DD 240 CASE STUDY

An example of a DD 240 fire safety engineering approach to the design of a proposed three-level file storage facility in a hospital

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THE CHALLENGE

A Victorian period hall 30m long by 14m wide by 10m high, used for file storage on the ground floor, is to have its file storage capacity greatly increased by the addition of two upper level storage areas without cutting out natural lighting or creating congestion. The proposed new file-support structure, which is of an unusual design featuring unprotected steel masts, beams and cable stays, incorporates open upper level walkways and open stairways at either end. Does it provide an acceptable level of safety for the occupants and fire-fighters should fire occur?

SCOPE

The writer was contracted by a firm of architects and project managers to provide advice on structural stability, means of escape and fire-fighting facilities so as to assist the architect in getting building approval from the Home Office Fire Inspectorate. The safeguarding of medical records was an additional consideration. Advice was given which included a recommendation to employ smoke beam detection, and building approval was granted, but the project did not go ahead because of lack of funds. The project seemed an ideal basis to demonstrate how a fire safety engineered approach might be followed using DD 240 Part 1 'Guide to the application of fire safety engineering principles'[1], hence this article. The DD 240 design process is briefly described in the Appendix.

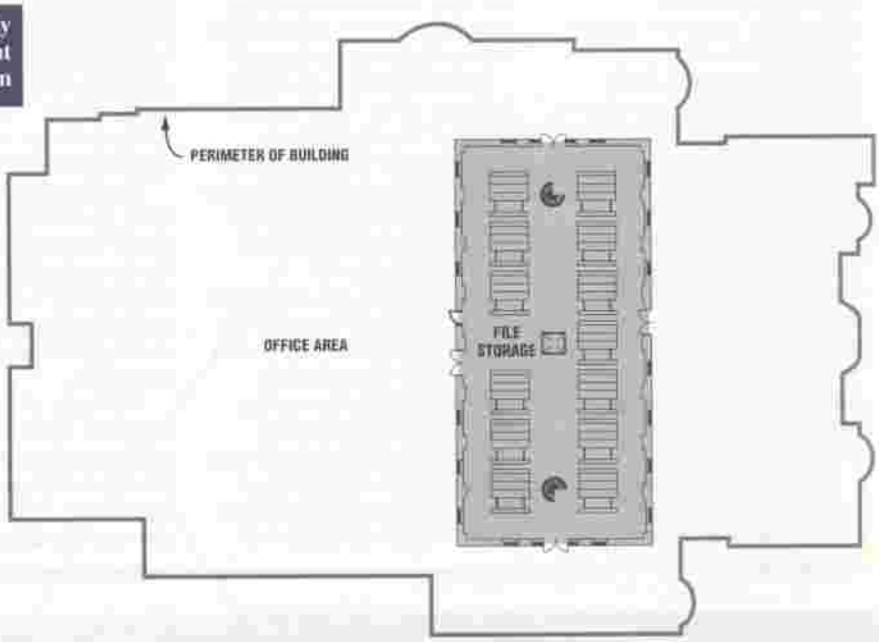


Figure 1. Plan showing file storage area

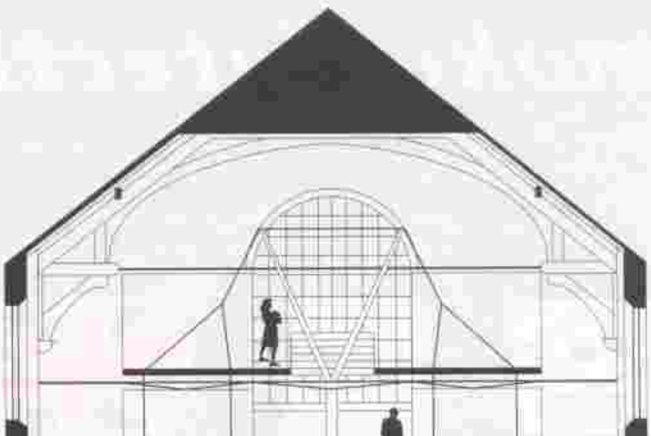


Figure 2. Section through hall

OBJECTIVE OF STUDY

The objective is to show that occupants on the uppermost level would have adequate time to escape before a smoky atmosphere would become untenable. DD 240 Part 1 would be used to calculate and compare the time available and time required for escape based on smoke fill times using severe design fires. By adopting severe design fires, the complications of using DD 240 Part 2 are avoided. Another purpose of the article is to highlight the importance of a structured and transparent approach which DD 240 recommends. Aspects of professional judgement are also highlighted. Attention is confined to a consideration of means of escape.

