suitable electrically operated fire warning system with manual call points sited adjacent to exit doors and sufficient sounders to be clearly audible throughout the building'

Automatic fire detection is required

- if there are sleeping risks,
- areas which are unoccupied where a fire may develop and threaten the MoE. - means of escape

AFD may also be fitted for compensatory purposes

bre

Assumptions implicit in the Regulations – speculative new build occupancy unknown ?

- The fire starts within a compartment
- The fire does not start in an escape route (corridor or stairway)
- There is a single seat of ignition
- The initiating fire is small (i.e. no accelerant)
- Passive and active safety systems are intact and operational (within reliability limits)
- The building is well managed & occupants behave

bre

Changes to Regulations requires ongoing Fire Risk Assessment of **occupied** buildings

- Fire load
- Working practices
- Ignition sources

Must consider Arson (>50%)

- Therefore
  - Multiple seat with accelerant?
  - External fires
  - Fire on MoE
  - Security vs MoE

More demand for AFD?

bre

The Fire Safety Engineers' requirement

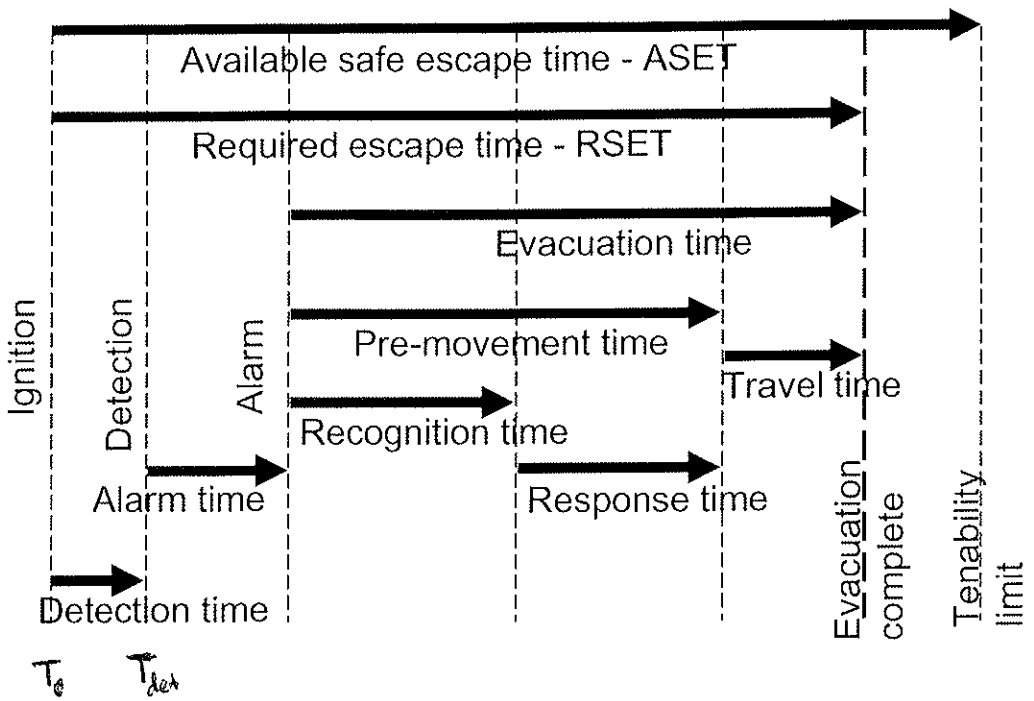
Detection of fire is a critical event on the FSE time-line as it represents when the fire is discovered

Detection of the fire is the first event which triggers active systems

- This includes triggering the fire alarm system
- In a Fire Safety Engineered Design T_0 is when the fire starts
- T_0 is before T_{det}

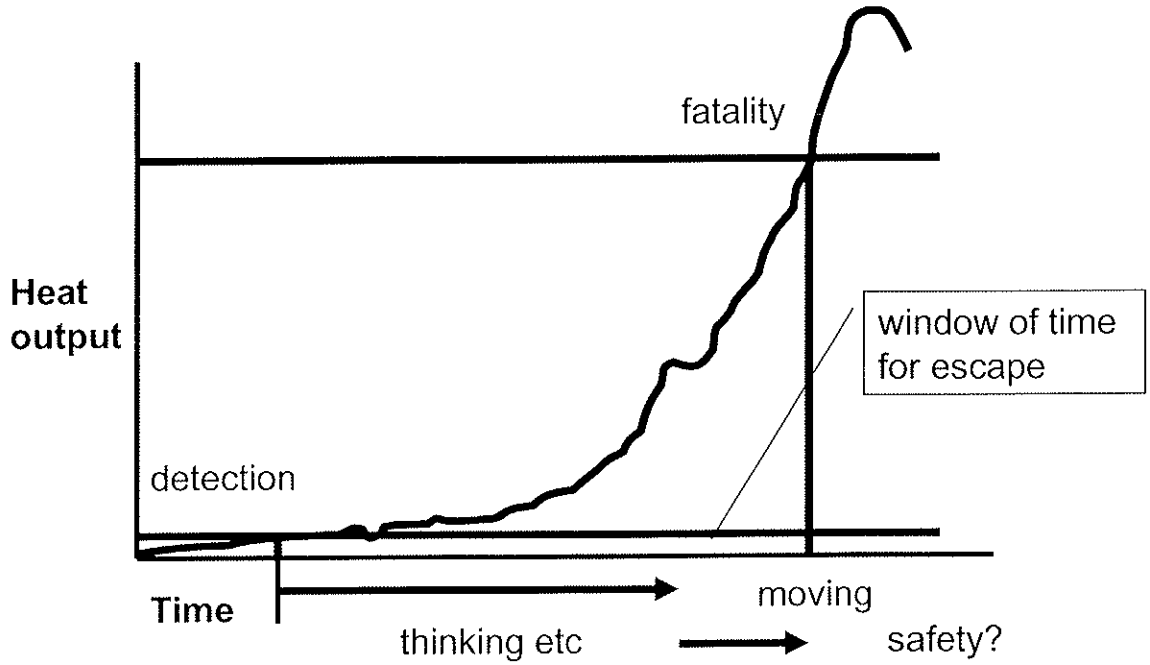
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ASET and RSET timelines



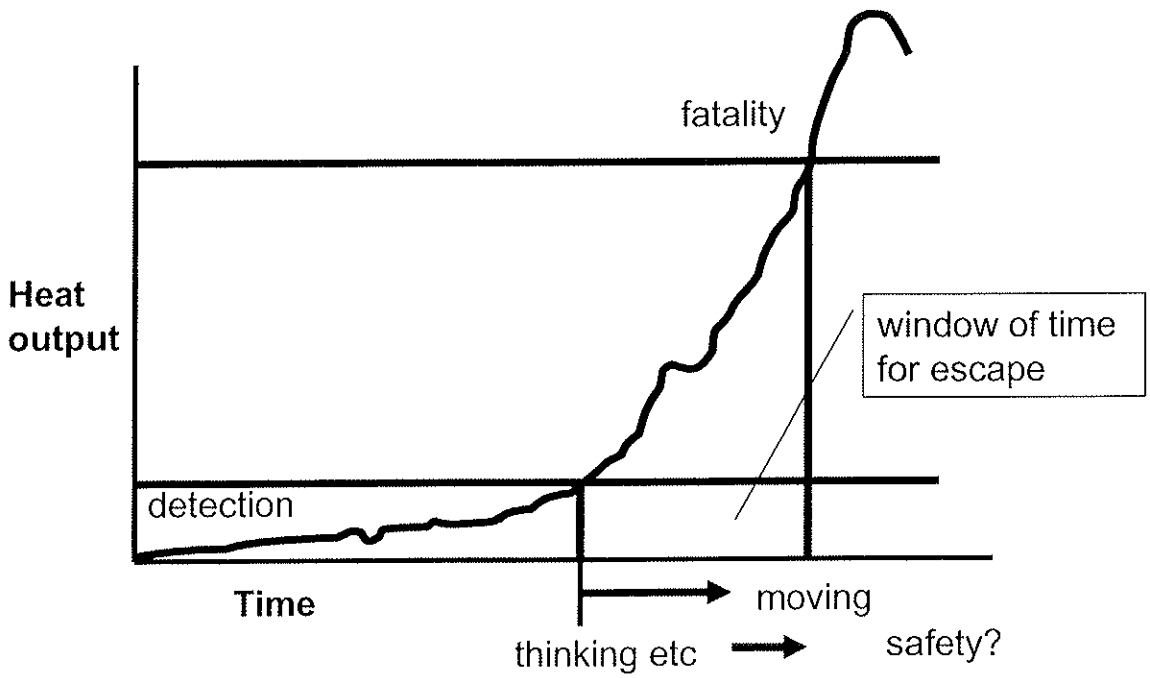
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Life Safety - time scales



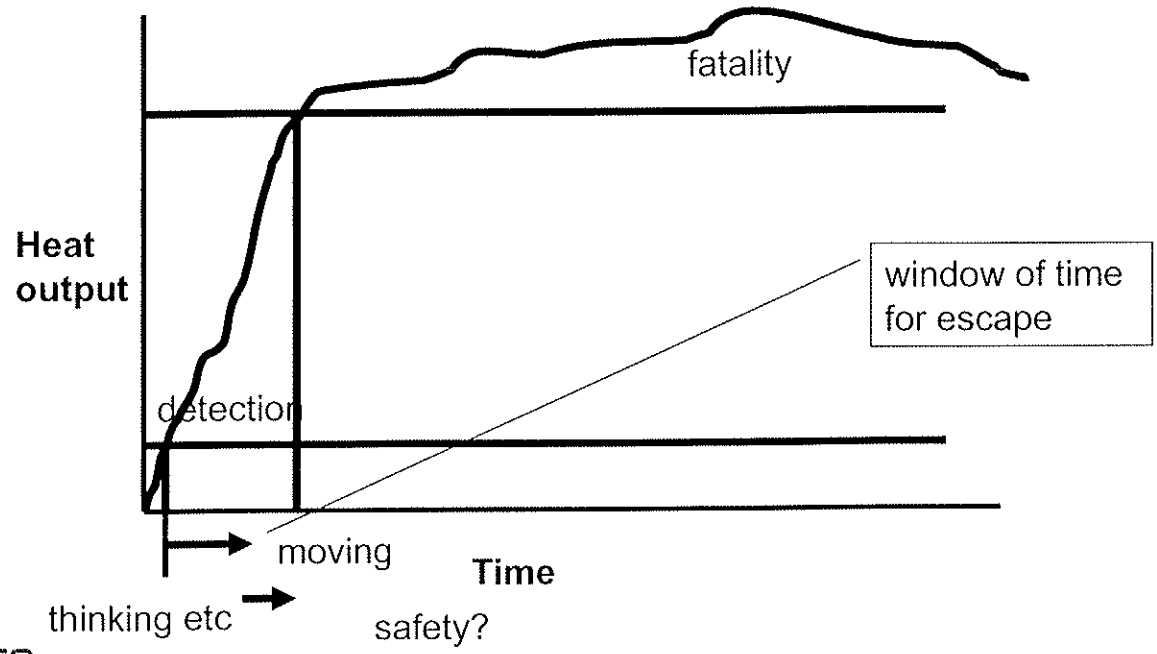
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Life Safety - time scales



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Life Safety - time scales



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The Fire Safety Engineers' requirement

Fire detection system may trigger many events:

- Fire Alarm + Alarm transmission systems
- Door closers, door release mechanisms
- Emergency lighting
- Lift Controls
- Dampers in ducts
- HVAC controls
- Suppression systems
- Smoke control systems
- Shut off fuel supplies etc.

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Insurers + owners requirement

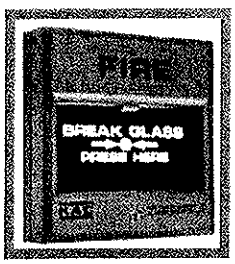
Insurers may require AFD to be fitted to their standards and linked to an alarm centre

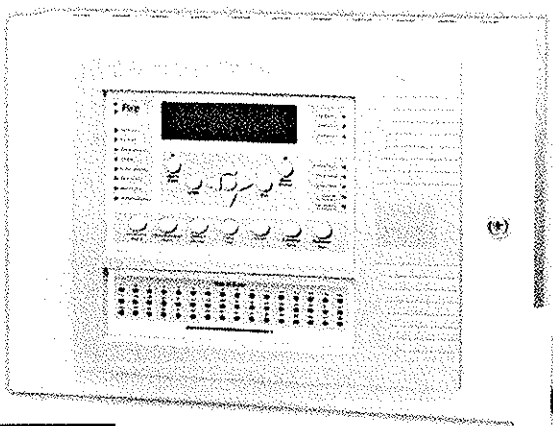
There is an increasing trend towards the use of automatic fire detection – particularly smoke detectors, for property or asset or business continuity protection purposes

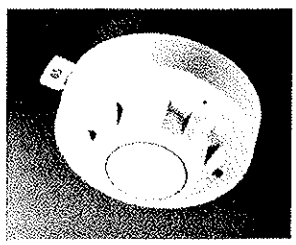
This is often felt to be a good thing to do by the owner and may or may not have been the result of a fire risk assessment

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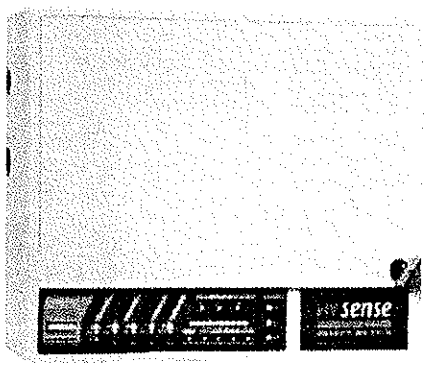
Fire alarm & detection – Components & Technology











bre

Standards, Codes/Guidelines, Regulations,

- It is unusual for AFD components to be accepted by the Enforcers or Insurers unless they have passed a recognised test such as BS, EN, CEA, LPS, FM, UL etc.
- The tests tend to be very technology specific, therefore as new fire detection technology develops, new standards or specifications and supporting tests have to be produced to support the technology
- This is expensive and time consuming. Therefore there is usually a long lead time between new technology becoming available and it being accepted for fire detection applications in buildings
- Alternatively the technology is developed to pass existing tests

Engineering - Detection of fire

Detection time –

- No Standard for detection time –
- Still no real calculation methods except Δ T
  - *Smoke generation rate?*
  - *Smoke characteristics?*
  - *Smoke movement?*
  - *Time delays to enter sensing element?*

Engineering - Detection of fire

Smoke detectors are very sensitive devices all tested against same 'fires' but different types of detector have different characteristics:

- The smoke needs to enter the detection chamber/zone
- Convection currents
- Stratification
- Wrong type of smoke

Reliance on Installation/Application Guidelines is the norm

bre

Installation guidelines

The design, installation, commissioning and maintenace of the system is crucial to its performance

Installation guidelines vary from country to country and typically support the Building Regulations. Generic guidelines are:

- EN 54 TS 14 Fire detection and fire alarm systems. Guidelines for planning, design, installation, commissioning, use and maintenance

UK has a long and pioneering tradition in this area

bre

An example of Codes handling FSE

Installation guidelines

BS 5839 Part 1 Fire detection and fire alarm systems for buildings —

- *Part 1: Code of practice for system design, installation, commissioning and maintenance*
- *Part 8. Code of practice for the design, installation and servicing of voice alarm systems*

Installation guidelines are typically taken as being prescriptive rather than 'guidelines' and the Engineer may typically specify the AFDAS shall comply with L1 system in BS 5839 Part 1. – which is total cover.

An example of Codes handling FSE

Categories of systems within BS 5839 Part 1 were increased in the 2002 revision to include L1 through to L5:

L5 Systems in which the protected area(s) and/or the location of detectors is designed to satisfy a specific fire safety objective (other than that of a Category L1, L2, L3 or L4 system). A Category L5 system may form part of a fire engineering solution, in which automatic fire detection is just one component of the solution.

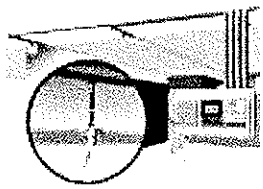
False or 'unwanted' alarms





Do we have any true fire detectors ?

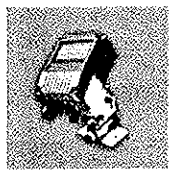
Do they all detect secondary phenomena ?



- Smoke – particles, dust
  - Optical – light interference
  - Ionisation – sub micron interference
  - Beam – obstruction
  - Aspirating
- Flame – EM radiation, IR, UV
- Heat – temperature, sun
- Gas – CO, CO2,

Is this why they are so sensitive ?









bre

False or 'unwanted' alarms

Discrimination is the issue not sensitivity with most AFD. This leads to false or unwanted alarms.

Reduction techniques include

- Double-knock
- Coincidence
- Multi sensor or multi criteria
- Delayed alarms
- Algorithms in detector, in panel, distributed
- Telephone confirmation

bre

Research and Developments

Recent examples – now becoming ENs

- Aspirating inc single point - BFPSA, CEA
- Gas sensing (in particular CO) - LPS
- Line heat ?

Newer developments

- Nano-technology gas sensors
- Variations on optical point configurations and wavelengths for smoke detection
- More Multi-sensor & Multi-criteria optical heat CO
- Spatial/volumetric sensors

AFD System Reliability 3rd Party Certification

Most Regulators for example require 3rd Party Certification to demonstrate AFD Components comply with the relevant standard

The design installation, commissioning and maintenance of the system is equally important

3rd Party Certification schemes are in place to cover these aspects

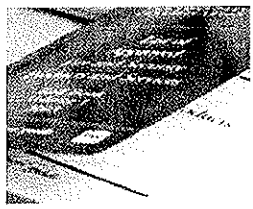
Certification and Approval

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What is Certification and Approval ?

- **Independent** third party confirmation that products, services, systems and personnel meet and continues to meet those standards and specifications to which the certification applies, through:

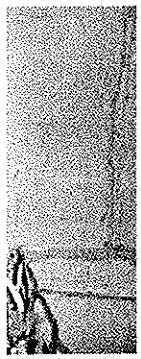
- independent assessment of : manufacturing facility and/or processes
- independent and competent : testing and/or assessment of service
- independent review : of test results against a technical standard
- ongoing : surveillance of production and assessment of management systems
- ongoing : audit sampling and testing where appropriate



bre

Benefits of Approval

- Risk management for manufacturers, end users, insurers, clients, specifiers, contractors, legislators .....
- International acceptance
- Market entry
- Differentiation
- Product and process and improvement
- Customer satisfaction
- Consumer confidence
- Enhanced marketing



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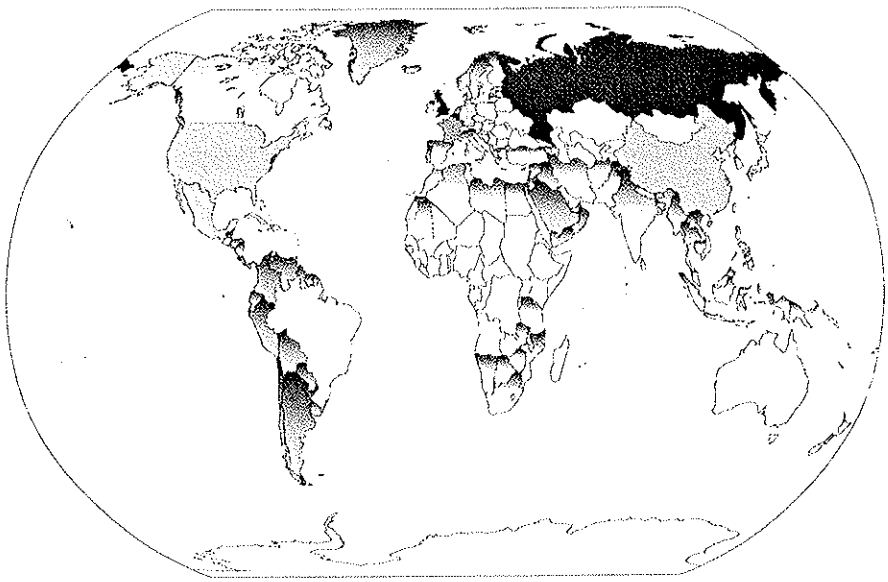
BREC / LPBC

- The leading centre for loss prevention testing and approvals in UK
- LPCB can trace its history back to the 1880s
- Approved > 5000 loss prevention products from manufacturers in > 35 countries
- Approvals cover products including:
  - electronic security, fire detection, fire suppression, passive fire protection, physical security
- Approvals cover quality systems, installers, and service and maintenance companies
- Published over 70 loss prevention standards (LPS's)

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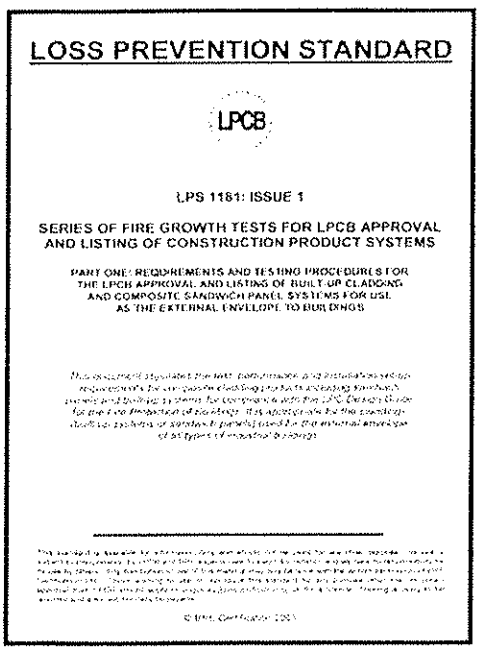
BREC/LPCB Coverage

- Customers in 38 countries
- Recognised in 42 countries
- Most product customers now in international ownership



bre

Loss Prevention Standards



LOSS PREVENTION STANDARD

LPCB

LPS 1181: ISSUE 1

SERIES OF FIRE GROWTH TESTS FOR LPCB APPROVAL AND LISTING OF CONSTRUCTION PRODUCT SYSTEMS

PART ONE: REQUIREMENTS AND TESTING PROCEDURES FOR THE LPCB APPROVAL AND LISTING OF BUILT-UP CLADDING AND COMPOSITE SANDWICH PANEL SYSTEMS FOR USE AS THE EXTERNAL ENVELOPE TO BUILDINGS

Download from
www.redbooklive.com
website

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Loss Prevention Standards

- LPS standards cover:
  - All aspects of loss prevention
  - Issues that are not addressed by national/international standards
  - Risks that require higher standards than those published by national/international bodies
  - Issues faced by specific specifier groups requiring tailored solutions to the risks they face
- LPS standards undergo thorough independent consultation and vetting and are supported by the insurance industry and interested stakeholders.
- Only those products approved by BREC / LPCB or other suitably trained and licensed third parties may claim compliance with LPS standards

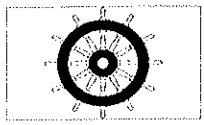
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CE marking

- CE marking – even at attestation level 1 provides only performance against essential requirements – it is not a quality mark.
- CE marking
  - a declaration of conformity
- Differs from third party certification schemes in relation to
  - on going certification and market support for products against both life safety and property protection performance criteria.

