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The assessment of fire hazards, tenability and human evacuation behaviour for fire safety engineering design
Erasmus Mundus

Hazards in Fire incidents and fire investigation

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Lunds Tekniska Högskola, Sverige
Friday 15th April 2011

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David Purser Structural performance requirements for Life safety

There are different considerations depending upon whether the building occupants are inside the fire enclosure or in another enclosure or compartment

For occupants in the fire enclosure:

- No structural failure until occupants have had time to escape
- No fire growth or spread involving structural components within the enclosure while occupied (e.g. from flame spread and fire involvement of wall linings or coatings)
- Not vulnerable to external fire penetration or fire spread within the structure (for example within cavities) while occupied



Stardust Disco - Dublin

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Structural performance requirements for Life safety

For occupants beyond the fire compartment (or enclosure):

Fire and smoke should be contained within the compartment of origin until all building occupants have evacuated, this requires:

- Passive containment of fire and smoke for a sufficient period – in some cases needs to withstand complete burnout of the fire load
- Fire stopping of penetrations, expansion joints, fire and smoke seals (and vent closures) – common cause of smoke and fire spread
- Escape routes protected for as long as necessary for occupant safety
- Fire safety management must ensure that passive (or active) systems upon which structural containment relies are maintained - i.e. a 2 hour wall is not much use if the door is left open.
- Structural integrity maintained for as long as necessary

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Examples from major incidents

- Fires have grown rapidly in enclosure of origin
King's Cross subway station, Bradford Football stadium, Manchester Woolworths and Chesterfield Littlewoods, Port Stanley and Warrington Park hospitals, Stardust disco, station nightclub
- and/or have broken out of containment so that fire or fire effluent has spread rapidly through multi-enclosure buildings (e.g. Dupont Plaza and MGM Grand hotel fires, New York tower, Dusseldorf Airport, Summerland leisure centre, Heliopolis Sheraton Hotel)



Station nightclub Rhode Island



Heliopolis Sheraton Egypt



King's Cross underground



Manchester woolworths
Bradford football stadium

David Purser Reasons for failure to protect occupants

Causes of hazard:

- inadequate control of combustible contents with rapid fire growth and spread, or from
- failure of construction or design with fire or effluent penetration and spread between compartments

Littlewoods



Failure of safe escape due to:

- late evacuation warning
- failures to understand extent of fire risk and needs of occupants,
- failure to provide adequate warnings and fire safety management
- failure to provide adequate structural fire containment and to protect escape routes



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How long does structural performance need to be maintained for life safety?

Single storey, single enclosure uncomparted building:

- **Examples:** small office, workshop, warehouse, supermarket, DIY store, assembly hall, school, dormitory.
- **Simultaneous evacuation is feasible in fires.** Escape time depends on occupancy type, fire safety management strategy, detection and alarm system, occupant numbers and characteristics: may only be a few minutes. Time required for structural integrity to be maintained is the time required for escape (plus a margin or safety).



Cambridge Arts Theatre



Harvey Centre Shopping Mall

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How long does structural performance need to be maintained for life safety?

Single storey, multi-enclosure, multi-compartment building:

- Examples: airports, single-storey shopping malls, multi-screen cinema complexes
- Additional hazard of a fire growing undetected in one enclosure or compartment with sudden break out into large and heavily occupied spaces
- Longer fire containment needed to protect occupants in other enclosures or compartments to enable safe escape (plus a margin or safety).

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How long does structural performance need to be maintained for life safety?

Multi storey, multi-enclosure, multi-compartment building:

- Examples: Most large buildings, including stores, hotels, apartment blocks, office blocks, factories, hospitals, schools.
- Rapid evacuation may not be feasible due to the nature of the occupancy coupled with the size (especially the height) and design of the building.



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Cases where a long period of maintained structural performance is required

- Any sleeping risk (residential domestic, institutional or other [e.g. hotel or HMO]), health care.
- Hotels and hostels an immediate simultaneous evacuation strategy may be used, but long periods are needed and some occupants may not evacuate. (one hour or more)
- Each room or suite needs to be a compartment, at least in relation to the common escape routes
- For apartment blocks or flats or maisonettes the main strategy is to defend in place. Only the affected unit and adjacent areas are evacuated.
- The structure thus needs to withstand burnout of any particular unit

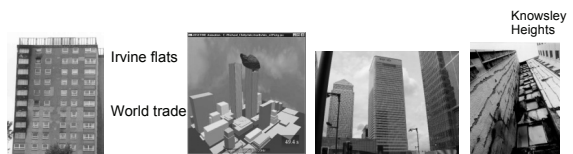


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Cases where a long period of maintained structural performance is required