QUALITATIVE DESIGN REVIEW (QDR)

The QDR team

A meeting was held with representatives of the local health authority, Home Office Fire Inspectorate, the architect, and the writer.

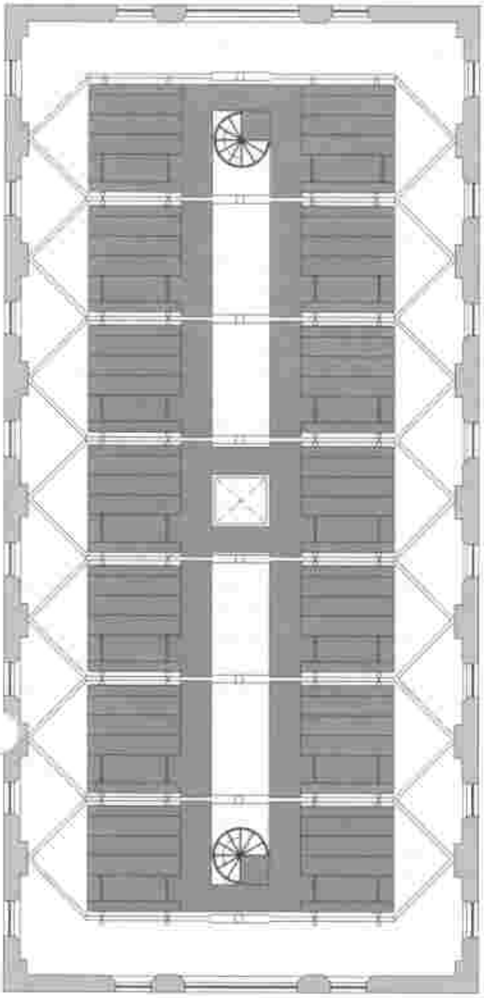


Figure 3. The floor panels and open areas

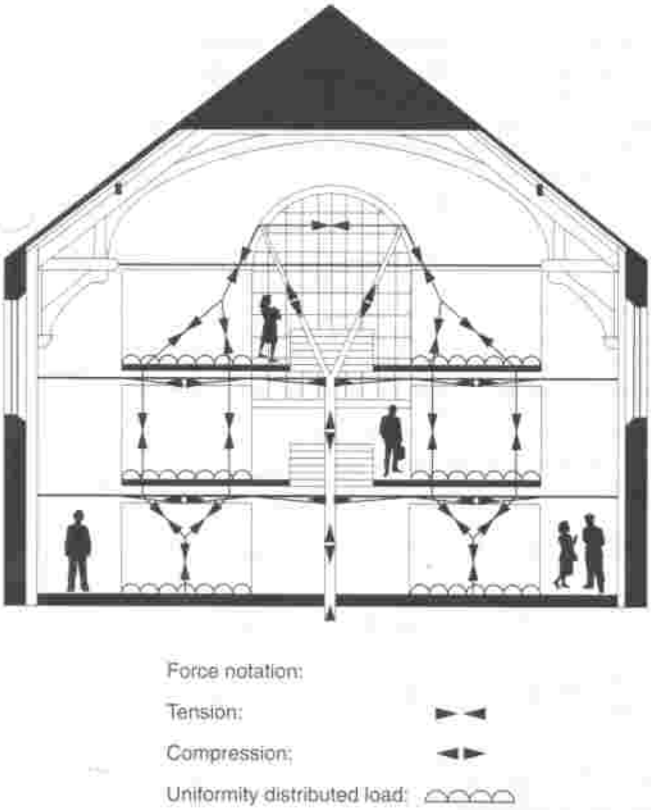


Figure 4. Force systems in steel structure

Building and occupant characterisation

The present design of the hall and the proposed new facilities were reviewed, and the building, its contents, and the occupants were characterised.

Building characterisation

The hall is a large, undivided space 30m long by 14m wide by 10m high, with masonry walls and a pitched timber roof. It has four exits (one in the centre of each wall) into surrounding rooms and corridors as shown in figure 1.

The file-support structure comprises eight equi-spaced Y-shaped masts fitted with cantilevers at both upper walkway levels, as shown in figure 2. Cable stays attached to the mast support lateral and longitudinal beams which, in turn, support the floor panels and rolling filing cabinets. A plan showing the floor panels (shown shaded) and open areas around them is shown in figure 3. The force system is shown in figure 4.

Diagonal bracing connecting each of the lateral steel beams to the masonry buttresses serves to transmit dynamic loads associated with the rolling cabinets back to the robust hall; they also serve in a severe fire condition to give lateral and longitudinal stability to the file-support structure. Vertical circulation is achieved by an unenclosed spiral access/escape stair located at each end of the file support structure giving a 25m separation. Clerestory windows exist in all four walls. There are no smoke ventilators.