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Accreditation and Notification EUROPE



MED Mark

0832

CE

CPD Mark

CE

PED Mark

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BREC & LPCB Marks

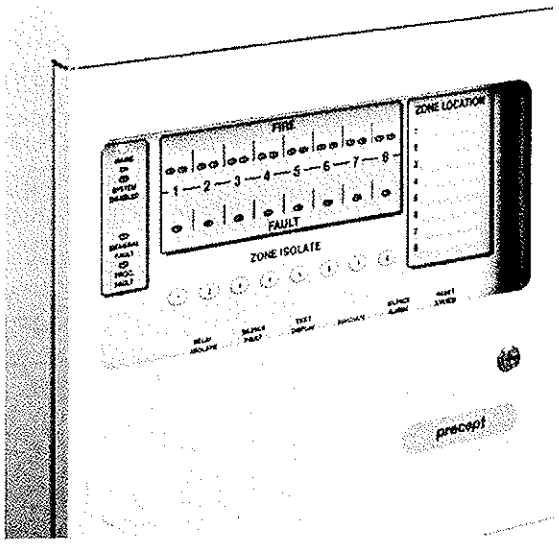


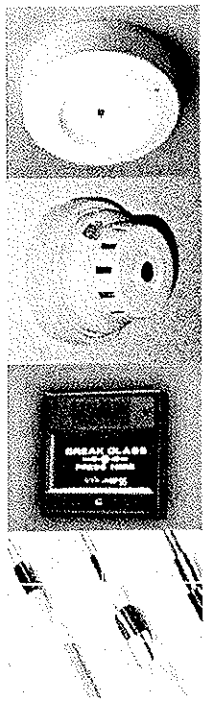


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Detection and alarm

- EN 54 series for listing and approvals





Sounders

Control panels

Detectors

Manual call points

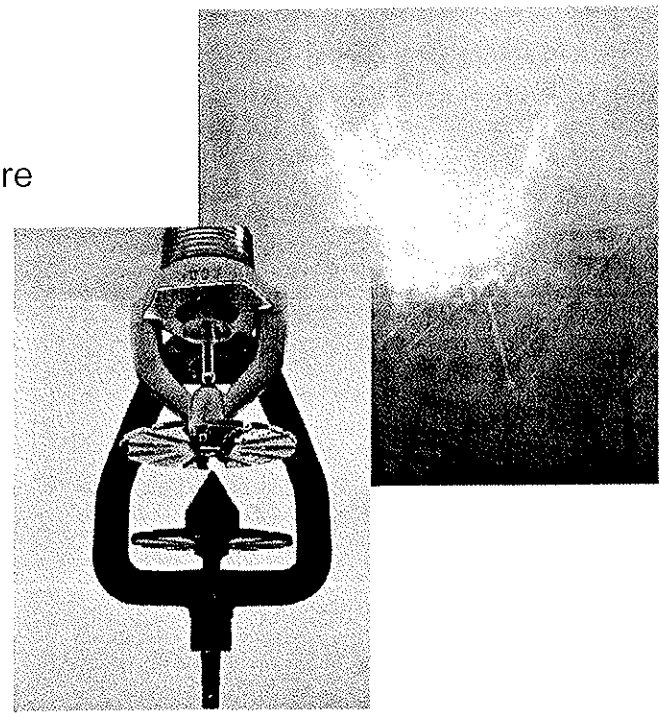
Fire resisting cables

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Control panels

Active Fire Suppression

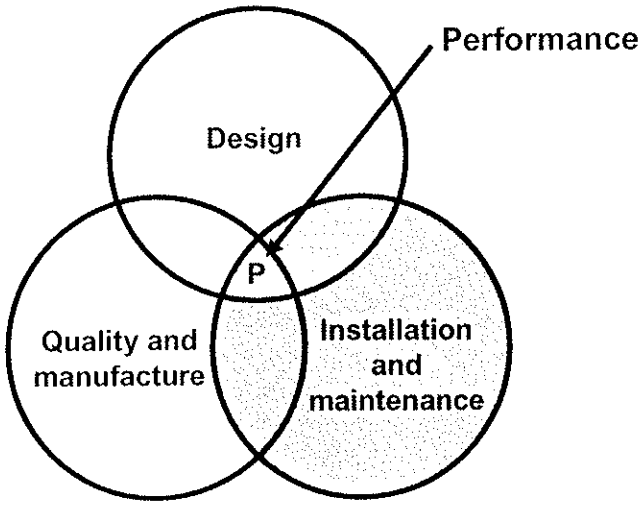
- LPS 1036 – Certification of Automatic Fire Sprinklers
- LPS 1230 – Fixed Gaseous Fire Extinguishing Systems
- Portable Fire Extinguishers:
  - EN 3,
  - BS 7937 (Fire Blankets)
  - BS 6165



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BREC / LPCB - Ensuring continued compliance

The approval process focuses on managing all the factors that affect product/service performance



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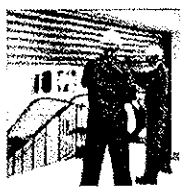
Installer Schemes

- Installation – It is vital that the system is installed correctly if it is to performance correctly.

- Hence a range of installer schemes have been developed to support many of the LPS standards

  - To ensure that systems are properly installer
  - Use reliable equipment
  - To maintain and improve standards of installed work
  - To ensure systems are properly maintained

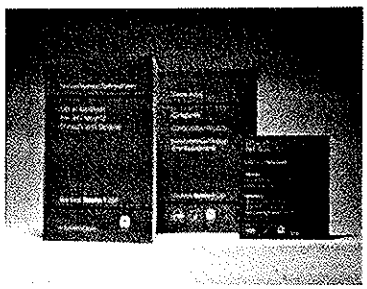




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The Red Books

Products and services approved by us are listed in the Red Books



- Volume 1 Fire and Security products and services
- Volume 2 Companies, Construction Products and Environmental Profiles and Assessments
- Available on-line at www.redbooklive.com
- CD and hard copy

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Thank you

Recent Fire Research and its implications for fire safety engineering

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New understanding of human responses and movement in fire

Prof David Charters, PhD, CEng, FIFireE, MIMechE

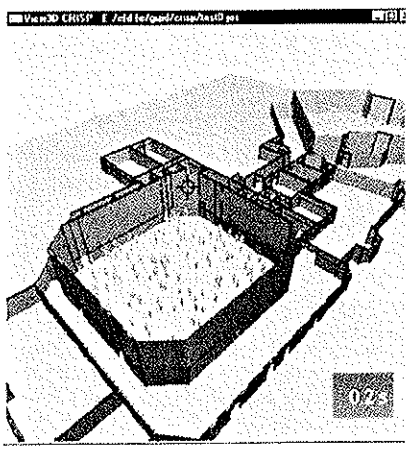
Director of Fire Engineering

Visiting Professor of Fire Risk Analysis at the University of Ulster

Immediate Past International President of the Institution of Fire Engineers

Overview

1. Introduction
2. Human behaviour in fire
3. Pre-movement
4. Movement
5. Future opportunities/challenges



Traditional Means of Escape Design

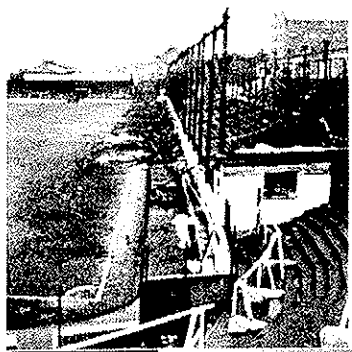
Traditional design and regulation of means of escape relies control of:

- Adequate escape route provision:
  - number and width of exits and protected escape routes
  - limitations on maximum travel distances to an exit
  - floor space factors
- Fire separation:
  - passive protection between compartments
  - passive protection of escape routes
  - fire and smoke doors and lobbies
- Provision of warnings:
  - manual or automatic detection and alarm system
  - fires safety management
- Active fire protection and/or smoke extraction
  - sprinklers, smoke extraction

bre

Fire Disasters

Multi-fatality fire in large structures:	
Department Stores:	Manchester Woolworths, Chesterfield Littlewoods
Hospitals:	Warlingham Park ,Falklands Hospital
Underground Station:	Kings Cross
Leisure Centres:	Summerland, Mayfield
Clubs, disoctheques:	Stardust Disco (Dublin), London drinking and cinema clubs
Hotels:	Aviemore, MGM Grand, DuPont Plaza, Cairo Sheraton
Stadium:	Bradford
Airport:	Dusseldorf
Aeroplane:	Manchester Airtours
Train:	Ladbrooke Grove
Tunnels	Mont Blanc, Austria, (Channel Tunne),
Fires in Dwellings Approximately 700 deaths and >15,000 injuries each year in houses, flats, HMOs and residential homes	



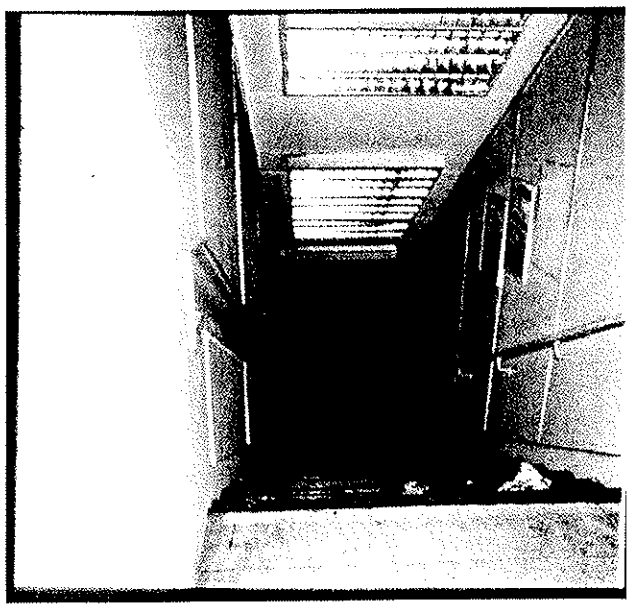




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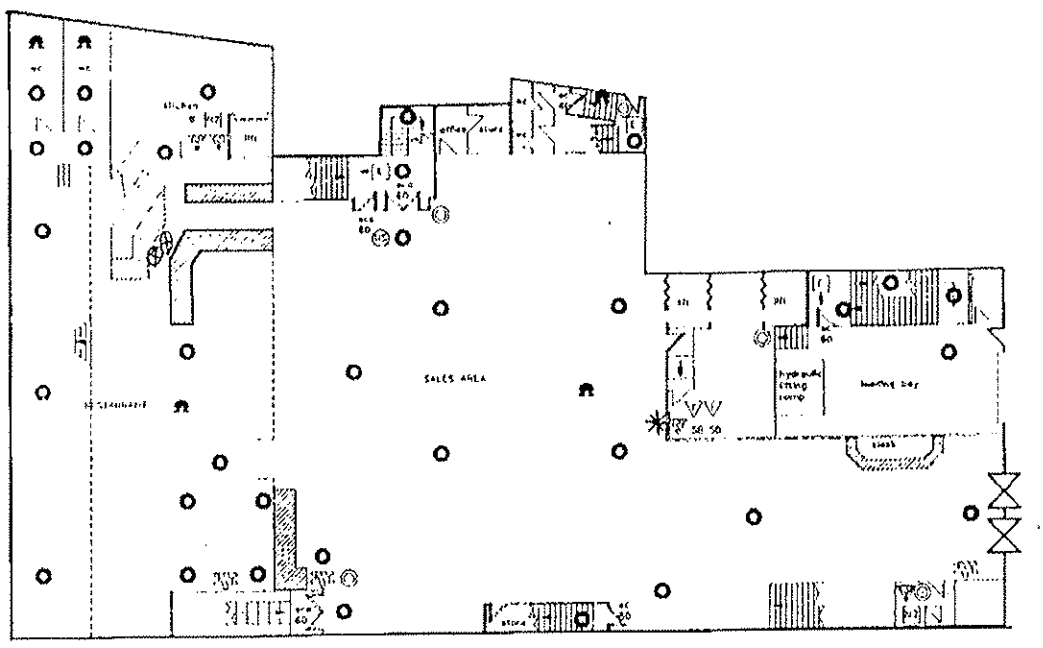
Chesterfield Littlewoods





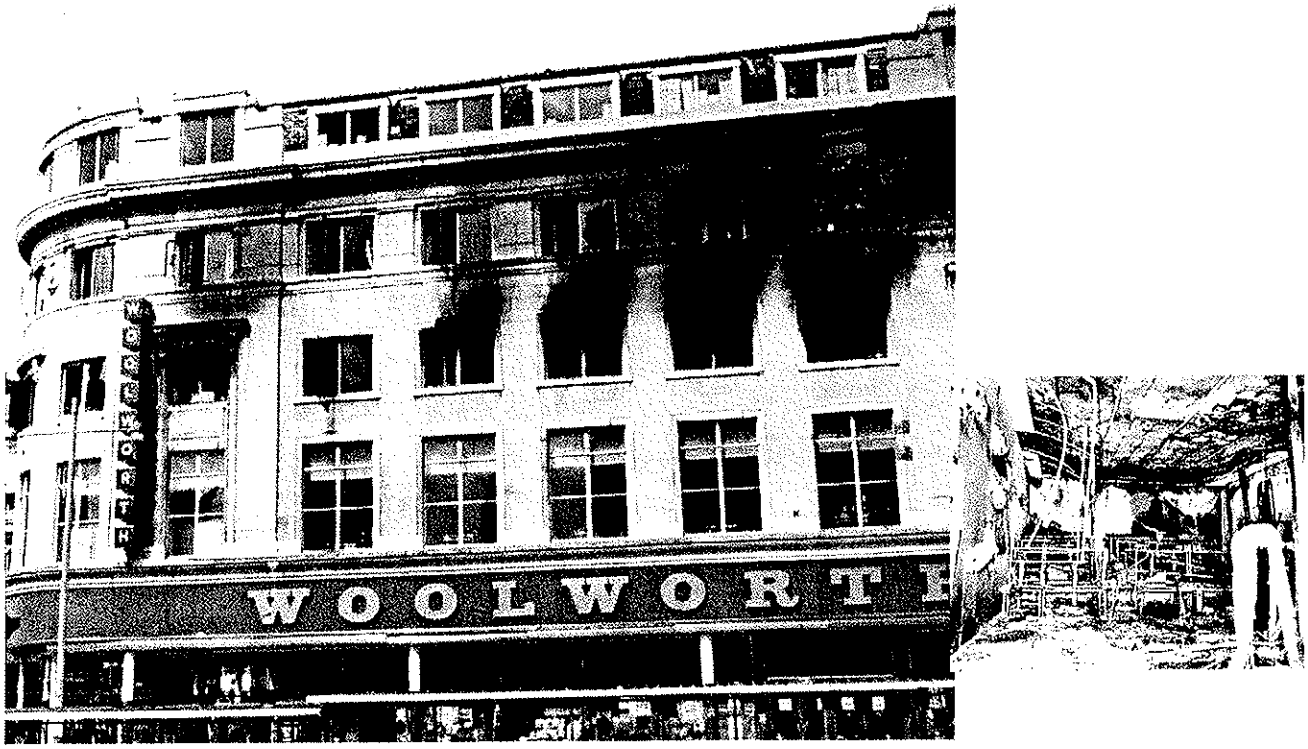
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Chesterfield Littlewoods

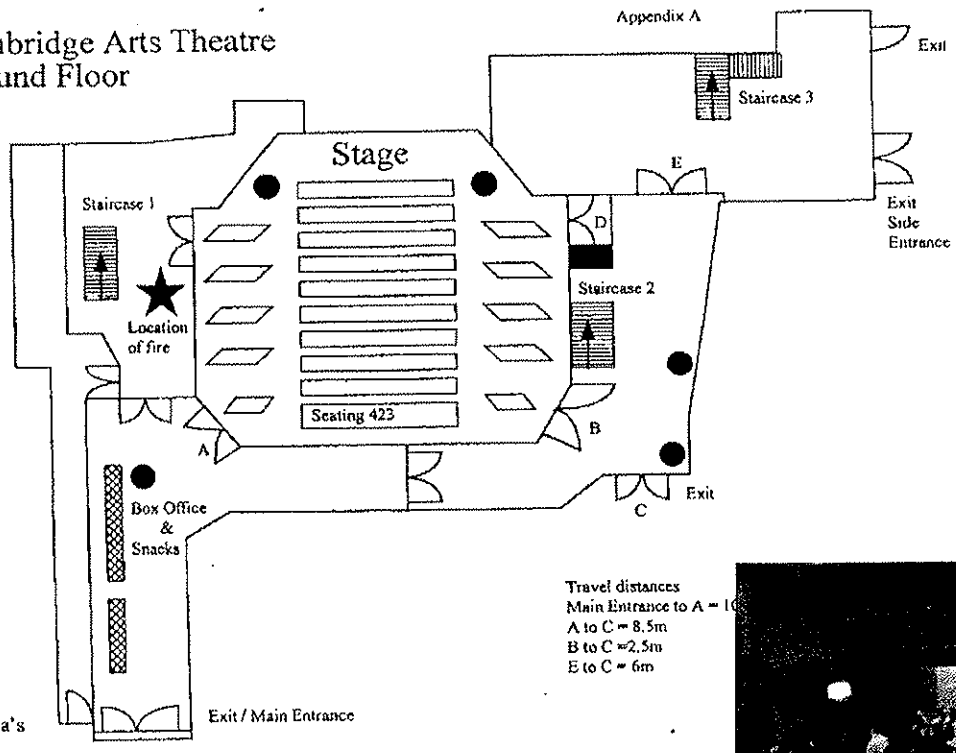


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Manchester Woolworth's



Cambridge Arts Theatre
Ground Floor



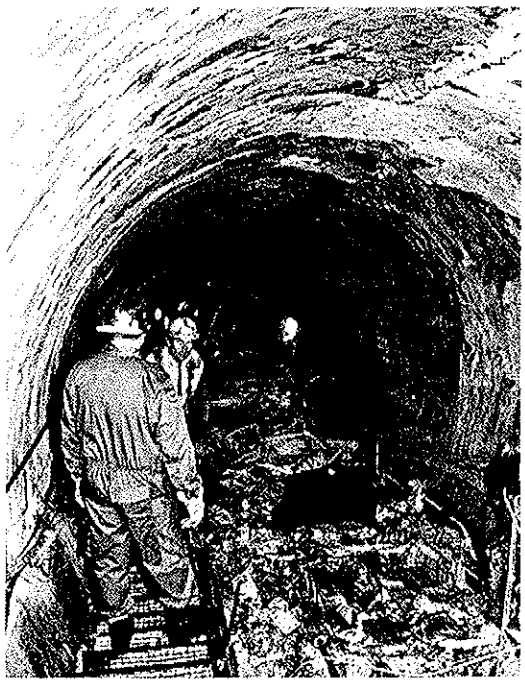
Travel distances
Main Entrance to A = 1
A to C = 8.5m
B to C = 2.5m
E to C = 6m



bre

Kaprun cable car tunnel fire

- The loss of the hydraulics left the doors closed in a locked shut position, so that the occupants had great difficulty escaping
- The tunnel was very narrow with a narrow walkway, further impeding escape.
- There were no lights in the tunnel.
- There was no obvious evacuation plan or procedure.
- The tunnel doors failed to close and the chimney effect resulted in rapid fire growth
- Some passenger escaped from the front of the train and went up. They were rapidly overcome by fumes.
- Others escaped from the back. They went down and survived.
- 156 people died



Adequacy of prescriptive guidance

- There have been a number of major disasters in large buildings and quite a few near misses, when occupant have narrowly escape injury.
- Examples of current concern are:
  - Large warehouses (particularly those visited by the public)
  - Large retail stores
  - Tall buildings

Adequacy of prescriptive guidance

Limitations of the prescriptive guidance:

- Does not make allowance for the behavioural requirements of occupants and fire safety management needs
- Inadequate escape route capacity where needed
- In some cases there has been a failure to control contents adequately so as to prevent rapid fire growth and spread. We now know that certain types of fire tend to grow very rapidly and produce very rapid contamination of enclosures with fire effluent
- In some cases there has been a failure of containment of fire or fire effluent. Sometimes this results from construction defects, sometimes from paths of smoke spread (such as open doors from areas of fire origin or wind effects.

bre

Traditional Means of Escape Design

Basis for safety design:

- Practical experience over many years:
  Design and control has evolved with experience of fire disasters

  The methods achieve a relatively safe design by the interactions of the various design rules

  They are not primarily time-based but some of the rules are time-based
- Advantages

  Achieve safety by application of relatively simple rules that have been found to work empirically

  Rules control more aspects than actually stated (with FSE every factor must be identified and calculated)
- Disadvantages

  Not easily adapted to modern design, imposing limitations

  Ignores some aspects now known to be important (e.g. occupant behaviour)

bre

Interactions between rules

The rules on travel distance, exit provision and occupancy factors interact to provide safety limits on a design:

- Travel distance and exit number are the main limitations on the size of a compartment

  Alternative escape routes should be available and the distance to the exits is limited. The size of a compartment can be increased to some extent if the number of exits is increased

- Exit number and width, together with floor space factors limit the number of occupants

  For a given enclosure size the maximum population depends upon the floor space factor