- For other occupancies, such as high rise office blocks or stores with several stories, a phased evacuation strategy may be used
- Immediate evacuation for the fire floor and at least the floor above
- Other floors are evacuated if the fire becomes severe or spread of fire or smoke beyond the compartment of origin
- Involves several phases and evacuation of large numbers of people from large buildings, so requires a long period to accomplish (up to 1 hour)
- Stairs designed for phased evacuation are narrow, so that a total building evacuation is slow, but can be faster if lifts used in addition to stairs



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U.K. Fire Deaths

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U.K. Fire Injuries

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Fire Disasters

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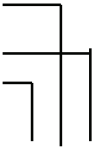

UK Fire statistics – fatal fire scenarios

- Spectacular conflagrations destroying houses make the headlines, but most fires are very small – at least during the critical period when the occupants are exposed
- For 80% of non-fatal dwellings fires the fires did not spread beyond 20% of the area of the room of origin.
- For 50% of fatal dwellings fires the fires did not spread beyond 30% and for 35% not beyond 10% of the room of origin
- People are injured or killed by small fires

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Room of fire origin damage - non-fatal and fatal fires

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Room of fire origin damage - with sprinklers

Data interesting but incorrect

Small sample but:

No deaths

No injuries (statistically expect 25)

11% failed to operate

75% controlled or contained

14% extinguished

94% room damage < 10%

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Floor of fire origin damage - without sprinklers

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Fires in large retail buildings

- How do occupants respond to fires in large "awake and unfamiliar" scenarios?
- How has this interacted with the fire development to produce hazardous or safe outcomes?
- What can be learned from incidents and experiments?
- How can these be incorporated into FSE design

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Fires in large retail buildings

Fires occurring in large single enclosure when the victims are in the same enclosure as the fire –

- Structural aspects therefore of lesser importance
- Detection, warnings, fire safety management, escape route provisions and occupant behaviour are of great importance
- Fire behaviour of contents and linings of great importance
- Did compartment size or travel distance have any bearing on these incidents?
- What about the exit and stair width requirements?

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Four fires in large retail buildings

- Poundstretcher discount clothing store – Scotland
- Littlewoods department store – Chesterfield
- Woolworths department store – Manchester
- Harrods department store - London

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Sequence of events in clothing store fire

Time	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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Chesterfield Littlewoods



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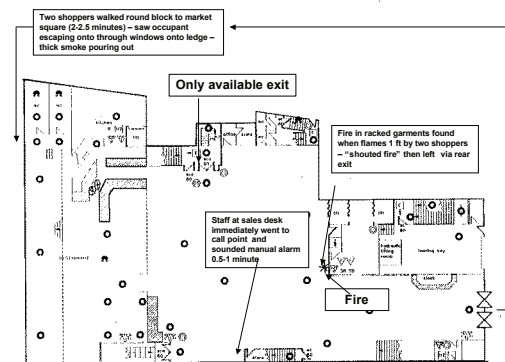
Fire Disasters - Chesterfield Littlewoods



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Chesterfield Littlewoods



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Manchester Woolworth's



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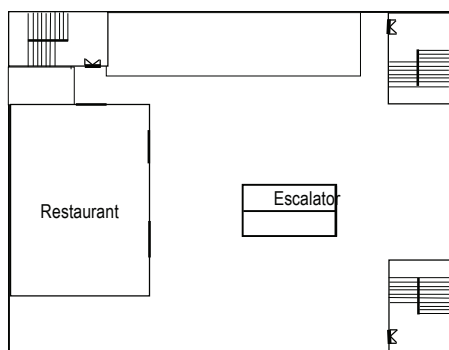
Woolworth's



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Woolworth's



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Four fires in large retail buildings

- Harrod's department store – London

A similar fire to Manchester occurred in Harrod's. The fire was started deliberately in furniture on an upper floor. The floor was sprinklered.

The voice alarm instructed occupants to leave the fire floor. The staff responded in a timely manner and swept occupants towards the emergency stairs. The stairs led to the street staff went to the muster point.

Many shoppers did not use the emergency stair, but went down the main stair (by which they had entered) to the floor below. At this level they got a new message telling them to stand by. Quite a few people therefore assumed the fire had now been extinguished, and went back up to the fire floor. There were no staff present to prevent this since they had all left by the emergency stairs and were no longer in the building.