  The aggregate width of the exits (exit number x exit width) must then be sufficient for this population

bre

Power of controlling travel distance

The simple expedient of controlling travel distance to an exit affects a number of variables relating to fire hazard:

- If distance is short, the probability of fire between an occupant and an exit is small
- If distance is short, occupants should be able to see an exit and be aware of any fire while it is small. It is less likely that the route to exit would be complex or that exit would be hidden from view
- If there is a choice of exits, occupants should be able to escape in a direction away from the fire
- If smoke logging occurs, it is more likely that an exit would be visible and could be reached without travelling far through smoke
- The relationship between rate of fire spread and travel distance:

  If travel distance is long, there is a higher probability that a fire will reach the rapid t^2 growth phase before it is discovered, overtaking occupants before they can escape

- Effect on occupancy: short travel distance rule = more exits

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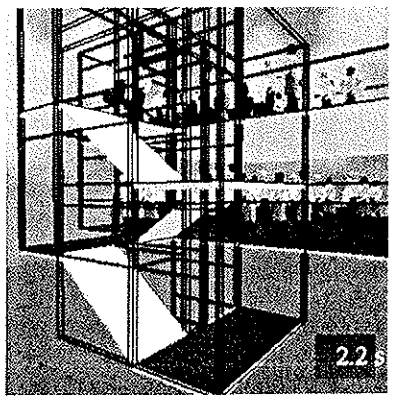
Limitations of prescriptive approach and performance based design

- The prescriptive approach concentrates on the structural aspects of means of escape and ignores the point that fire hazard and safe escape are basically time dependent
- It ignores occupant behaviour in emergencies and the time required for occupant responses
- Using a performance-base (time line dependent) approach enables a range of factors affecting fire hazard and escape time to be placed on a common framework so that the effects of altering various design features can be calculated
- This enables alternative design solutions

bre

Evacuation and human behaviour

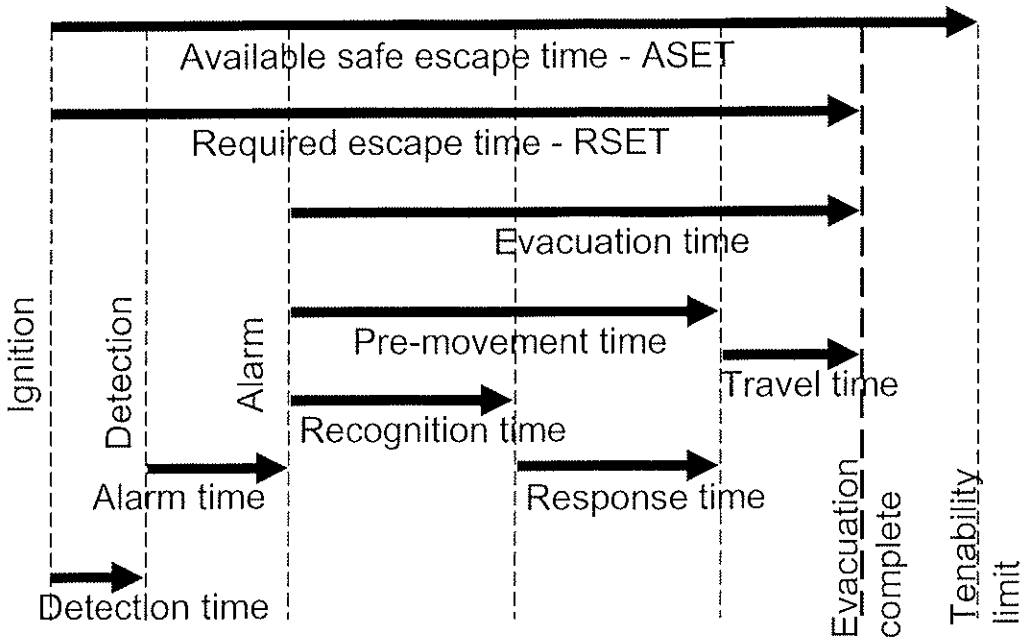
- Recognition time?
- Pre-travel activities and duration?
- Travel time?
- Tenability?





bre

ASET and RSET timelines



bre

Escape time formula

$RSET\ (\Delta t_{esc}) = \Delta t_{det} + \Delta t_{a} + \Delta t_{pre} + \Delta t_{trav}$

$\Delta t_{pre} = \Delta t_{pre(first\ occupants)} + \Delta t_{pre(occupant\ distibution)}$

- For each occupant pre-movement time depends upon recognition and response behaviours

Δt_{trav} depends upon:

- time to walk to an exit (walking time) time to flow through exits into protected escape routes
- merging flows and time to flow through horizontal and vertical escape routes
- for populations of occupants there are considerable interactions between the different phases

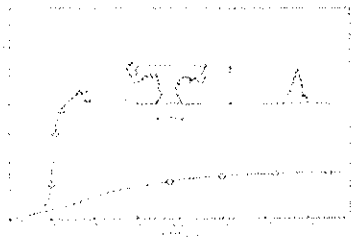
bre

Scientific knowledge…

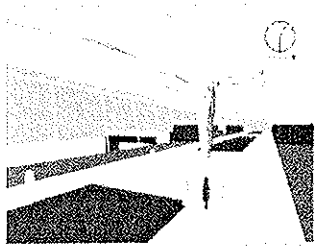
- Observation
  - Qualitative understanding



- Measurement
  - Quantitative understanding



- Theory
  - Fundamental understanding



bre

Scientific basis…future development

- Observation
  - Human behaviour in fire
  - Fire safety management
- Measurement
  - Fire growth
  - Plume modelling
  - Movement of people
  - Time equivalence
- Theory
  - Computational Fluid Dynamics
  - Finite Element Analysis

bre

Human Behaviour in Building Fires

- Three stages of behaviour
  - recognition
  - response
  - evacuation
- People rarely panic
- People often form groups (family, social or ad-hoc)
- Person's role has a major impact on their behaviour





bre

Key aspects of occupant behaviour during fire emergencies

- Commitment to original activities
- Slow recognition of ambiguous cues
- Friendly fire syndrome
- Role and responsibility
- Responses other than egress (family, belongings, theft etc.)
- Fighting fire
- Exit choice and way-finding
- Reactions to smoke and heat

bre

Performance-based approach

- To solve we only need to know three main things
  - Building characteristics and fire safety management procedures
  - Occupant characteristics
  - Fire simulation dynamics
  - (Intervention effects)
- The problem is that each one involves a large number of factors with many complex and unknown interactions

bre

Building characteristics and fire safety management strategy

- Layout and geometry
- Escape routes
- Building use
- Fire safety management system
- Life safety strategy
- Application of active systems
- Signs and lighting
- Refuge areas
- Environmental considerations

bre

Occupant characteristics

- Population numbers and density
- Familiarity with building
- Distribution and activities
- Alertness
- Mobility
- Physical and mental ability
- Social affiliation
- Role and responsibility
- Location
- Commitment
- Focal point
- Responsiveness
- Condition (from analysis of occupant condition)

bre

Fire simulation dynamics

At any point in time during the fire incident:

- **Fire alarms and cues:**
  What information is available to occupants?
  - **visibility of flames and smoke,**
  - **time when automatic alarm system triggers**
- **Fire size and extent, smoke density, toxic gas concentrations, temperature and heat flux in all building enclosures, activation of suppression and smoke control systems**
  - **in order to assess tenability and effects on escape capability**

bre

Peoples' estimates of fire growth rates

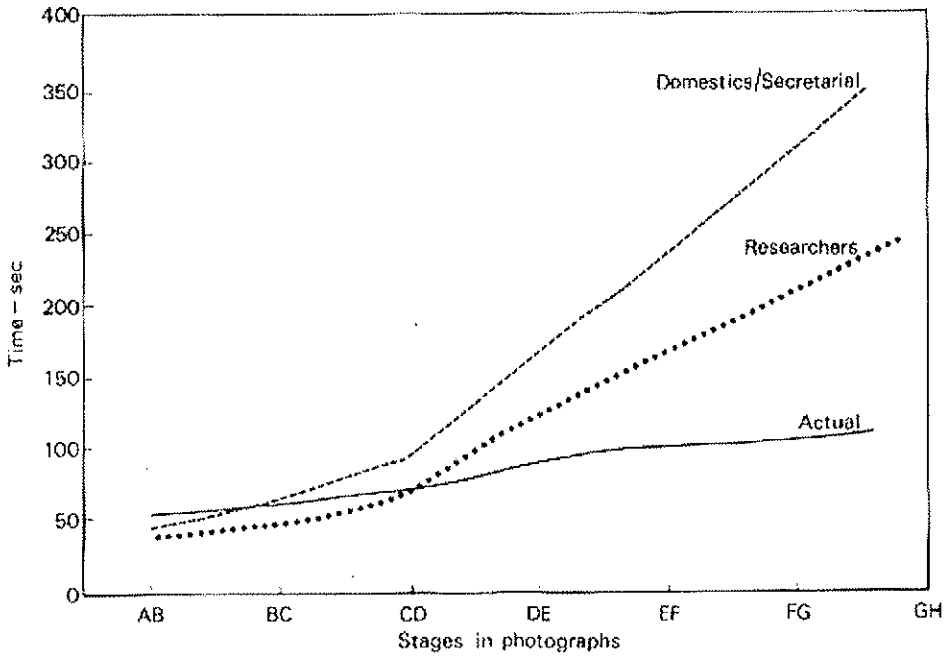


Figure 2 Judged times between consecutive stages of a fire for 2 experimental groups compared with actual times between stages

bre

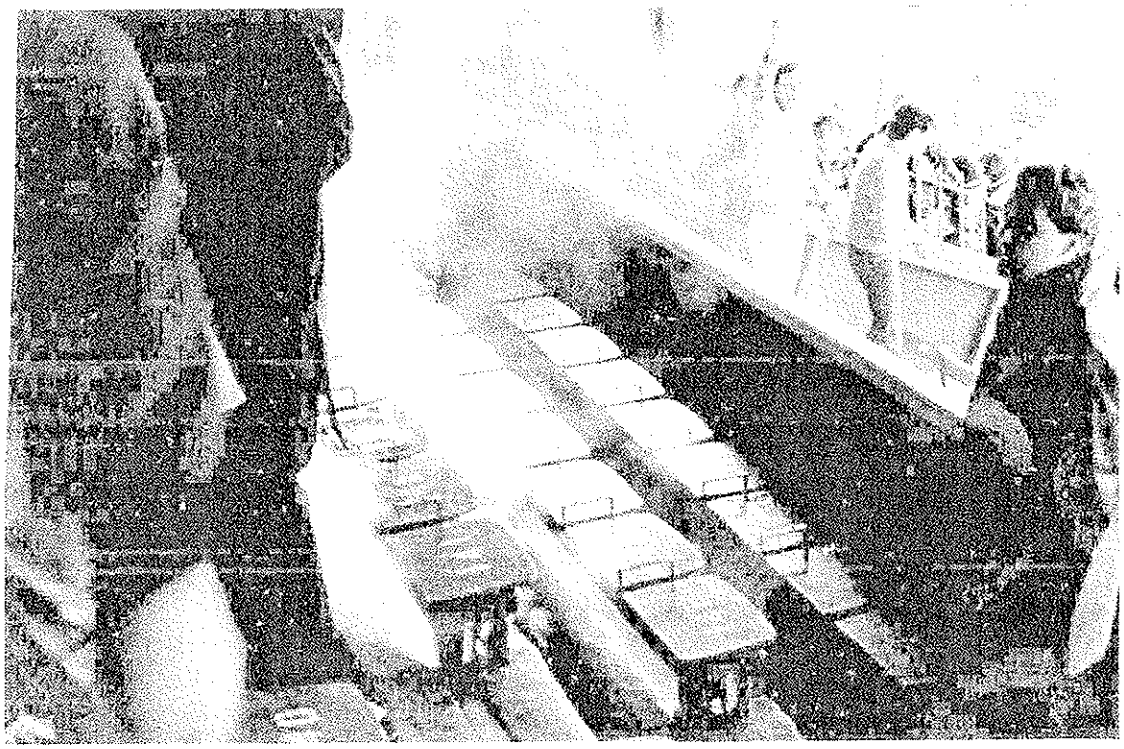


0.30 1.15 2.15



bre 3.00 3.17 3.20

Bradford stadium

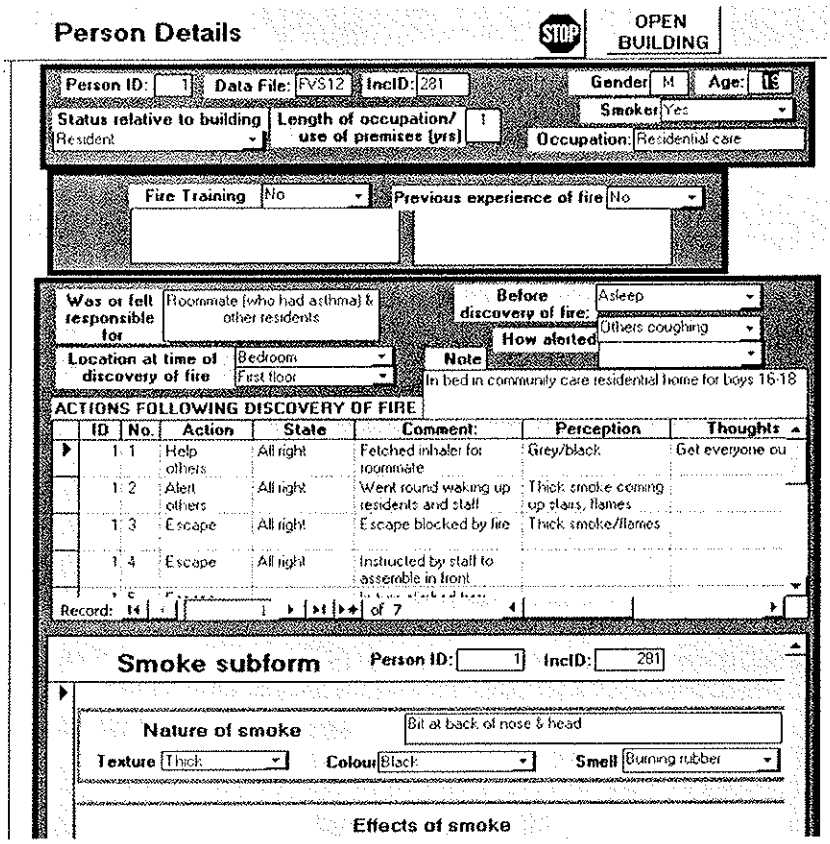


bre

Recognition

bre

Fire investigation Access database



bre

Fire investigation database

- Detailed examination of 98 fires in terms of building, fire and occupants.
- Majority of non-cooking fires caused by electrical malfunctions in wiring and appliances.
- Smoke detectors alerted occupants in only a very small number of cases.
- Once alerted occupants carried out six or more actions before escaping. These delayed escape while fires grew.
- Actions included investigating, warning others, mitigating actions (shutting doors, fighting fires, turning off heat), calling for help, being passive.

bre

How occupants were alerted

Alerted	Frequency
Told by others	37
Heard noise	16
Saw smoke	12
Saw flames	9
Saw sparks/flash	4
Saw flames and smoke	4
Smelt smoke/burning/fumes	23
Heard alarm	10
Woke up coughing	2
Felt heat	1
Saw Fire Brigade	1
TV went off	1
SUM	124

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How alerted occupants in and not in fire room

Alerted	Frequency
Saw flames	5
Heard noise	4
Told by others	2
Smelt something	2
Saw smoke	2
Saw flames & smoke	2
Heard alarm	2
Woke up coughing	1
Smelt smoke	1
Smelt burning	1
Saw sparks	1
Not known	1
Heard screaming	1
Felt heat	1
SUM	26

Alerted	Frequency
Told by others	33
Heard noise	11
Saw smoke	10
Smelt smoke	8
Smelt burning	8
Heard alarm	7
Saw flames	4
Saw flames & smoke	2
Saw sparks	2
Woke up coughing	1
Smelt fumes	1
Smelt something	1
Saw FB	1
Remembered chip pan	1
TV went off	1
Heard FB	1
Saw flash	1
SUM	93

Effectiveness of smoke detectors

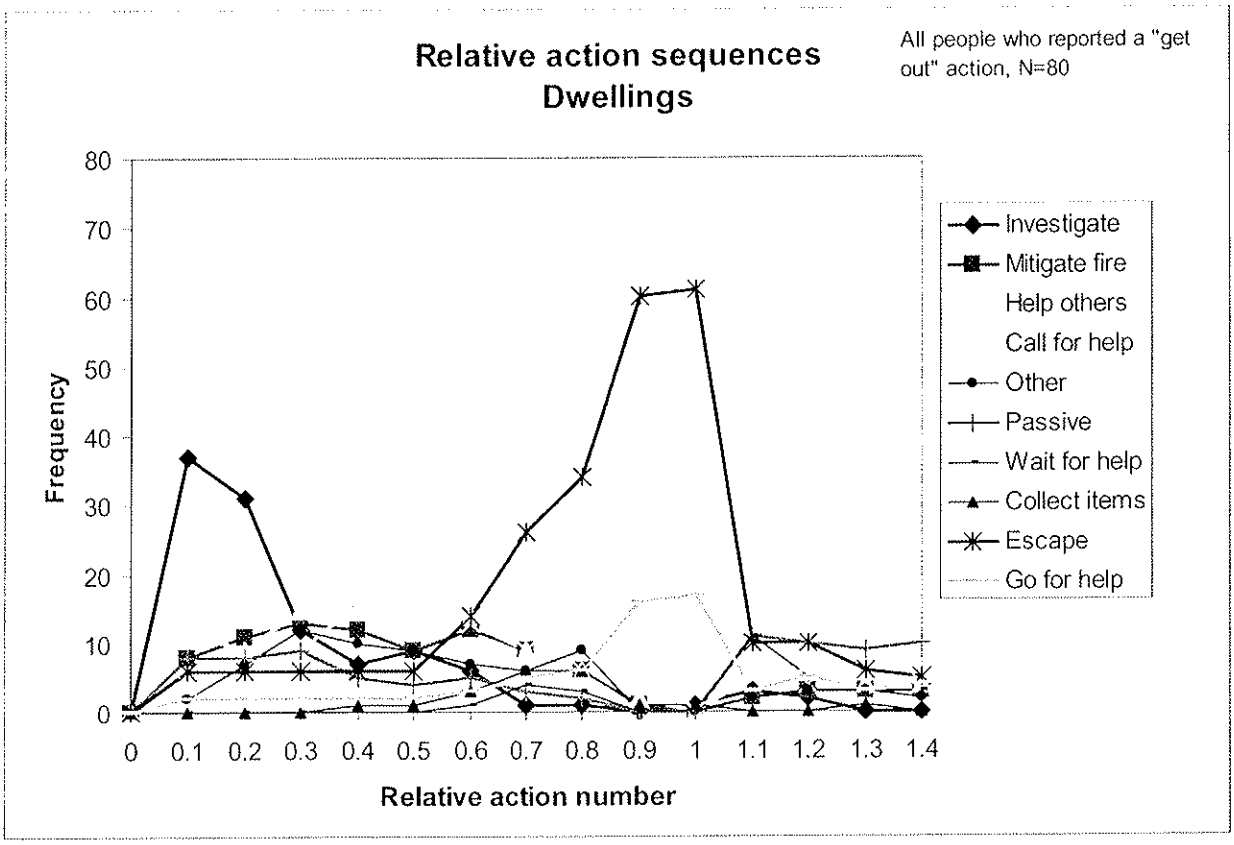
Frequency		Detector	Functional	Activated	Effective
	37	No	No	No	No
(49)	12	Yes	No	No	No
(73)	24	Yes	Yes	No	No
(88)	15	Yes	Yes	Yes	No
	10	Yes	Yes	Yes	Yes
	98	Total			

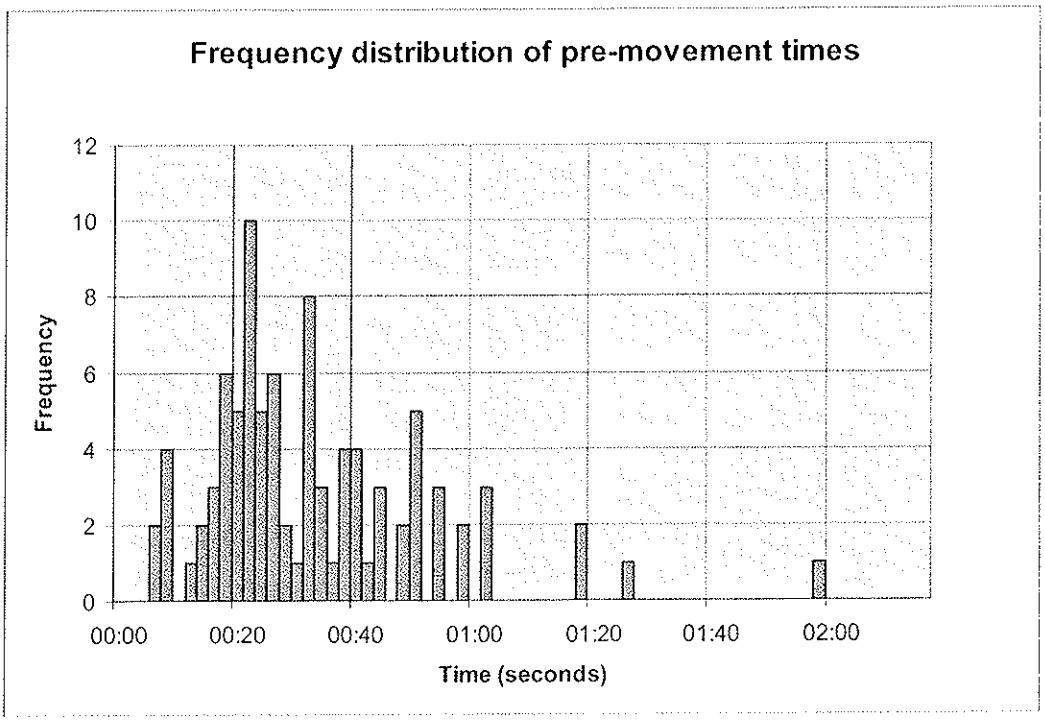
bre

Reaction

bre

Action sequences





bre

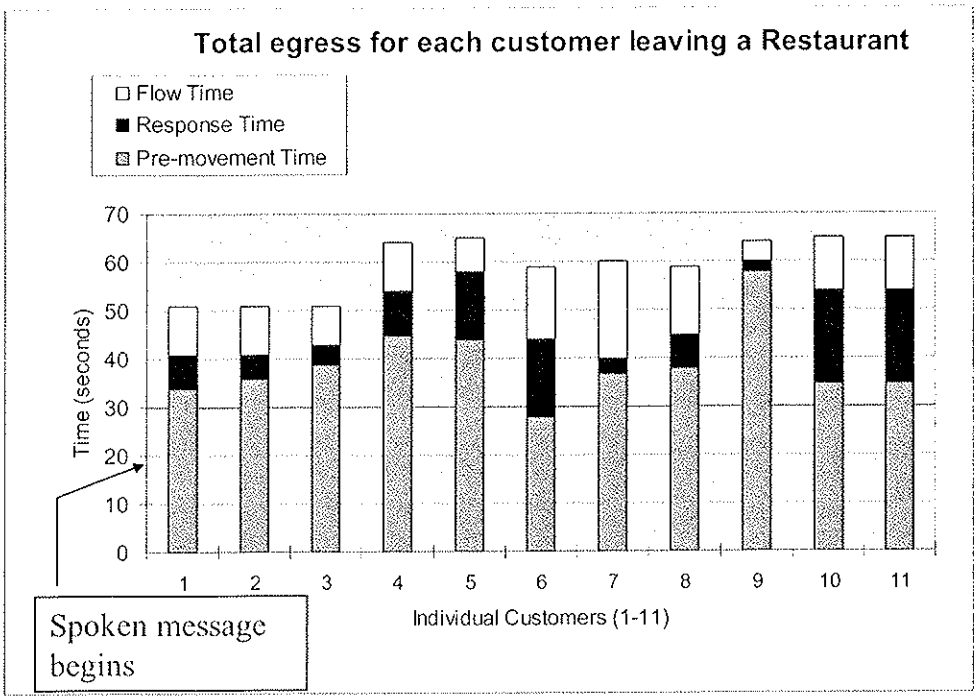
Movement

bre

SEQUENCE OF EVENTS IN CLOTHING STORE FIRE	
Time from ignition (min.sec)	Occupant behaviour
0.19	Fire visible on camera approximately half metre flame height. Customer sees fire and warns shop assistant who investigates and goes to fetch fire extinguisher
1.19	Assistant fighting fire with extinguisher, flame height approximately 1 metre, fire quite large, fails to extinguish and moves away
0.19-3.30	All this time people are entering the shop, passing the fire, shopping, and waiting at the checkout to pay for goods.
3.30	Shop filling with smoke, people reluctant to leave shopping
4.00	People evacuating through thick smoke
4.15	Staff evacuating
4.00-5.00	A few people occasionally re-enter near doorway
6.00	Front doors shut from outside

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Shopping centre evacuation behaviour measurements



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Management

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Fire safety management

- Maintenance of building and emergency systems
- Emergency plan
- Training
- Provision of warnings
- Management of emergency
- Regular evacuation drills with feedback
  - (reporting evacuation time should be made a requirement)



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Fire safety management

Management factor	Management level		
	Level 1	Level 2	Level 3
Ownership	Known	Limited	Not known
Manager's role	Single responsible person	Known responsible persons	Not known
Resources/authority	Good	Average	Minimal/none
Staffing level (staff-occupant ratio)	High	Medium	Low/none
Fire training	Good	Average	Minimal/not known
Security	Good	Medium	Minimal
Work control (e.g. repairs to structure)	Good	Average	Minimal/none
Communications procedures	Good	Average	Minimal
Maintenance/testing of fire safety systems	Frequent	Occasional	Minimal
Liaison with fire & rescue services	Good	Average	Minimal
Contingency planning	Good	Adequate	None
Degraded systems planning	Good	Adequate	None
Abnormal occupancy planning	Good	Adequate	None
Testing/auditing of management system	Fully independent	In-house	Minimal/none
Risk management	Good	Poor	None
Fire load management (contents control)	Good	Poor	None

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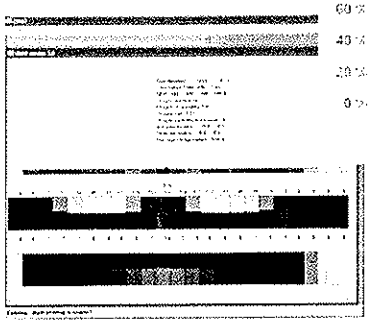
Applications

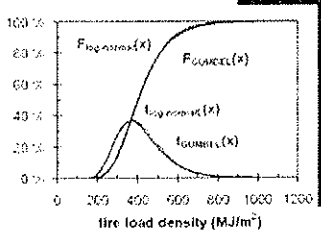
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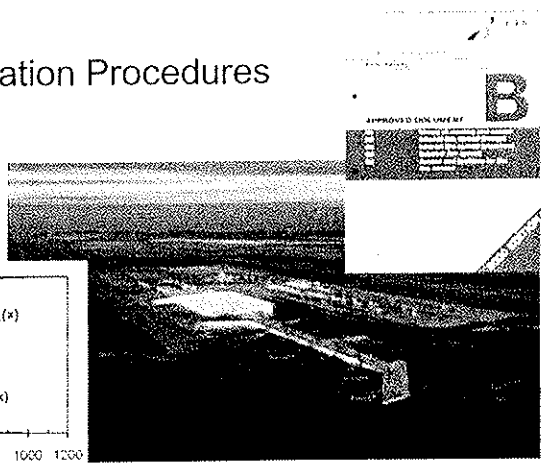
Regulatory Impact Assessment

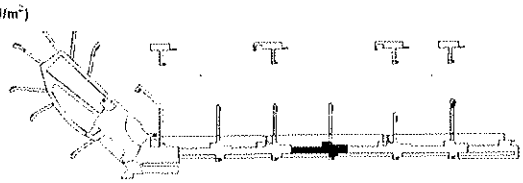
CRISP is ...

- Computation of Risk Indices by Simulation Procedures
- Simulation of the entire fire 'system'
- Monte-Carlo method









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Investigation into the WTC collapse

- One event
- A-typical

- Unprecedented investigation
- New insight into qualitative processes
- Significant new data
- Opportunity for model refinement
- Professional duty of care/moral imperative

NIST NCSTAR 1

Final Report on the Collapse of the World Trade Center Towers



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Flow rates down stairs

New data in next SFPE handbook

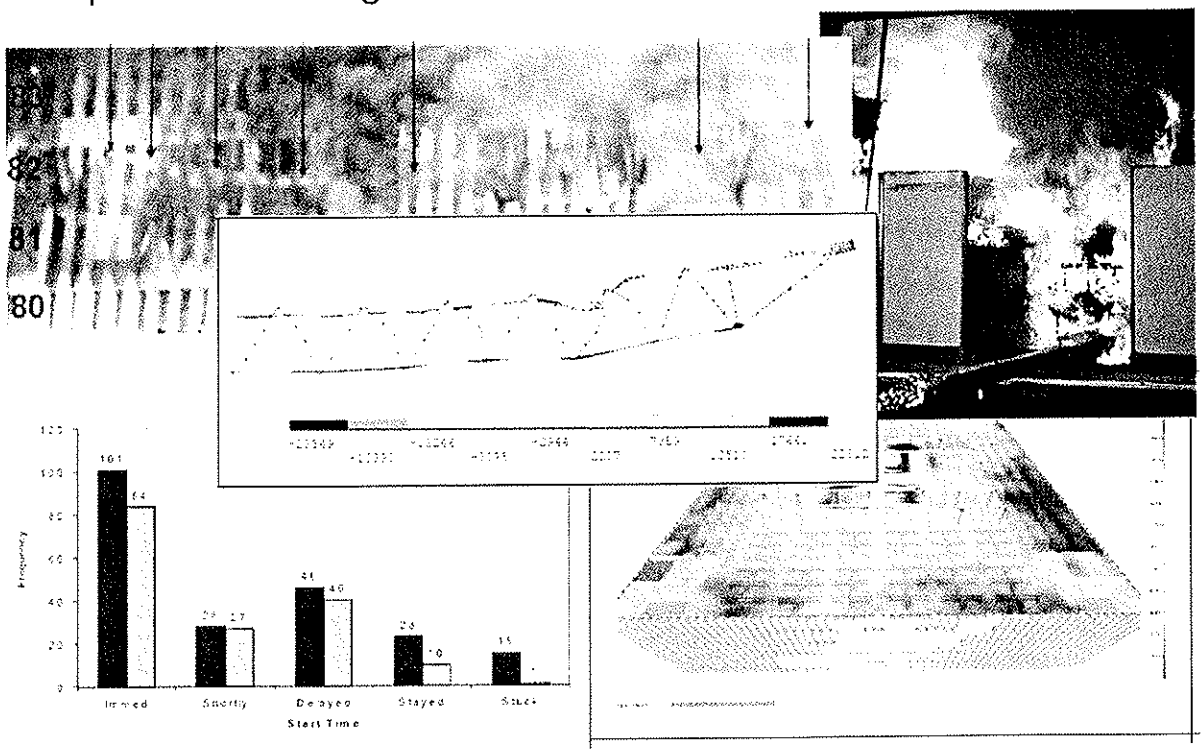
Table 40: Summary of descent speeds

		Reliable estimated average (ms)	Less reliable estimated average (m/s)	Unreliable Estimated average (m/s)	Estimated average (m/s) using all data	Estimated average (m/s) excluding unreliable data
WTC1	Min	[0.25] (0.28)	[0.08] (0.13)	[0.18] (0.22)	[0.08] (0.13)	[0.08] (0.13)
	Max	[0.41] (0.41)	[0.31] (0.83)	[0.32] (0.39)	[0.41] (0.83)	[0.41] (0.83)
	Mean	[0.29] (0.33)	[0.19] (0.34)	[0.27] (0.32)	[0.24] (0.33)	[0.22] (0.34)
	Data points	[5] (5)	[10] (10)	[5] (5)	[20] (20)	[15] (15)
WTC2	Min	[0.2] (0.37)	[0.15] (0.17)	[0.16] (0.16)	[0.15] (0.16)	[0.15] (0.17)
	Max	[0.56] (0.71)	[0.26] (0.57)	[0.39] (0.47)	[0.56] (0.71)	[0.56] (0.71)
	Mean	[0.33] (0.49)	[0.21] (0.34)	[0.26] (0.3)	[0.27] (0.39)	[0.27] (0.42)
	Data points	[6] (7)	[6] (6)	[5] (5)	[17] (18)	[12] (13)

[ ] = conservative estimate, ( ) = optimistic estimate

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Computational integration



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Thank you

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Recent Fire Research and its implications for fire safety engineering

bre

Improvements to smoke movement modelling

Prof David Charters, PhD, CEng, FIFireE, MIMechE
Director of Fire Engineering

Visiting Professor of Fire Risk Analysis at the University of Ulster

Immediate Past International President of the Institution of Fire Engineers

Overview

1. Introduction
2. Simple calculations
3. Zone models
4. Computational Fluid Dynamics
5. Future opportunities/challenges

Quantitative analysis

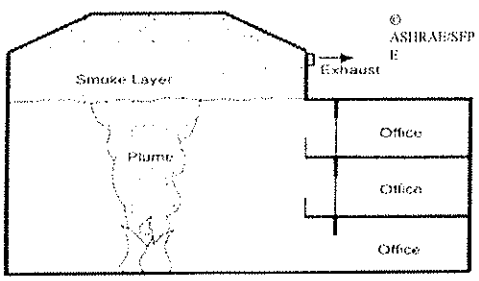
- Initiation and development of fire
- Smoke movement beyond the room of origin
- Response of structure to fire
- Activation of detection and suppression systems
- Fire service intervention
- Human response and evacuation
- Probabilistic risk assessment

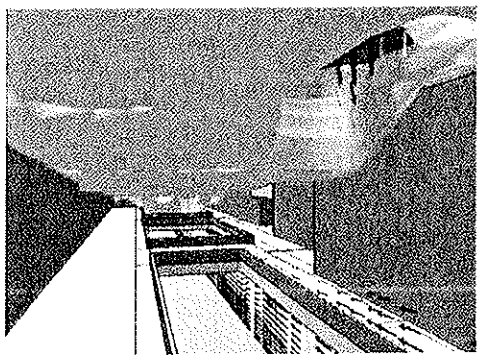
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Smoke movement

Grid dependency in CFD studies?

- Temperature?
- Depth?
- Toxicity?
- Visibility?
- Radiation?





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The controlling physical processes

- Internal building/structure airflow
  - due to stack effect, vehicle motion (in tunnels & metros), elevators
- Buoyancy forces
  - due to the density difference between hot smoke and ambient air
- Air expansion forces
  - generated by heat from the fire
- Forced ventilation
  - smoke exhaust, HVAC
- Wind effects
- Availability of make-up fresh air

bre

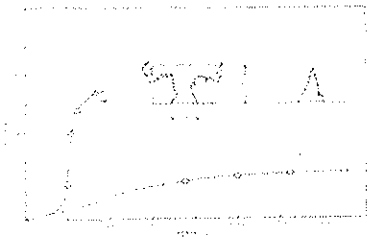
Smoke control

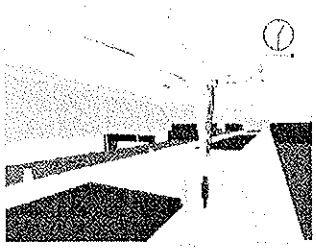
- Containment
  - Use the time to fill a big space for evacuation
    - *E.g. Airport terminals*
- Extraction
  - Remove smoke to keep layer away from occupants
- Pressurisation
  - Prevent smoke entering critical areas
    - *E.g. escape routes*

bre

Scientific knowledge…

- Observation
  - Qualitative understanding
- Measurement
  - Quantitative understanding
- Theory
  - Fundamental understanding





bre

Scientific basis…future development

- Observation
  - Human behaviour in fire
  - Fire safety management
- Measurement
  - Fire growth
  - Plume modelling
  - Movement of people
  - Time equivalence
- Theory
  - Computational Fluid Dynamics
  - Finite Element Analysis

bre

Experimental Fires

- Heat Release Rate
  - Weighing platform to measure mass loss
    - *Need to know heat of combustion*
  - Oxygen depletion
    - *Need accurate measurement of oxygen concentration*
    - *Assumes most materials release same amount of heat for each unit of oxygen consumed*
- Product yield
  - Carbon dioxide, carbon monoxide
- Visibility
  - light beams (wave length)

bre

Design fires

- Steady state
- T-squared curves $Q = a\ (t\text{-}t_{start})^2$

– SLOW	(a = 0.0029)	Picture gallery
– MEDIUM	(a = 0.012)	Dwelling / Office / Hotel
– FAST	(a = 0.047)	Shop / stacked timber pallets
– ULTRA FAST	(a = 0.188)	Pool fire

- Exponential growth $Q = A \exp(Bt)$

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Background material

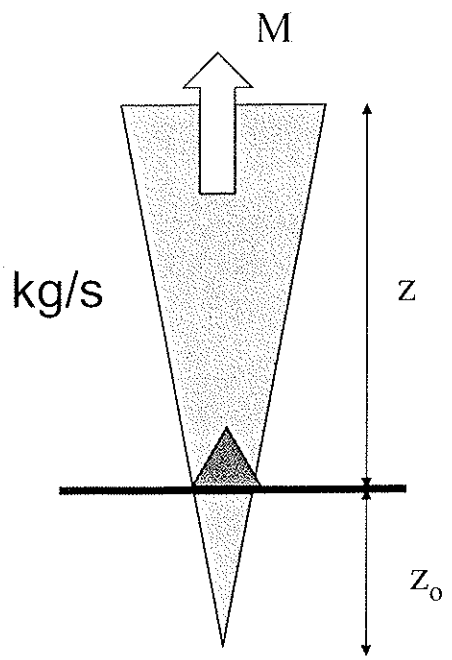
- Principles of Smoke Management (2002)
  - ASRAE & SFPE – a comprehensive guide (North American slant)
- SFPE Handbook of Fire Protection Engineering (3rd ed – 2002)
  - NFPA & SFPE – a good reference for all aspects of fire engineering
- CIBSE Guide E – Fire Engineering (1997)
- Technical Memoranda TM19:1995
  - CIBSE – summary of plume equations etc
- ASHRAE 1999 Handbook (HVAC)
  - Fire and Smoke Management Chapter
- Smoke Control in Fire Safety Design (1979)
  - Butcher & Parnell
- Other (e.g. PD 7974, NFPA Guides, PIARC)

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Simple calculations

- Axi-symmetric plume

kg/s



- Perimeter expression

kg/s

P = perimeter of the fire

There are many other expressions. Beware people may select to give best result!

bre

How much air does a fire need ?

- Mass burning rate: 50kW / 50000 kJ/kg = **0.001kg/s**
- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + Heat
  (16) (64) (44) (36)
- 1kg Methane requires 64/16 = 4kg of oxygen
- 0.001kg/s methane requires 0.004kg/s oxygen
- OR 0.004/0.23 = **0.017 kg/s** air

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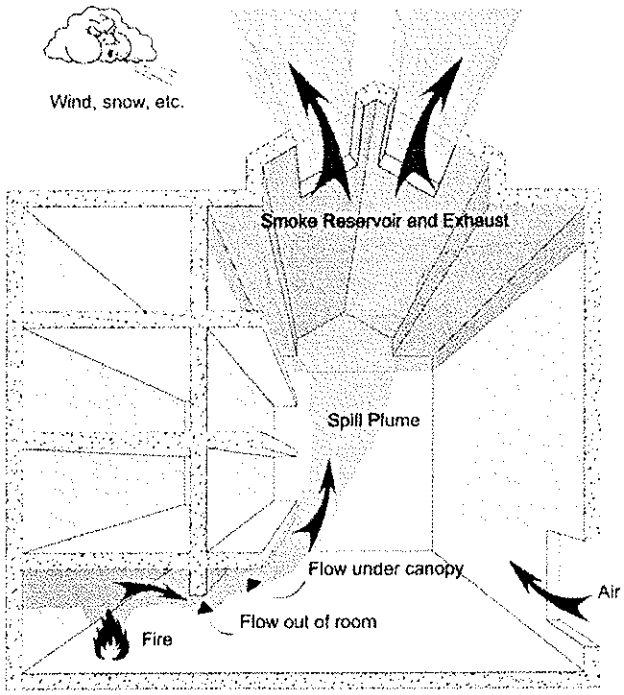
How much air does a fire need ?

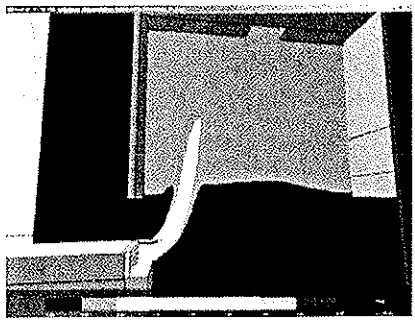
- Air entrained into fire plume $M = 0.2\ Py^{3/2}$
- Flame height (y) = $0.2Q^{2/5}$ = 1.26m
- Fire perimeter (P) = $4\sqrt{}$area = 1.25m
- **M = 0.35 kg/s**
- **Requires 0.017kg/s for ideal combustion but has 20 times that amount available in flaming region.**

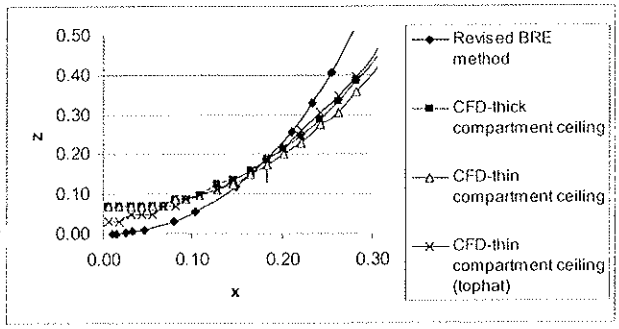
The fire is fuel controlled.

bre

Spill plumes revisited





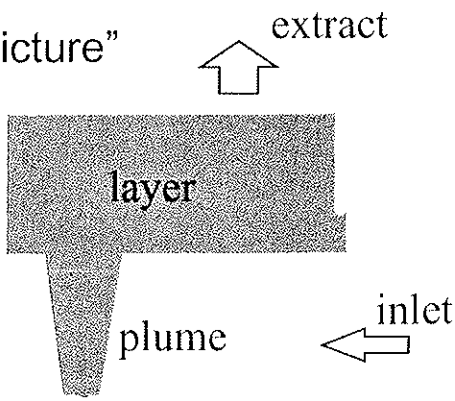


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Zone Models

- Principles
- Use experience to "draw a picture"





- Quantify
  - Conservation of mass
  - Conservation of energy
  - Empirical correlations

bre

Zone models

- Used in design methods e.g.
  - BR 386
  - BS 7346 parts 4 and 5
- Software
  - ASET
  - CFAST
  - Fire Simulator
  - FAS3D (Leeds University, developed for tunnels)

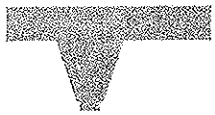
Zone models

- Easy to use
- Run quickly
- 'Simple' answers
  - Layer depth
  - Upper / lower temperatures
  - Total flow rates through openings
- Limited by original assumptions

Zone model limitations

Large floor area

- **Smoke does not cover ceiling**



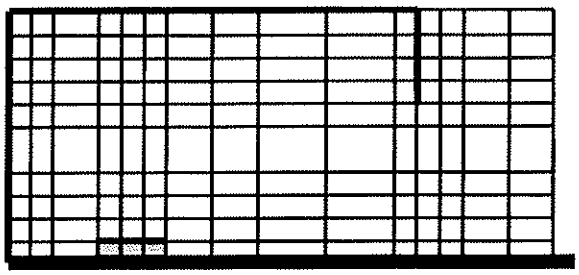
Tall buildings

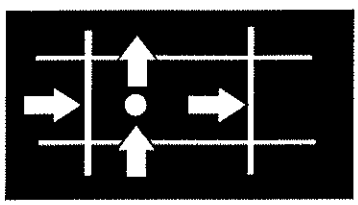
- **Smoke stratifies and does not reach ceiling**



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Computational Fluid Dynamic (CFD) Models





Geometry Sub Divided into a Large Number of Cells

Calculates:

- Velocity
- Temperature
- Pressure
- Concentrations

$$\frac{\partial}{\partial t}(\rho\phi)+\frac{\partial}{\partial x_j}\left(\rho u_j\phi-\frac{\Gamma_\phi}{\sigma_\phi}\frac{\partial\phi}{\partial x_j}\right)=S_\phi$$

rate — convection — diffusion — source

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Sub Models

- Turbulence models
  - k-ε model
  - LES and DNS
- Combustion models
- Heat transfer, solid phase conduction
- Radiation
- Flame spread
- Spray droplets

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CFD programmes

Fire Specific

- JASMINE
- SOFIE
- SMARTFIRE
- Kamelion
- FDS

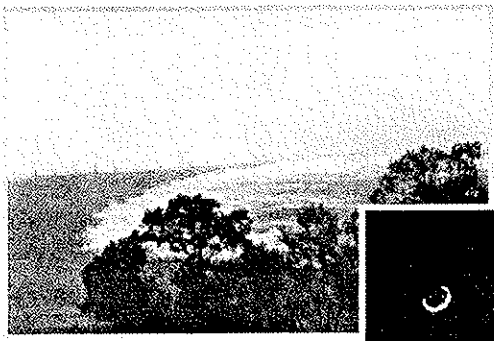
General Purpose

- CFX
- Star CD
- PHOENICS
- Fluent
- Flowvent

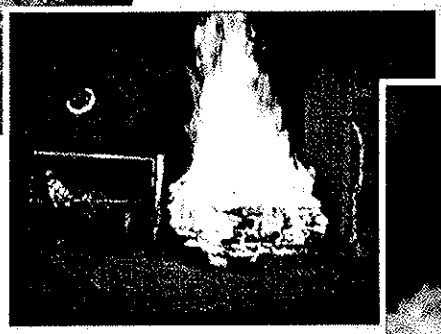
bre

Q* : Different Types of Fire

$$Q^* = \frac{Q}{\rho_0 c_p T_0 g^{1/2} D^{5/2}} = \frac{Q}{1110 D^{5/2}}$$

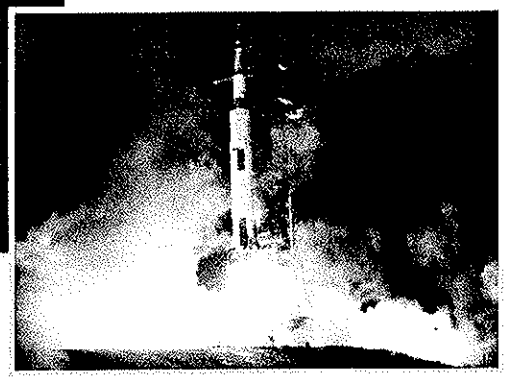


Q* < 0.2



0.2 < Q* < 2.5

(building fires)



High Q*

bre

Heat source or combustion model ?