There were no injuries but incident was useful in revealing the flaws in the emergency management system

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Fire involving structure and penetration from outside or from another compartment/enclosure

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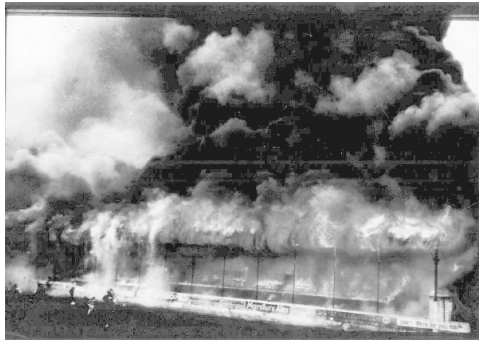
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Bradford stadium flashover



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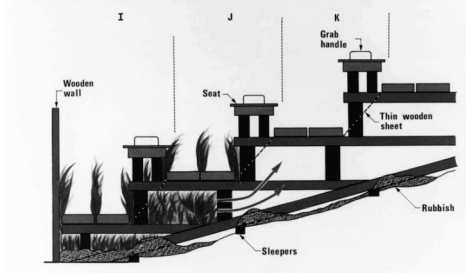


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Bradford stadium

Growth of fire from point of ignition

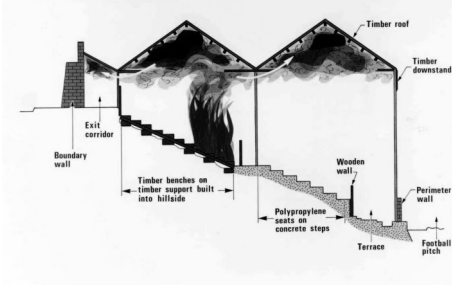


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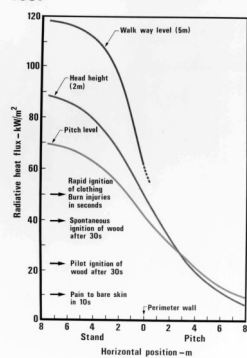
Growth of the fire



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Irradiance from flame beneath roof



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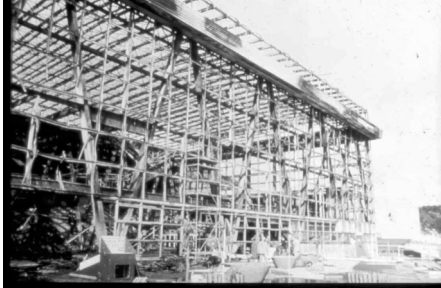


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Fire involving structure and penetration from outside or from another compartment/enclosure

Summerland



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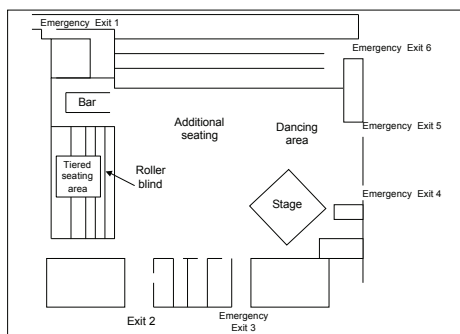
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Large-scale reconstructions e.g. Stardust
Disco recreation



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Stardust disco



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Station Nightclub Evacuation Scenarios

Gridflow output for different scenarios



Gridflow evacuation modeling



NIST FDS
analysis of
the fire

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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 wayfinding
- Reactions to smoke and heat

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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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Findings of fire investigations

FIRE SPREAD THROUGH STRUCTURE

Cavity barriers and fire protection in voids

- Terraced houses and other buildings
- Windsor castle - hidden voids
- Poor installation - supermarket and domestic flats (roof truss)
- Large house
- Terrace - lintels
- Penetrations - HVAC - Five ways

Façades

- PVC cladding - flats
- African Hotel - panels and penetrations
- Summerland

Sandwich panels

PVC Windows

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Structural performance requirements for Life safety

With regards to occupants beyond the fire compartment (or enclosure):

- The fire and fire effluent should be contained within the compartment of origin until all building occupants have evacuated, this requires:
 - Passive containment of fire and smoke for a sufficient period - for some situations this means that the structure should be able to withstand complete burnout of the fire load
 - Maintained performance of fire stopping of penetrations, expansion joints, fire and smoke seals (and vent closures)
 - Minor structural failures should not allow fire or effluent to spread beyond compartment boundaries
 - In particular the escape routes should be protected for as long as necessary for occupant safety
 - The fire safety management strategies and implementation must ensure that passive (or active) systems upon which structural containment relies are maintained - i.e. a 2 hour wall is not much use if the door is left open.
 - Structural integrity should be maintained for as long as necessary
- The fire effluent
- The structure should not be vulnerable to external fire penetration while occupied

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How long does structural performance need to be maintained for life safety?

Contrast between levels of passive protection between enclosure and compartments:

- From a human response perspective there is not difference between an enclosure and a compartment
- Since fire separation between enclosures can be minimal, occupants can be vulnerable to fires breaking out of an adjacent enclosure

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