- Heat Source
  - Solve fewer equations (faster result) ✓
  - Need to **prescribe where** heat is released ×
  - Effect of air (oxygen) limitation not included ×
  - Very simple estimate of concentrations of combustion products

- Combustion Source
  - More equations solved (longer processing time) ×
  - Model predict flame shape and where heat is released ✓
  - Heat release related to oxygen availability ✓
  - Prediction of product concentrations ✓
    - *One step reaction*
    - *Complex flamelet models*

bre

Checking Solutions

- Convergence criteria
- Global mass and energy balances
- Extreme values
- Grid sensitivity
- Validation experiments and empirical correlation's
- Analytic cases

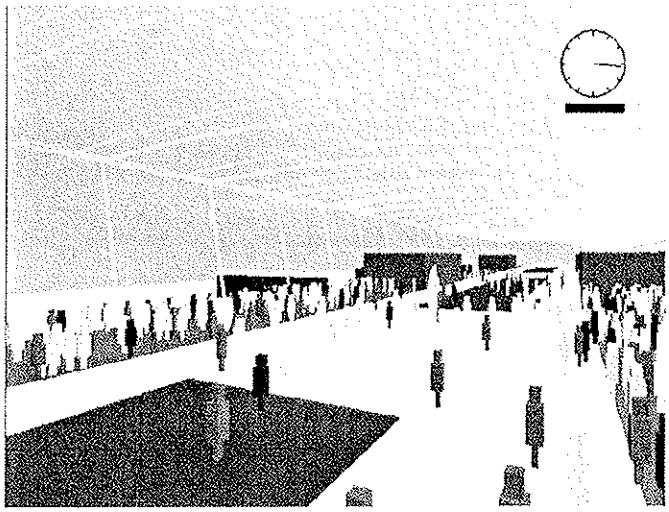
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Brussels Airport development



bre

Brussels Airport development



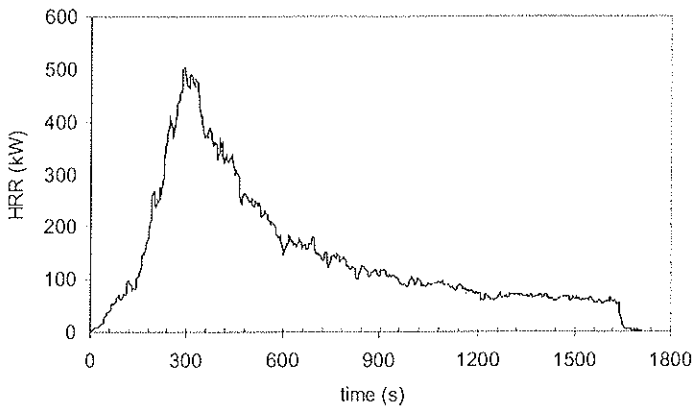
- No compartmentation
  - 12m high
  - 40m wide
  - 520m long
- Exposed steel
- Can people escape before smoke reaches low levels?
- Will exposed steel structure become too hot in the event of a fire?

bre

Brussels Airport development

- Fire Scenarios
  - Shop units have smoke extract systems and shutters
  - Seating materials are controlled
  - Area is "air side" so passengers only have hand baggage

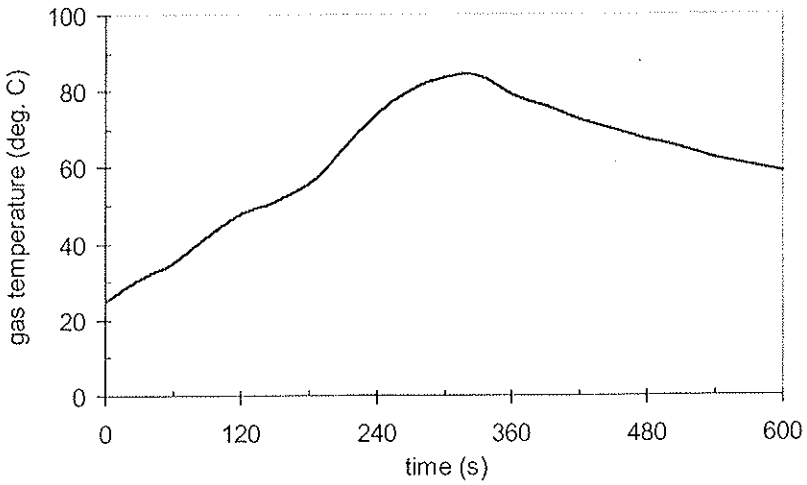
Heat release rate data obtained from experimental fires



bre

Brussels Airport development

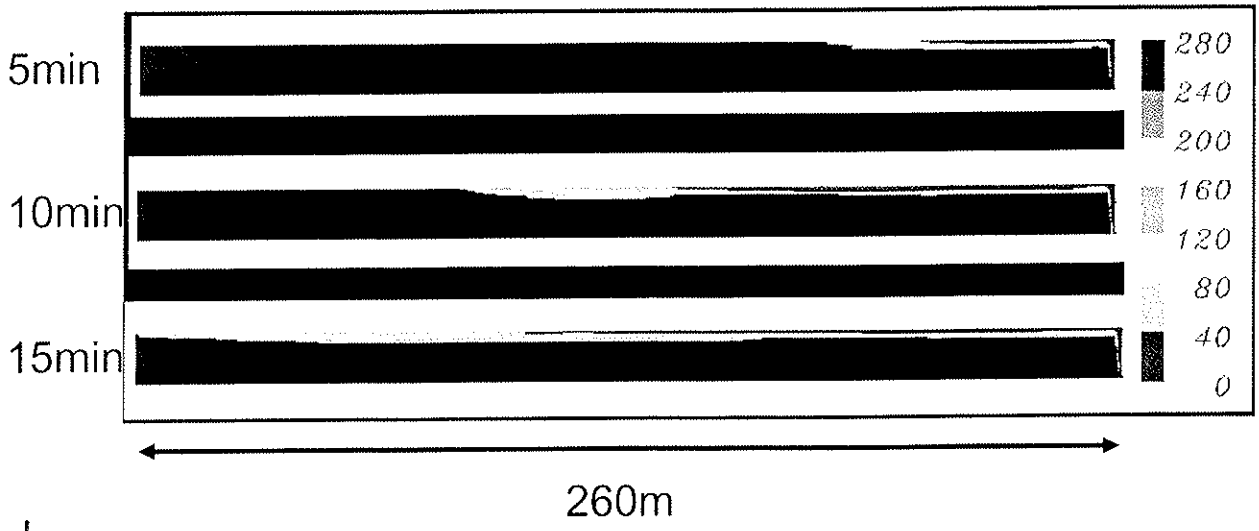
Peak temperature at ceiling level



bre

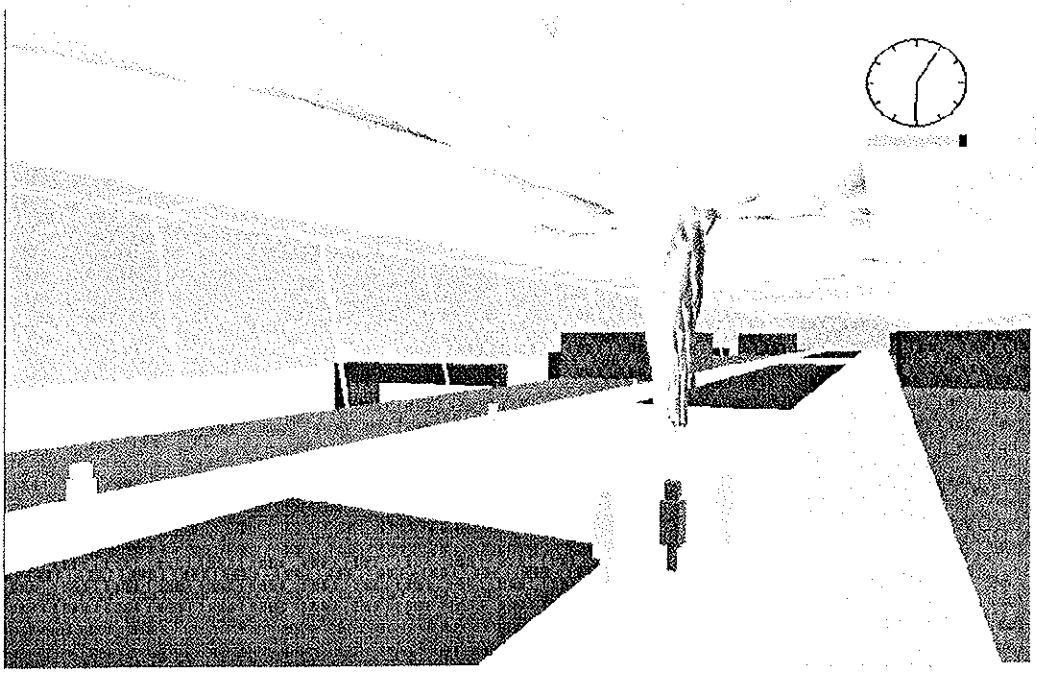
Brussels Airport development

Visibility on centre line



bre

Brussels Airport development



bre

Brussels Airport development

- JASMINE simulations of smoke movement
  - No significant heating of structure
  - Tenable conditions at ground level through out fire
- CRISP simulations of egress / people behaviour
  - 2000 people evacuated through
    - *Original entrance*
    - *Aircraft gates supervised by airline staff*

bre

Fire Science -Best Practice

- Fire source
  - Use combustion model to allow a proper coupling between local air flow and distributed heat release
  - Check that Q* represents typical fire (for buoyant fires 0.1 < Q* <2.5)
- Radiative loss from fire plume - important !
  - Fire plume can lose up to 50% of its heat by radiation
- Boundary heat losses - generally important !
  - These can cause ceiling layers to loose their buoyancy and cool wall currents to fall through a buoyant layer

bre

Fire Science -Best Practice

- Do the predictions make sense?
  - Flame temperature should not exceed **1300C**
  - Anything **higher than 2000C must be incorrect** due to an erroneous source specification
  - Anything higher than **1300C** should be examined closely
  - Compare the predictions of flame temperature, flame height, and plume entrainment with empirical correlations.

bre

Numerical aspects -Best Practice

- Boundary conditions
  - 'Far field' pressure boundary condition is particularly important for natural convection
  - Experience shows that the computational domain needs to be extended a long way from the primary flow to mimic 'infinity'
- Conduction into compartment boundaries - important !
  - can be difficult in transient simulation

bre

Numerical aspects - Best Practice

- Need to demonstrate convergence
  - Solution does not change significantly with increased iterations or finer mesh
  - Solution is not 'frozen' by too much under-relaxation
  - Global errors in mass and energy conservation are acceptable
  - Residual errors for each transport equation are acceptable, e.g., < 0.01

bre

Computational Fluid Dynamics

- CFD is a powerful tool if in right hands
- Requires knowledge of fire science and numerical aspects for avoiding misuse
- Requires proper simulation of physical and chemical processes with appropriate initial and boundary conditions
- Realistic treatment of fire source and its interaction with building envelope is essential

Beware of

Colourful Fluid Dynamics

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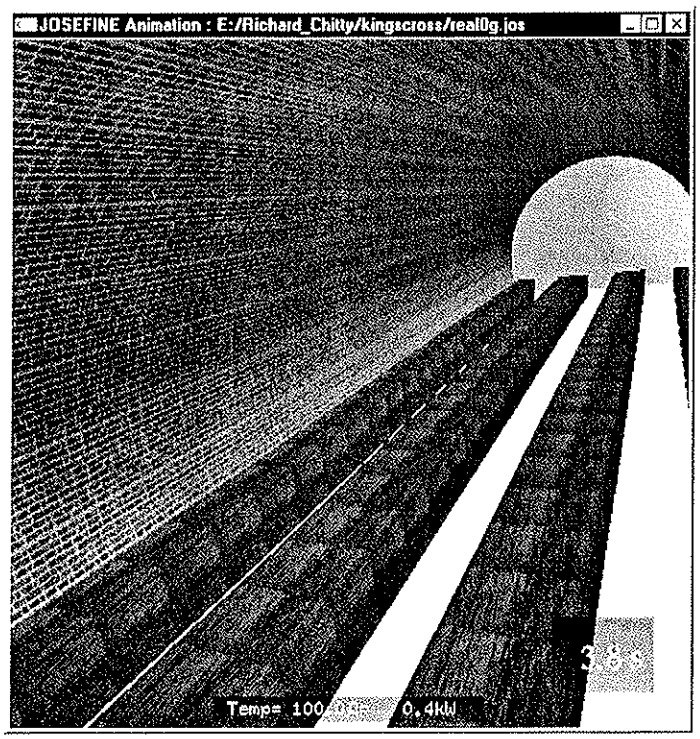
Different models

- Zone models
  - Needs prior experience
  - Limited application
  - Simple results and easy to use
- CFD models
  - Basic principles
  - Wide range of applications
  - Detailed results requiring careful analysis

Chapter 8, SFPE Handbook of Fire protection Engineering 3th Edition

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Kings Cross Fire (1988)



- Unexpected prediction

bre

Kings Cross fire



- Flow confirmed by small and large scale experiments
- Phenomena known in context of
  - forest fires
  - conveyor belt fires

bre

Investigation into the WTC collapse

- One event
- A-typical

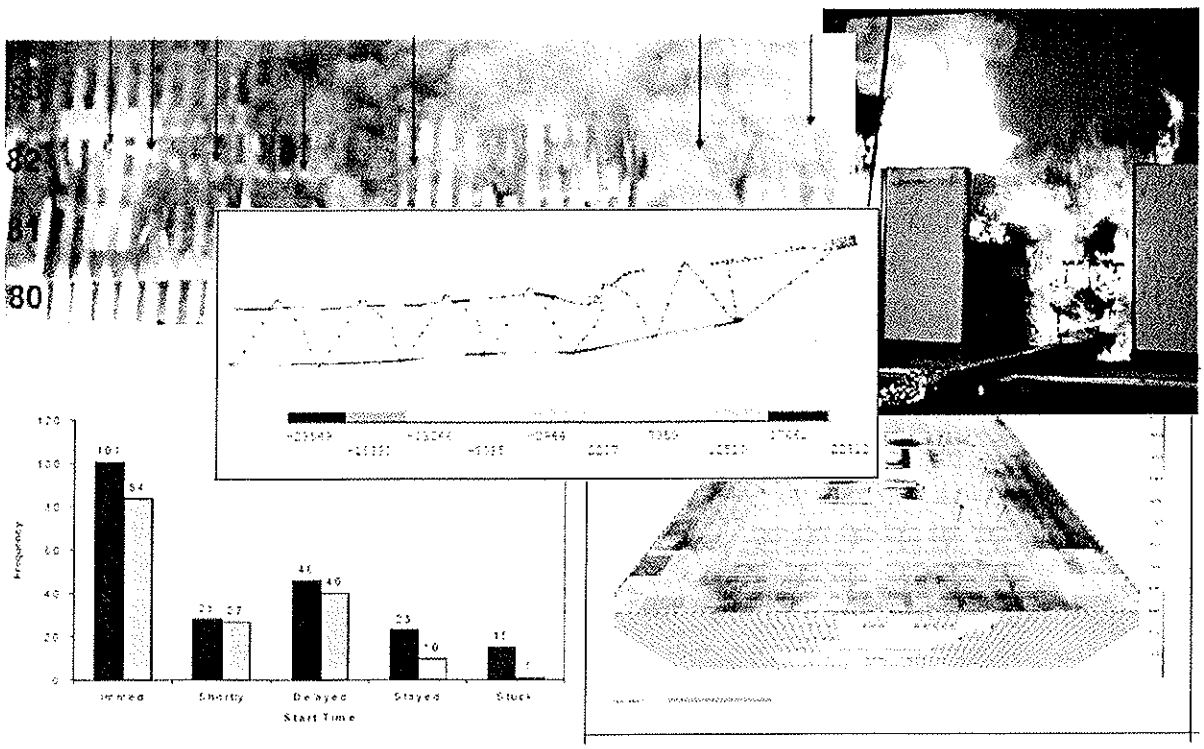
- Unprecedented investigation
- New insight into qualitative processes
- Significant new data
- Opportunity for model refinement
- Professional duty of care/moral imperative

Final Report on the Collapse of the World Trade Center Towers



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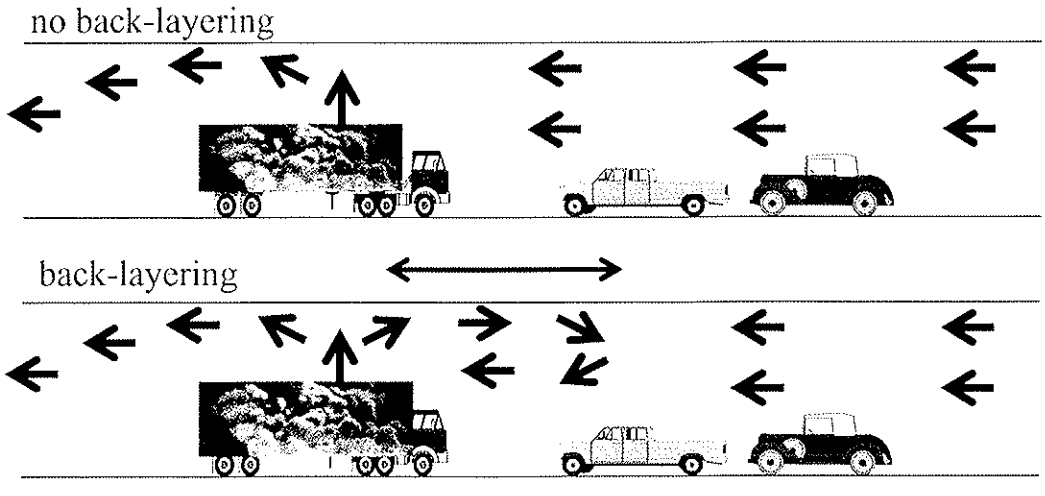
Computational integration



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Tunnel smoke control

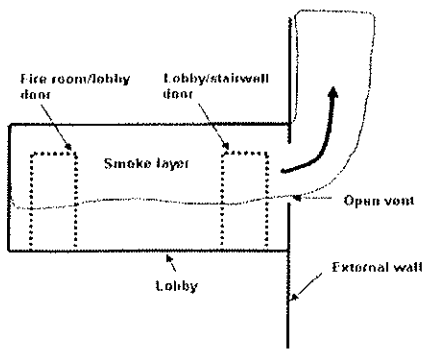
- Longitudinal ventilation
  - Jet fans force smoke in one direction
  - Aim to maintain clear air on upstream side
  - Generally smoke logging on downstream side

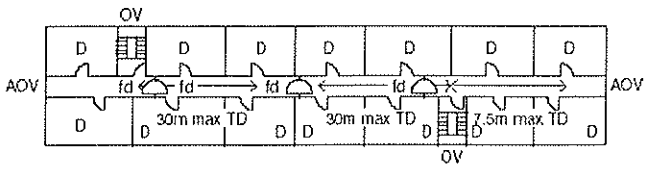


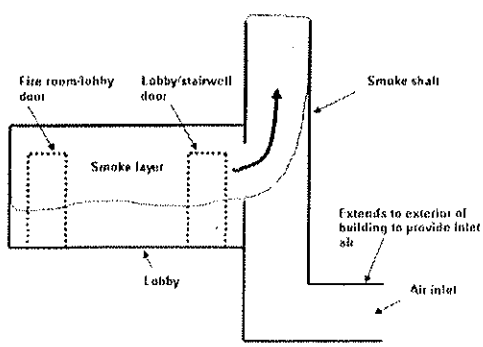
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Lobbies, stairwells and corridors

- Pressurisation
- Natural venting through vents on external walls and stairwell ceiling
- Smoke shafts for fire-fighting lobbies
  - Natural (buoyancy) driven
  - Mechanically driven ?
  - Extension to common access corridors







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Design limited by calculation methods ?

- Don't build things because design tools don't work
  - Upset the architect
- Impose restrictions
  - May impair function of building
- Improve the design tools
  - How are they validated?
- Use different approaches

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Thank you

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Recent Experience in Performance Based Design

The National Library Board & Ang Mo Kio Hub projects

Outline

- Principles relating to the use of unprotected steel buildings in Singapore
- Approvals issues
- Theoretical issues
- Two completed local projects:
  - The National Library Board building
  - The Ang Mo Kio Hub

Approval Issue - Performance Objectives

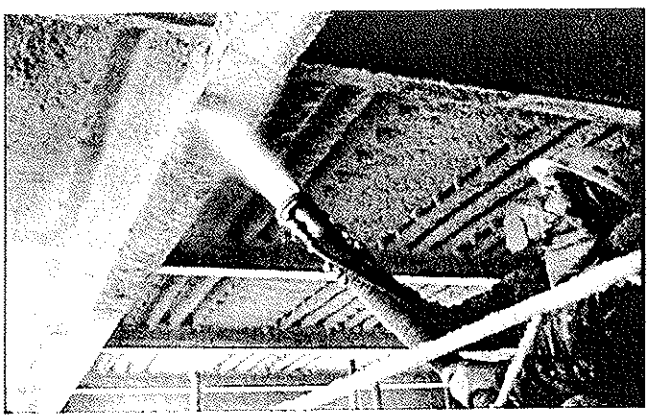
Structural adequacy of the building frame must be maintained until and during brigade intervention in the unlikely event that a major fire develops, i.e. the sprinklers fail to control or extinguish a fire

Code of Practice for Fire Precautions in Buildings:

R3.1 Prevent the untimely collapse of buildings due to the effects of fire that would affect the safe egress of the building occupants.

R3.3 The building shall remain structurally stable to allow adequate time for fire-fighters to conduct their fire-fighting and rescue operations.

Traditional Fire Protection to Steel Structures



Individual member test

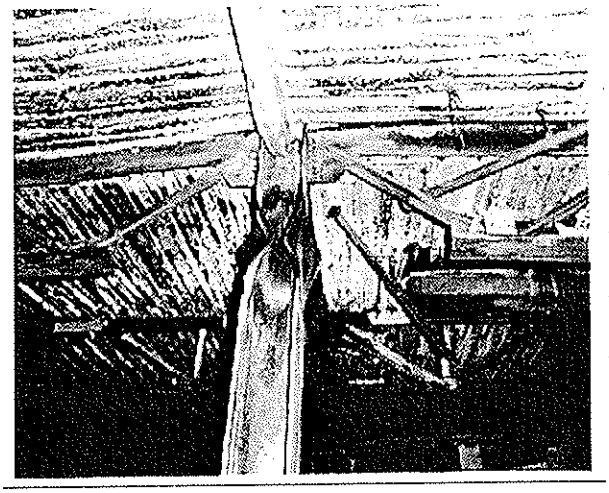
Small-scale 3 x 3 m furnace

Standard fire curve

Failure temperature 550°C.

Additional fire protection is generally required

Turning Point – Broadgate Fire, London, June 1990



14 storey office building

Final fit-out being completed

Partially protected

Sprinkler not operational

Fire lasted 4.5 hours

Large deflections but no collapse of any element of structure

Cardington - Composite Steelwork Fire Tests

How do real structures behave in fire?

Cardington Large Building Test Frame Program

8 storeys, 5 x 3 bays, composite metal deck floors

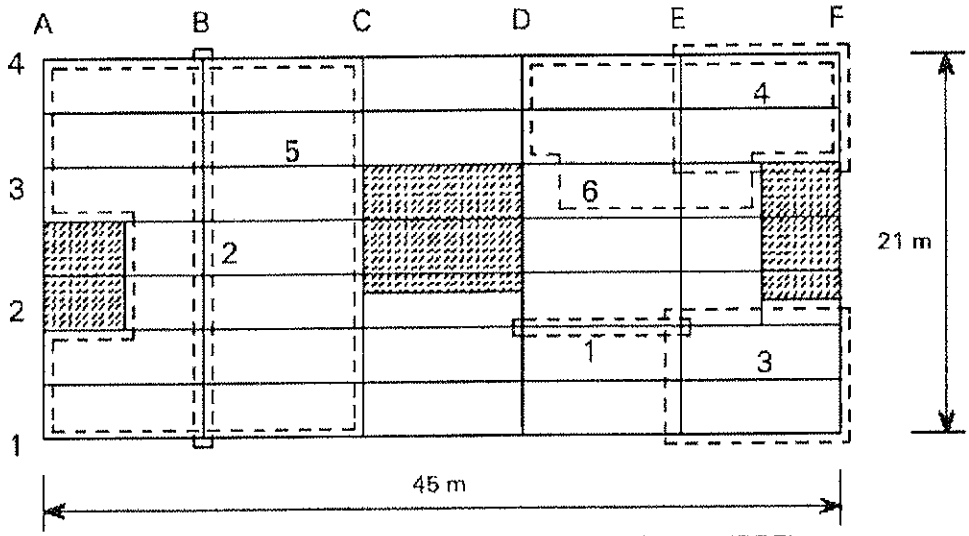
Only the columns were protected

Braced frame: Lateral restraint provided by cross bracing around three vertical access shafts

University of Edinburgh and the University of Sheffield developed models to predict behaviors and analyze results from the tests

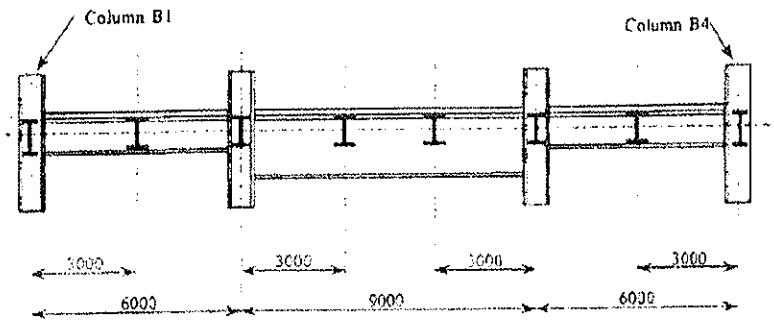


The Six Cardington Tests

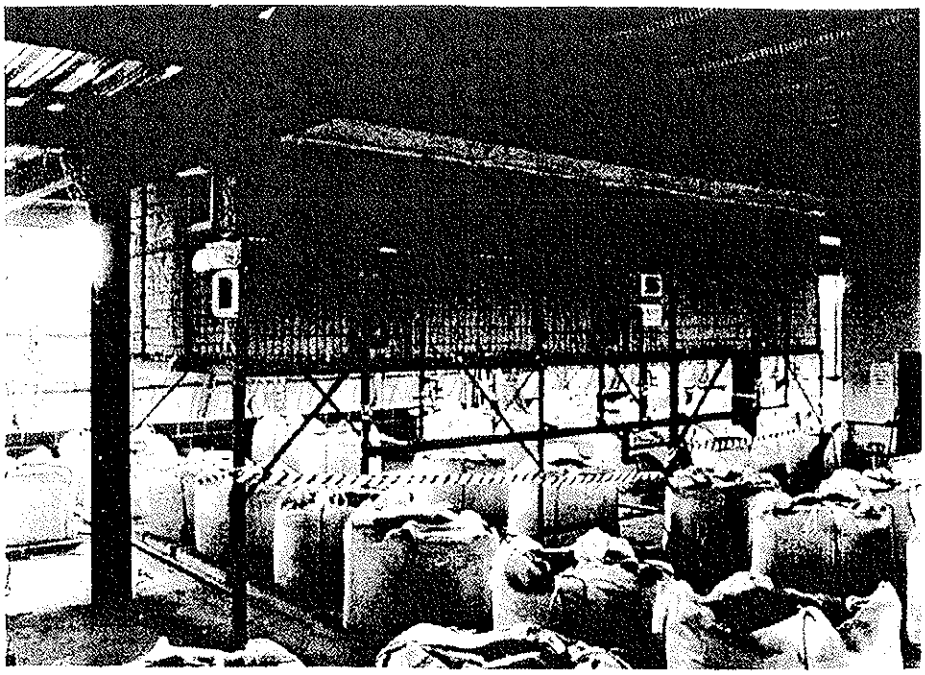


1. Restrained beam (ECSC)
2. Plane frame (ECSC)
3. Corner (ECSC)
4. Corner (BRE)
5. Large compartment (BRE)
6. Office demonstration (ECSC)

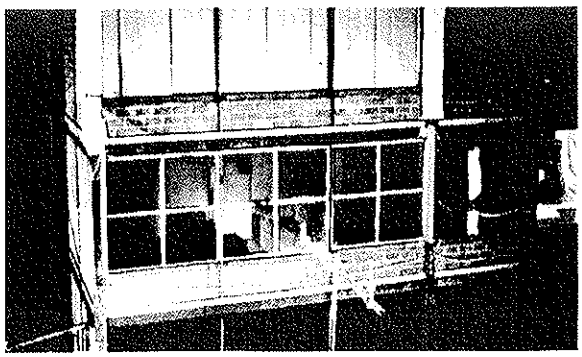
Cross-section of Composite System

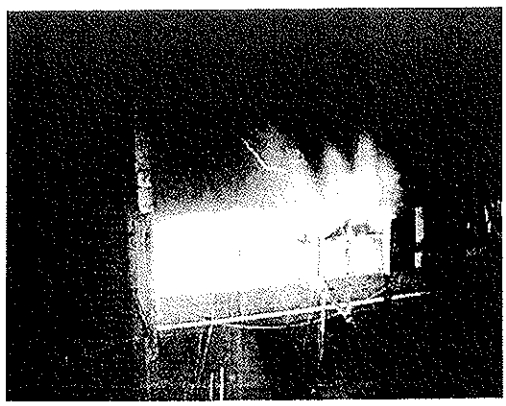


Cardington – Fire Test

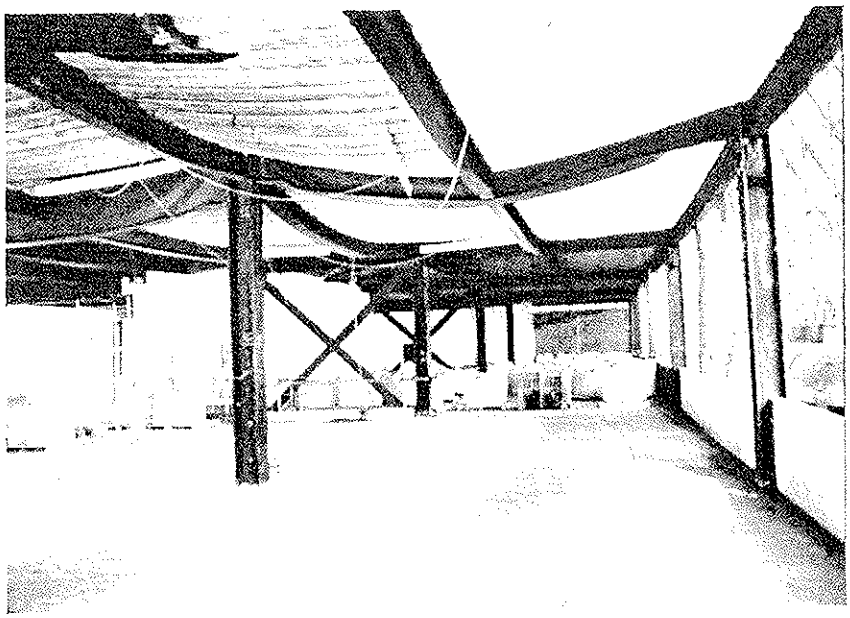


Cardington – Fire Test



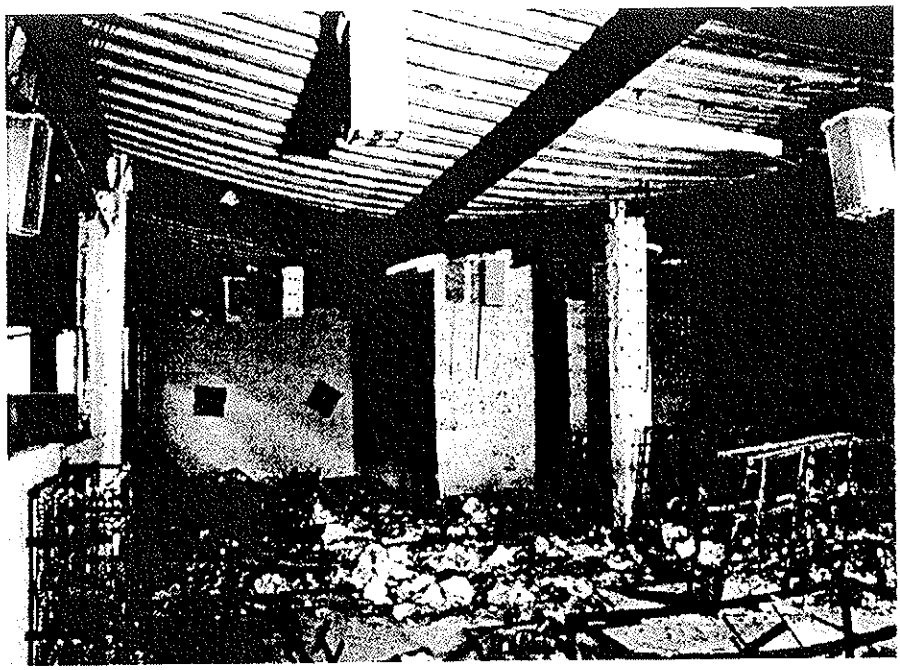


Cardington – Full-Scale Test Results



Deflection of floor slab

Cardington – Full-Scale Test Results



Main Conclusions from Cardington

For composite construction:

- Internal beams left unprotected
- Corner beams to be protected
- Columns and their connections should be protected
- Floor slab is key to increased strength in fire conditions
- Detailed numerical models created

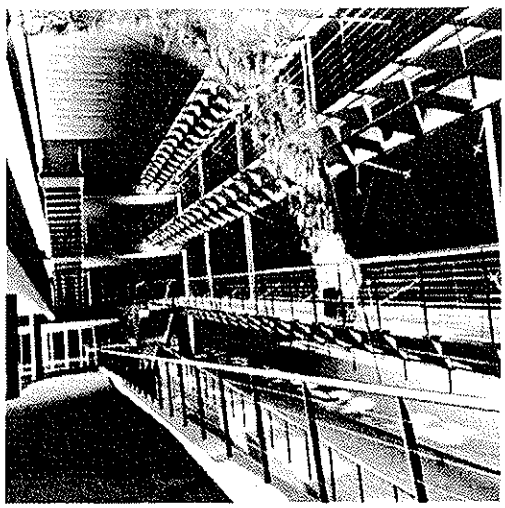
Design Consideration

Design Consideration

- Determine fire scenarios (ie, fire location, building geometry)
- Calculate heat transfer to structural elements
- Calculate mechanical response of elements
- Determine load-carrying mechanisms in the fire case
- Determine any weak points in the structural design
- Determine where fire proofing appropriate
- Determine structural alternations if required

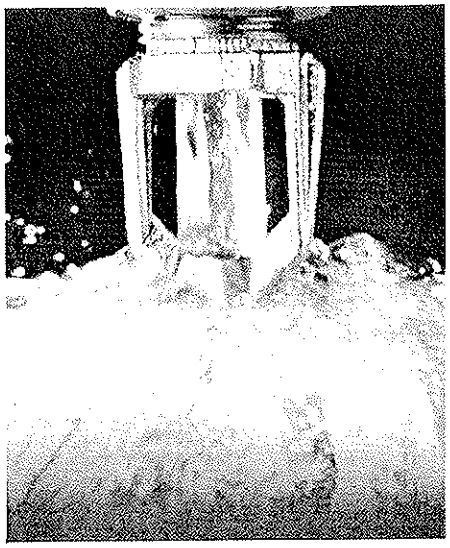
Fire Scenario

- A fire starts in a given storey of the building, and
- Occupants fail to extinguish the fire, and
- Sprinklers fail to control or extinguish the fire, and
- Fire continues to grow until the fire brigade intervenes to control and extinguish it.
- Redundancy assessment



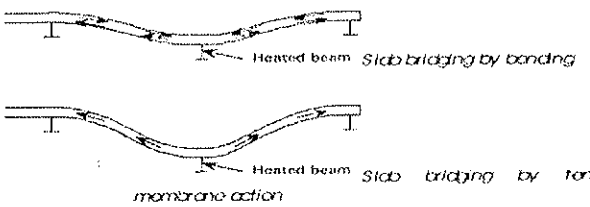
Reliability of Sprinkler

- Effectiveness of sprinkler system
- Statistic shows 96.7%of fires were controlled by 1-10 sprinkler heads
- Measures to increase the reliability of the sprinkler system



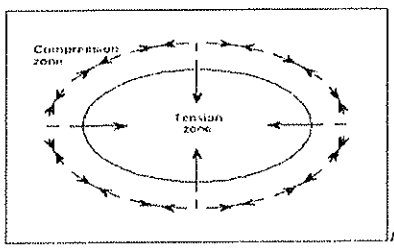
Mechanical Response - Composite Actions

- Anchoring tensile membrane action around the perimeter edge of the floor slab
- Anchoring through reinforcing mesh

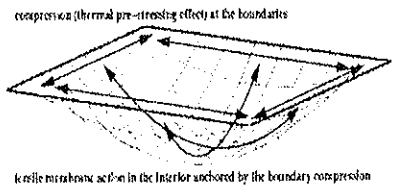


Slab bridging by bonding

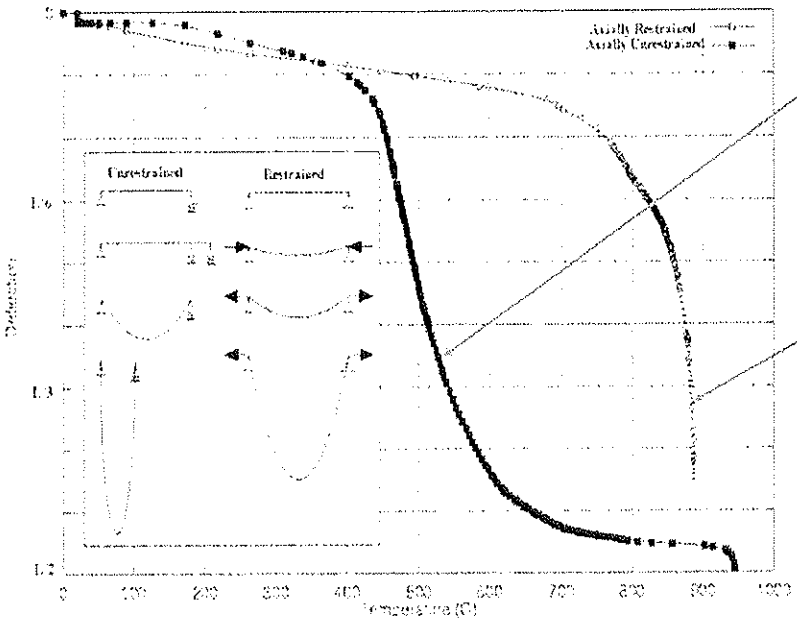
Slab bridging by tensile membrane action



Mechanism of tensile membrane action



Structural Effects – Restrained Beam



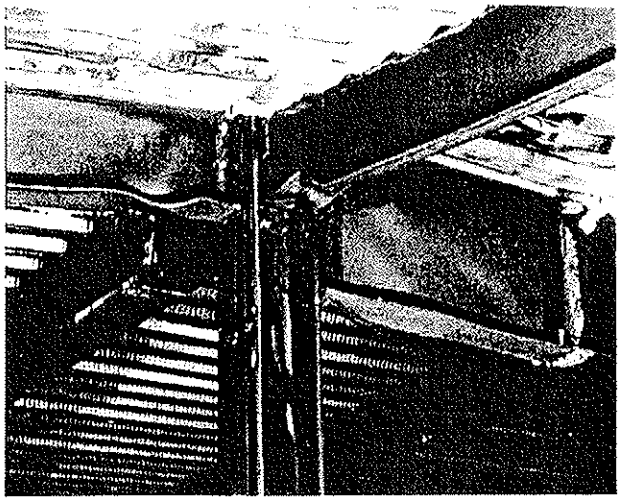
Unrestrained beam: Failure starts at 450°C

Restrained beam: Failure starts at 800°C

Typical Load Transfer Path

- from the secondary and primary beams into the composite slab via the cast-in shear connectors
- from the composite slab into the core walls via cast-in reinforcing bars
- from the beams into the core at the beam-core connections
- from the beams into the columns via the beam-column connections

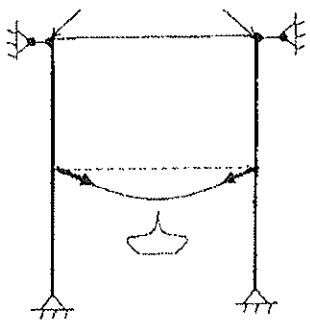
Load-carrying Mechanism - Connections

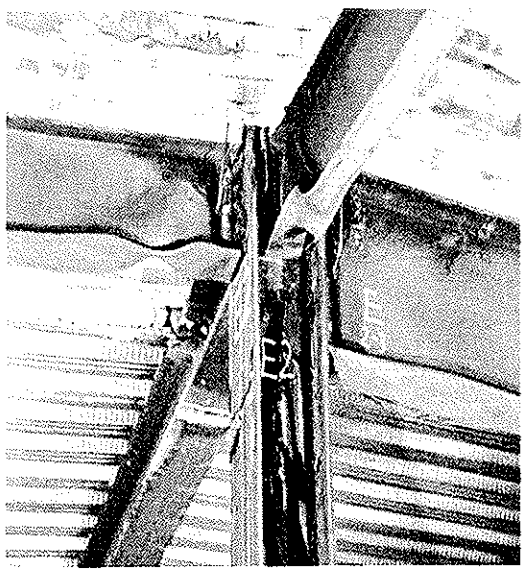


Integrity of connection is to be checked

Load-carrying Mechanism - Columns

Ability of a column to span over double floor height in a fire, given that it has been designed to span only a single floor height under ambient temperature conditions.





Cardington – Localised buckling

The National Library Building (NLB)

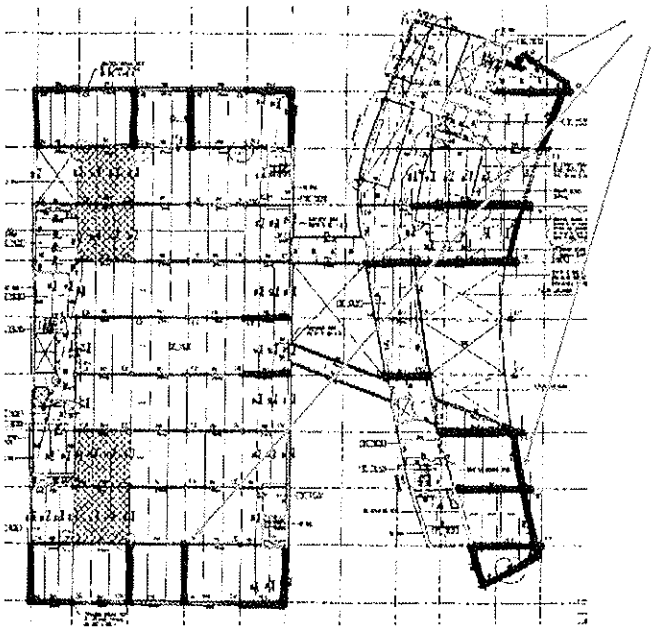
Introduction



- 16 storey building, divided into two blocks (Function and Programme Blocks)
- Interconnected by link bridges on most storeys
- Library areas, drama centre, associated ancillary areas, and offices.
- Steel-frame construction in the above ground storeys

Typical Floor - Example

Beams requiring fire protection

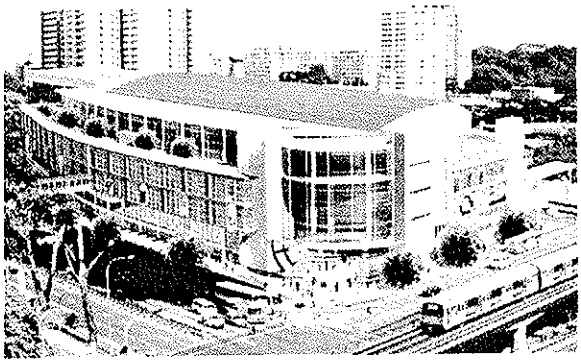


Function Block

Programme Block

Ang Mo Kio Hub (AMK)

Background



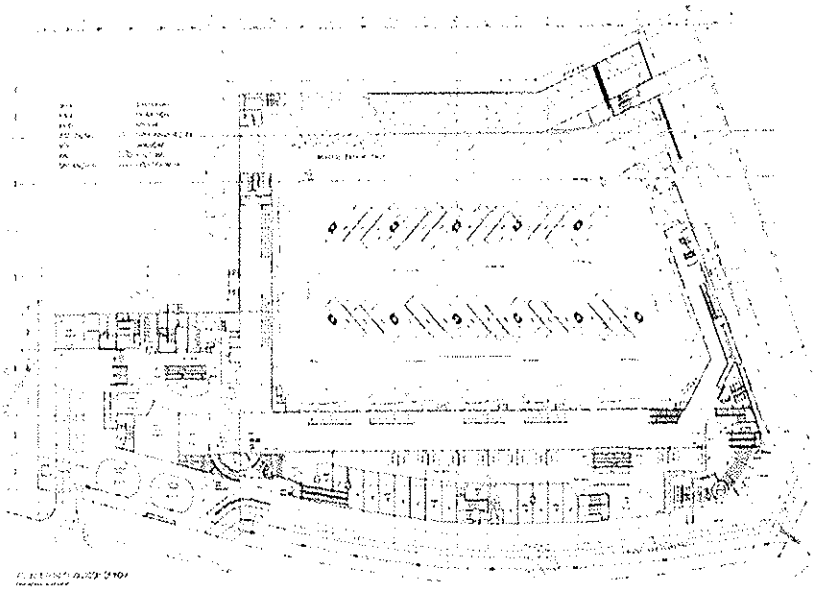
4 storey tall with 3 levels of basement

Underground link to nearby MRT station

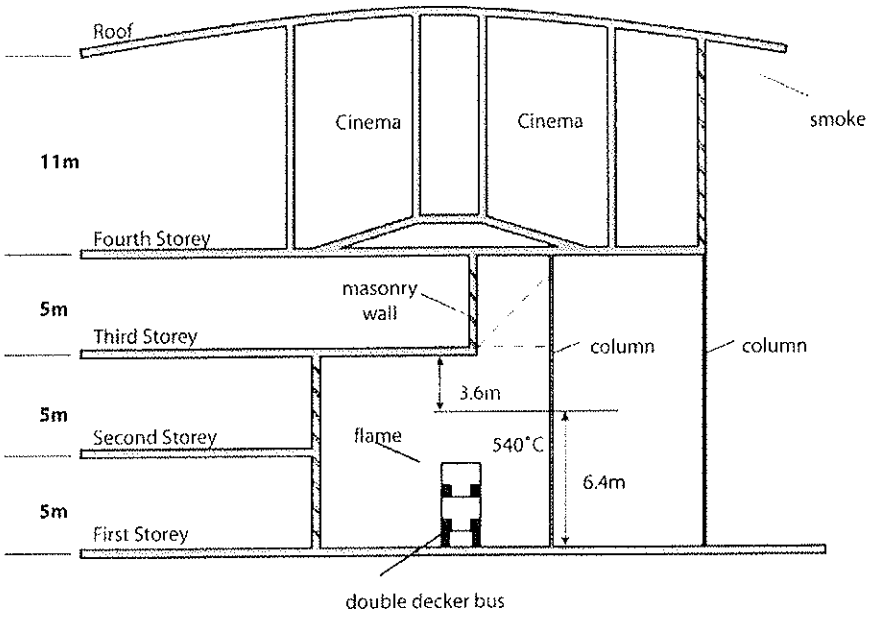
Mainly retail, restaurant and car park

Reinforced concrete substructure with steel-frame construction in the above ground storeys

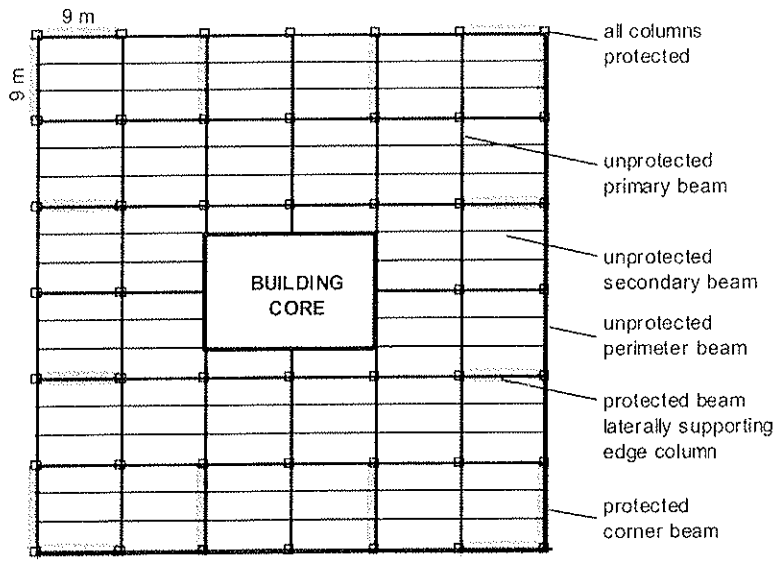
First Storey Plan



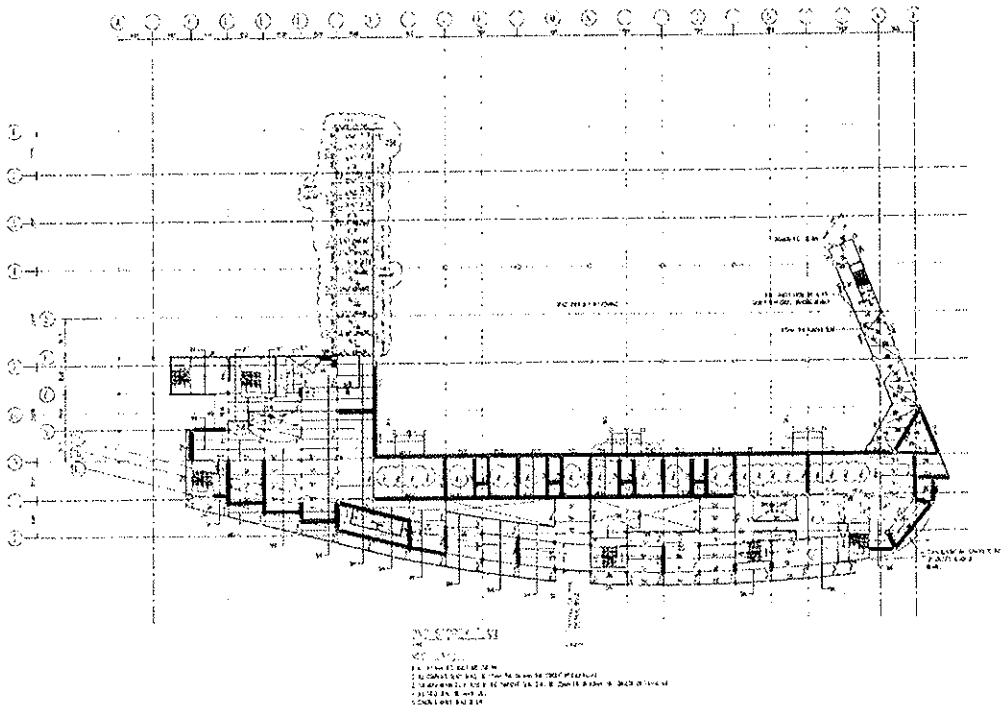
Building Geometry – Natural Advantage



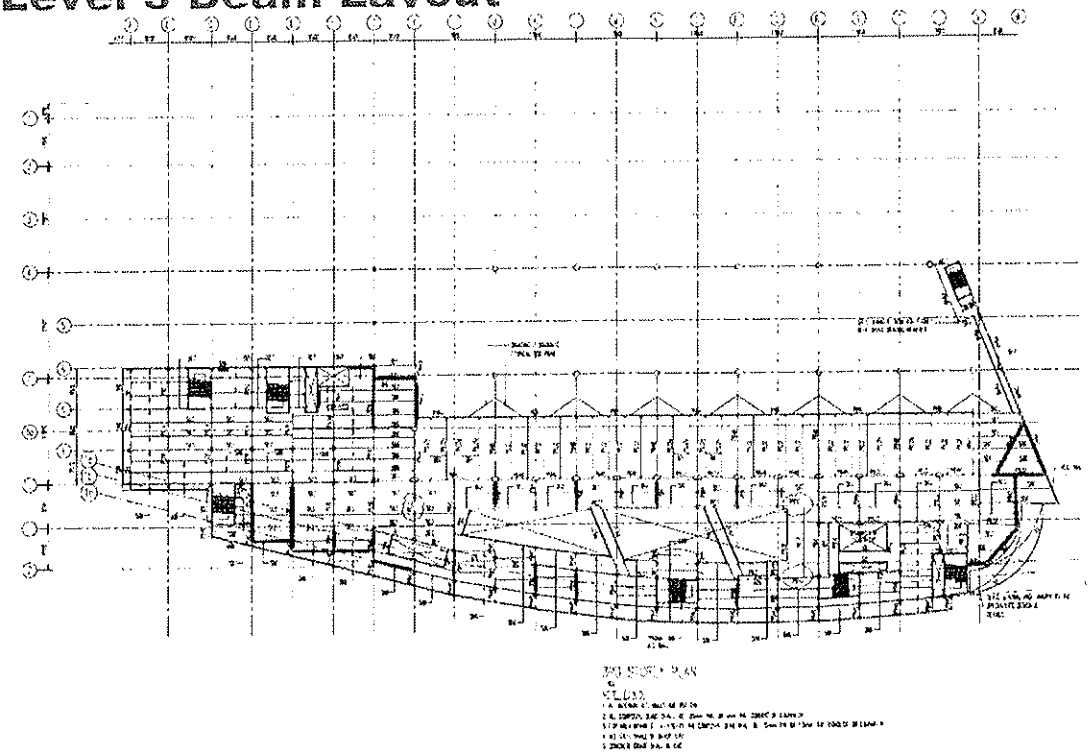
Schematic - Structural Framework



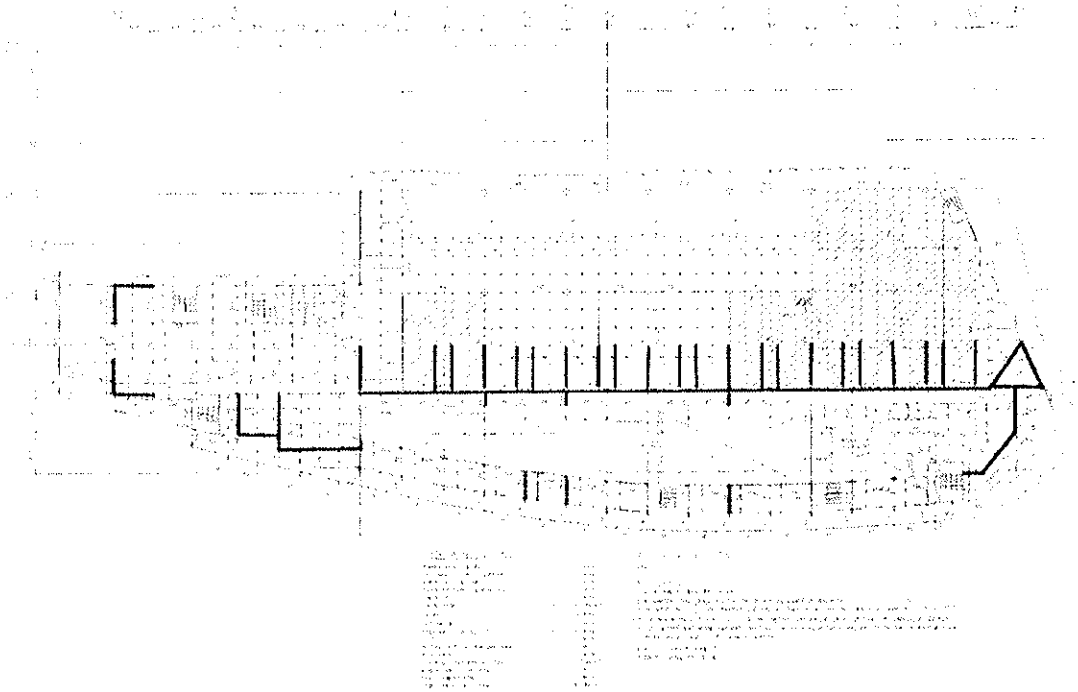
Level 2 Beam Layout



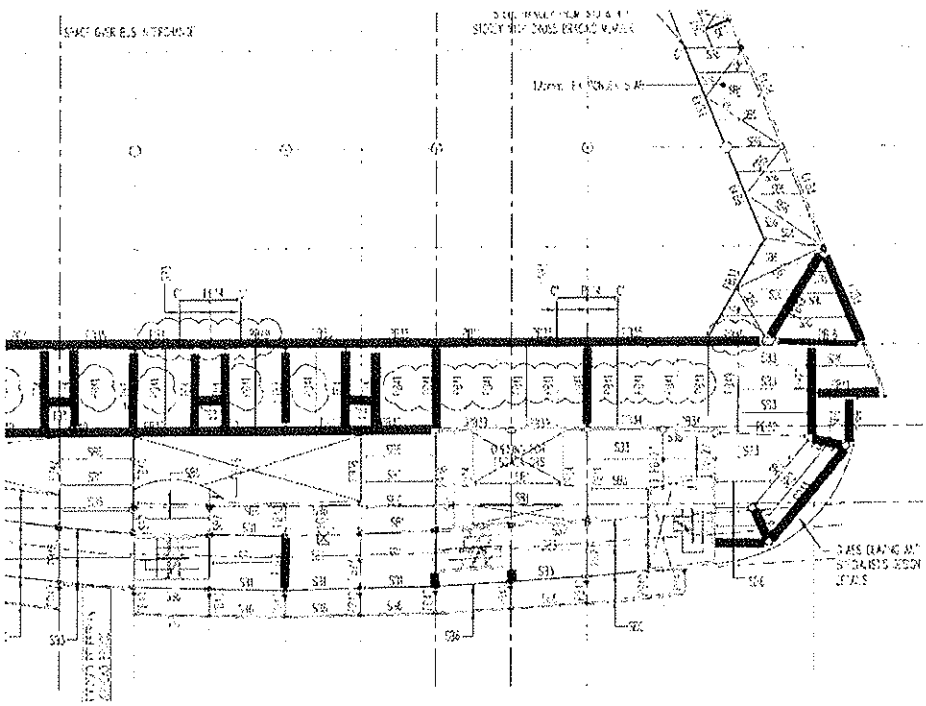
Level 3 Beam Lavout



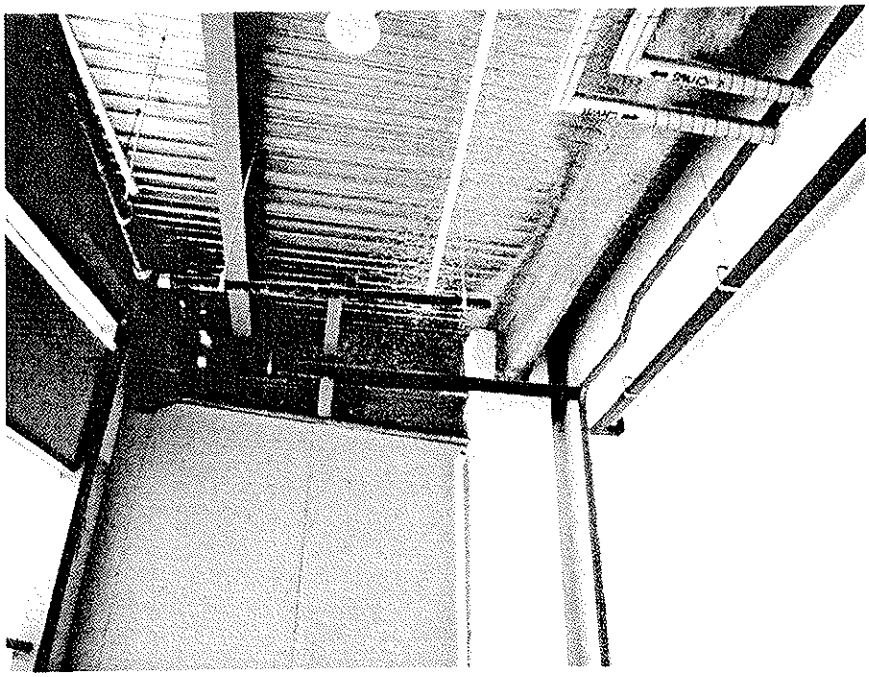
Level 4 Beam Layout



Part Plan of Level 2 Beam Layout



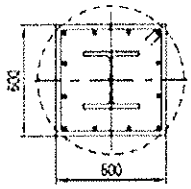
Fire Rated Beam – Level 4



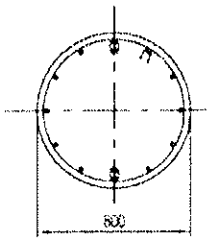
Example : Force Summary at Fire Temperatures

Output Parameter	*Beam 1*	*Beam 2*	*Beam 3*	*Beam 4*	*Beam 5*	*Beam 6*
Steel section temperature at maximum tensile force (°C)	920	1000	890	980	940	1020
Midspan deflection (mm)	700	660	820	670	670	660
Force in steel section (kN)	440	70	700	100	430	50
Force in reinforcement (kN)	550	260	450	200	520	260
Connection capacity at 20°C (kN)	2790	370	2790	370	2790	670
Connection force / capacity	0.16	0.19	0.25	0.27	0.15	0.07
Connection temperature limit (°C)	840	800[1]	760	750[1]	840	950[1]

Fire Rating of Columns



Concrete encased columns



Concrete in-filled columns

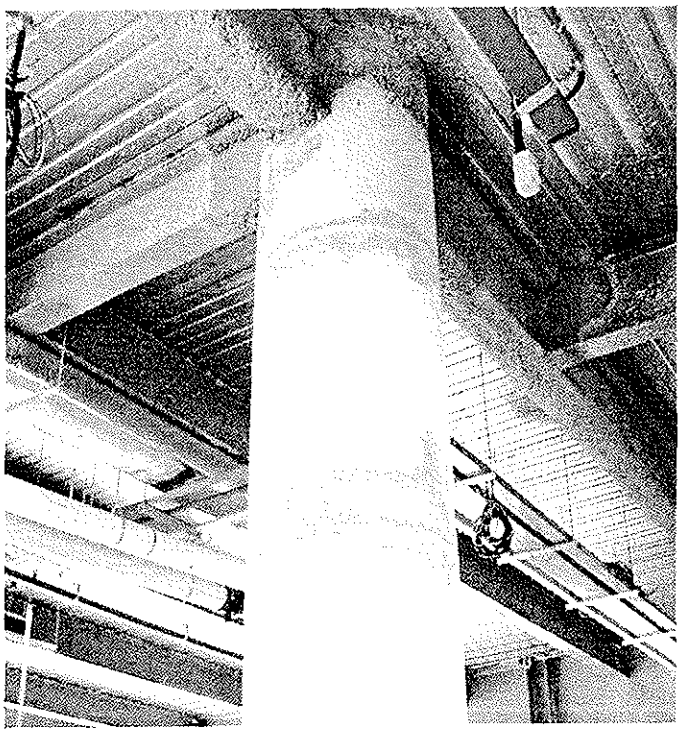
Catenary action induced force pulling the column inward

Column to restrain additional bending moment

Structural capacity of column at heated state compared with applied loading

Additional fire rating to columns that have inadequate capacity

Composite Column, Level 2



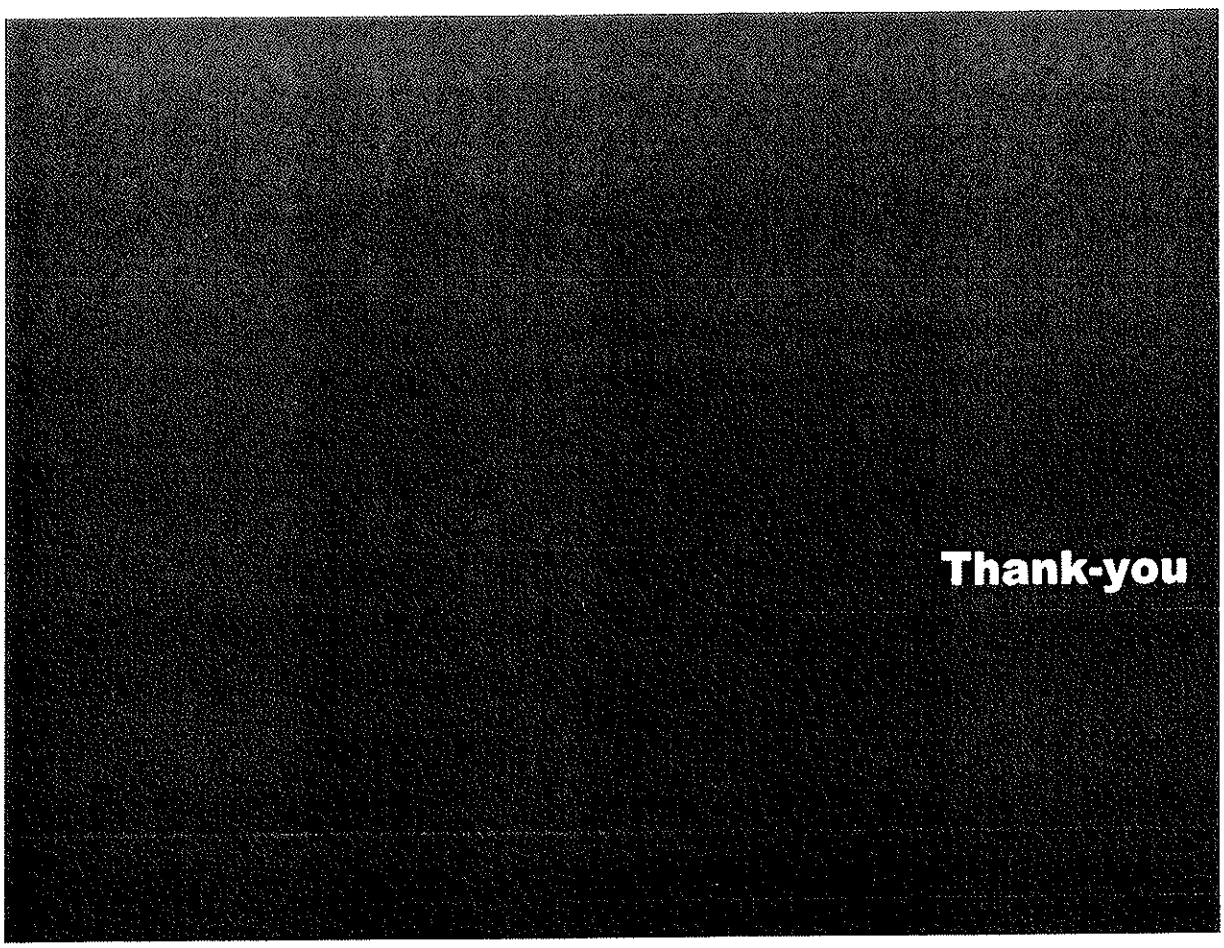
Summary

Performance-based design provides significant opportunities to the design community in terms of:

- Design flexibility
- Construction cost

These designs can be achieved without compromising public safety.

Singapore's new performance-based code should facilitate better levels of understanding of the real performance of buildings in emergency at the same time as enabling benefits to the community.



Recent Fire Research and its implications for fire safety engineering

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Fire Suppression Systems

Mr Nigel Smithies
BRE Associate
Visiting Professor of Fire Risk Analysis at the University of Ulster

Introduction

- Developments + Research
- Technology, Standards, Codes/Guidelines, Regulations
- Detection cf Suppression

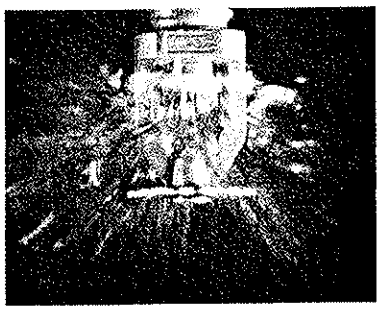
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Introduction

Sprinklers 'the' active protection system?

- Standards
- Description
- Design
- FSE
- Research

Other suppression systems



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Introduction – what sprinklers do?

- Suppress
- Control
- Extinguish
- Water Damage

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Introduction – sprinklers the facts (many myths)

- 99% of all fires controlled/extinguished
- 60% controlled by 4 sprinklers or less
- Single head ?
- 90% insured losses in unsprinklered buildings
- 50m sprinklers installed annually
- No deaths in sprinklered buildings

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Standards - sprinklers

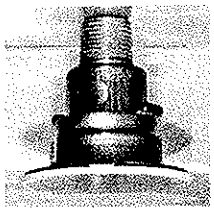
Long history – property protection

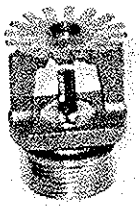
- 1888 - Fire Offices' Committee (FOC) Rules
- 1969 - FOC Rules 29th edition
- 1990 – British Standard (BS) 5306 Part 2
- 1990 – Loss Prevention Council (LPC) rules
- 2003 - BS EN 12845 + LPC rules
- 2004 – BS 9251 Residential sprinklers (systems)

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Description – sprinkler heads

- BS EN 12259-1 heads
- Pendent, upright, spray, conventional
- Concealed and recessed pattern
- Solder link, glass bulb
- BS DD 252 Residential sprinklers
- ESFR
- EPEC







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Description – types of system

- Wet
- Dry

- Alternate
- Pre-action
- Deluge

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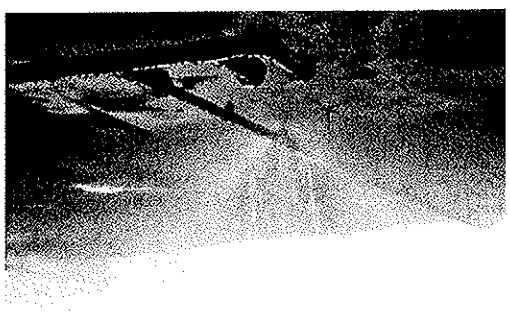
Introduction - why are sprinklers specified?

- Property/asset protection
- Life safety/means of escape
- Compensatory features
- Fire engineered solution

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Sprinkler system in operation water distribution

The historical - measure water distribution & flow rate



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BRE facility

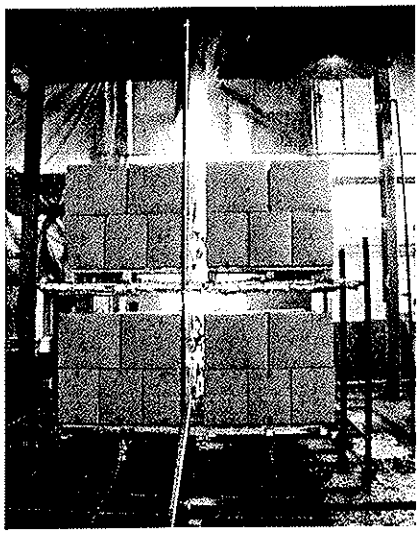
More recent test developments ADD + controllable 'fire'



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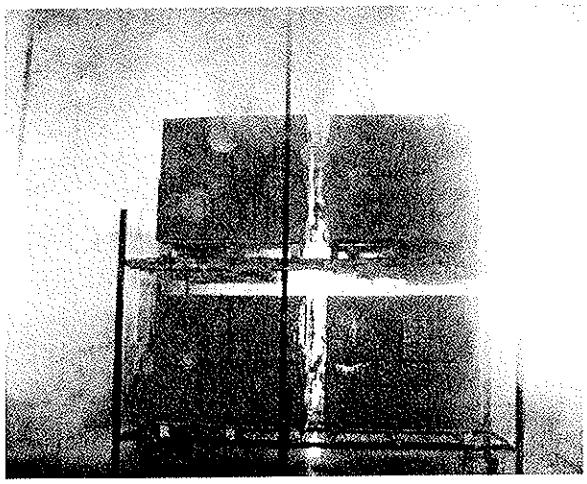
Commodity fire test at BRE

A repeatable commodity ?



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Commodity fire test at BRE

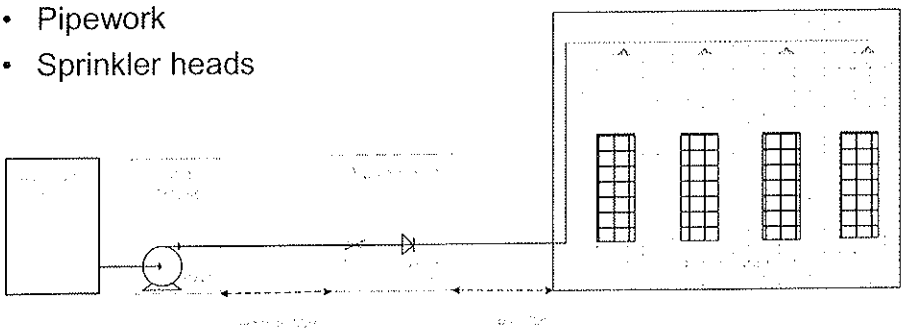


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Description

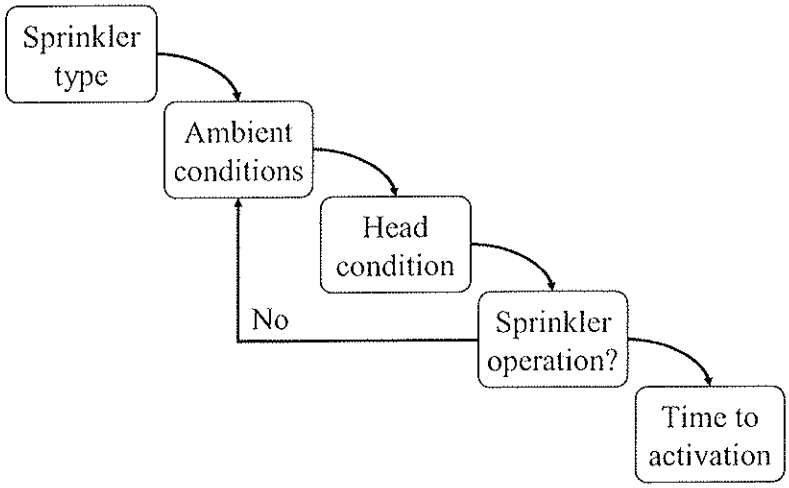
'Kits' not just systems

- Water supply
- Pump & valves
- Pipework
- Sprinkler heads



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Fire engineering - operation time



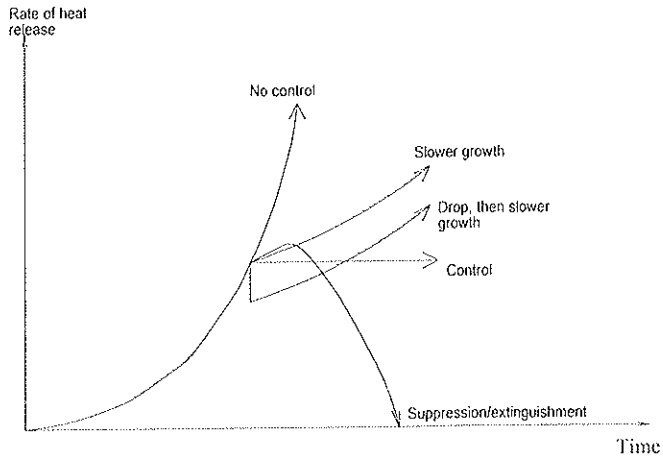
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Fire engineering – design fire

- Size of fire
- Type of sprinkler
- System design
- Geometry of room
- Shielding

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Fire engineering – design fire



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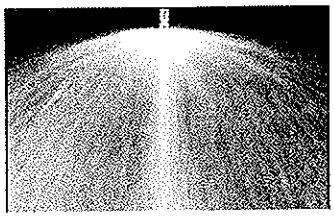
Fire engineering – non standard systems

- Building features
- Fire type and size
- Sprinkler type
- Water Cannon

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BRE Research - sprinklers

- EPEC sprinkler, TB222
  (Enhanced Protection Extended Coverage)
  - OH3, Improved suppression
  - Increased head spacing & reduced water supply
  - increased sprinkler coverage areas to 17.64 m^2 (as per TB222) as compared to 12 m^2 for conventional and standard spray sprinklers. Using the EPEC sprinkler the water supply storage volume is 50% smaller than using traditional protection methods (30 minutes water duration supply instead of 60 minutes). The maximum spacing between sprinklers of 4.2 meter compared to 4.0 meter gives flexibility in positioning the sprinklers.



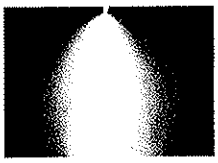
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Other Suppression Systems – typically have their own 'part' of the ISO standard

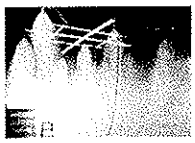
- Water mist many in domestic
- Scenario tests
- Tested for prisons, still no Standards in UK
- Chemical Agents/Halon replacement
- Inert gas
- N_2, CO_2
- Pre-suppression ? Reduced Oxygen Environment

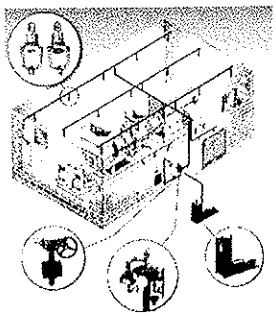
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Water Mist







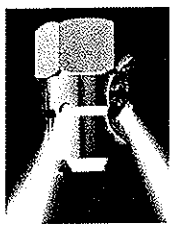


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* Not suitable for small fire in large spaces.

Chemical Agents

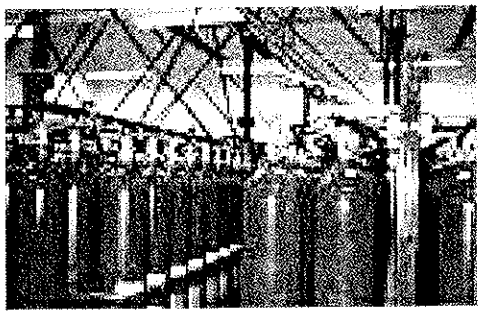






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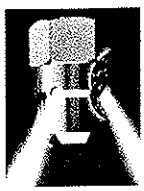
Inert Gas





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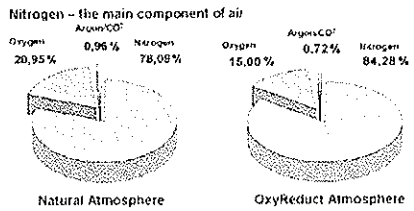
CO_2

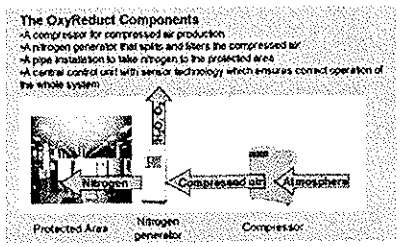




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Reduced oxygen - prevention of suppression





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BRE Research - sprinklers

- Domestic & residential sprinklers, BS 9251 & DD252
  - Domestic hazard fire test
  - Specific design criteria
  - http://www.bre.co.uk/adb/
- Actual Delivered Density for K115 and K80 sprinklers
  - http://www.bre.co.uk/filelibrary/LPC_ADD_Phase1.pdf

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BRE Research - other

- Ad-hoc sprinkler hazard classifications
- Gaseous extinguishing systems
  - Comparative testing, LPR6
  - Guidance, LPR16
- Water mist systems
  - Domestic & residential guidance
- Standard development- visit www.redbooklive.com

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BRE Effectiveness of sprinklers in residential premises

Some Outcomes of study

- For majority of scenarios experimentally studied, addition of sprinkler protection improved tenability conditions in both room of fire origin and connected spaces
- However, sprinkler protection did not prove to be a panacea
- Typical range of times of sprinkler operations was 2 to 20 minutes

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BRE Effectiveness of sprinklers in residential premises

- Smoke alarms fitted in rooms of fire origin responded typically in range 0.5 to 6 minutes from ignition (half of time required by sprinklers to be triggered by fire)
- Smoke alarms fitted in rooms of fire origin typically responded well before lower toxicity tenability criterion had been exceeded
- Smoke alarms fitted in adjacent rooms or compartments still provided useful warning - often before lower toxicity tenability criterion exceeded in room of fire origin, even when intervening door was closed

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Life Safety a 'real' test

- Small Hospital Ward
- Open door & open window

Material supplied by large UK hospital

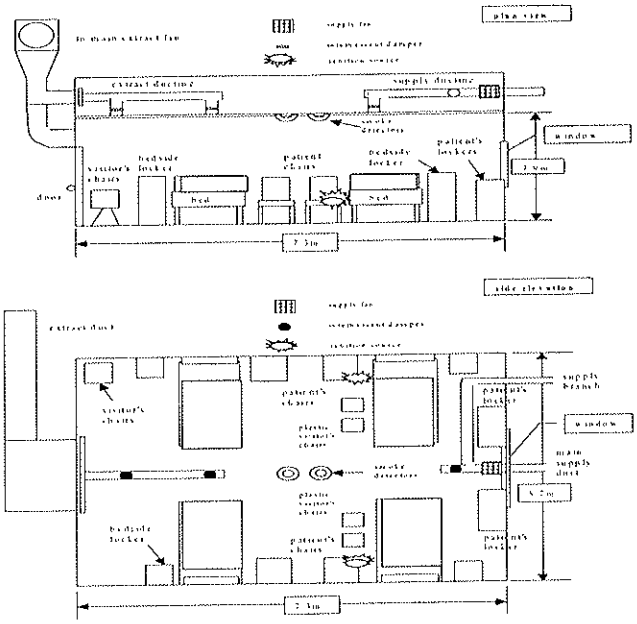
- Used hospital fabrics
- Used hospital bedding
- Used hospital furniture

- Small flame ignition of two sheets crumpled newspaper
- Smoke detectors
- No suppression – typical of UK

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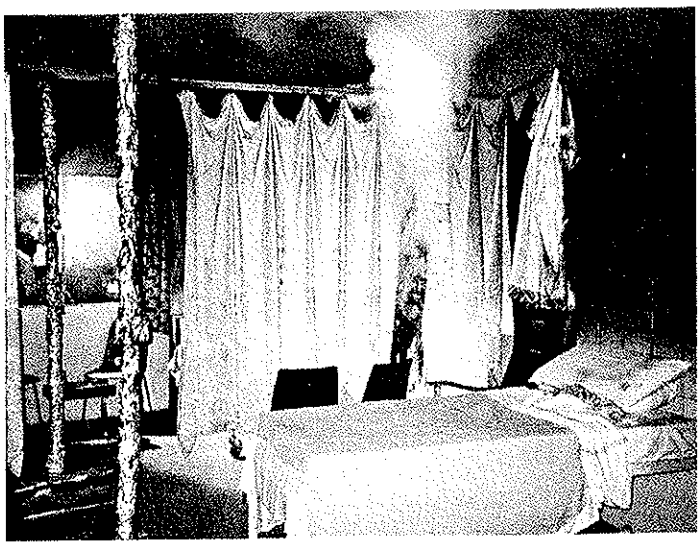
Detection & Suppression times - a 'real' fire

4 Bed hospital Ward



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Hospital Ward fire Detection ~ 40 seconds



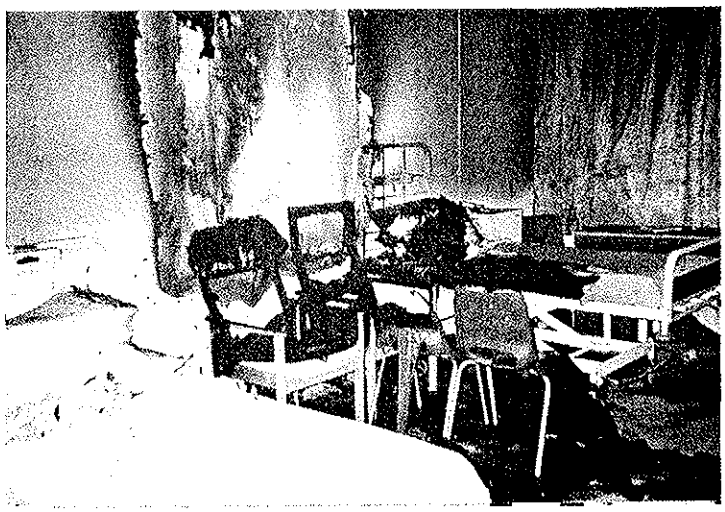
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Test 2 - smoke layer descending



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Test 1 - aftermath



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Test 1 - aftermath

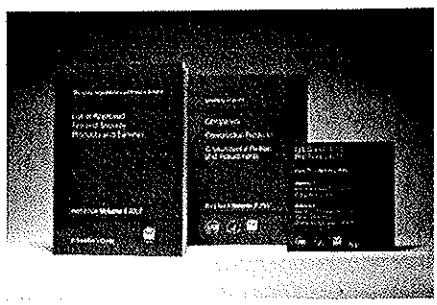


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The LPCB Red Book

'Red Book'

- Used extensively as a specification and reference document
- Also available on-line
- www.redbooklive.com



Approved fire and security products and services are listed in the Red Book

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Thank you