Hose reels and portable fire extinguishers are provided in accordance with the BS codes of practice.

Contents characterisation

Apart from the timber beamed roof and the paper files, the rest of the hall, including its finishes and contents, have negligible fire load. The medical records comprise papers in folders. The folders are densely packed and rest on steel shelves in enclosed steel sheet rolling filing cabinets 2.2m high by 3m wide by 300mm deep mounted on rails. Only the front face of each cabinet is open for accessing files, hence only the front face can be attacked by fire in the early stages of a fire. The total fire load is high (approximately 200 tonnes of paper) but much of it could be regarded as protected fireload since many of the cabinets would be in contact with each other – however this is unimportant in the means of escape analysis.

Occupant characterisation

The file storage area would be in use 24 hours a day and would only be accessible to hospital staff. Not more than 20 staff would be present at any one time, and for most of the time only four to six staff would be present. None of the staff would be disabled. The staff would have their own desks and chairs in a separate office outside the hall. There would be a non-smoking policy.

FIRE SAFETY OBJECTIVES

The predominant objective was safety of life for the occupants and fire-fighters. A secondary objective was safeguarding the medical records. As noted above, this example is confined to means of escape for the occupants.

ACCEPTANCE CRITERIA

A deterministic study was indicated which should show, for some reasonable worst case fire scenarios, that the fire safety objective was attained. Safety of the occupants would be assured if the time required for escape from an elevated walkway was less than the time available for escape dictated by untenable conditions of smoke.

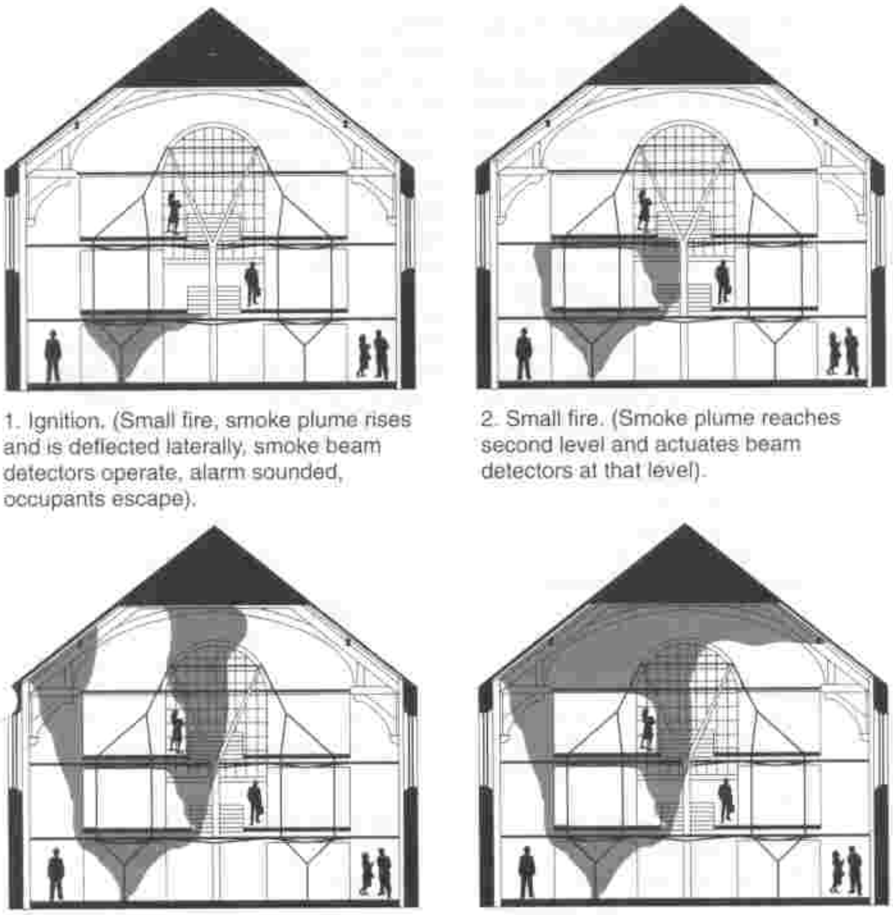
HAZARD ANALYSIS

The primary fire load in the hall comprises the paper files. Secondary fire loads are the egg-crate lighting diffusers used beneath the steel plate floor panels of the file groups, and the floor coverings which comprise rubber-studded sheet flooring on the ground floor and elevated walkways. Possible sources of ignition include electric light fittings and the electrics associated with the central hydraulic lift.

FIRE SCENARIOS

An examination of all possible accidental fire hazard scenarios suggests that the worst combination of location of fire and location of occupant is a fire in a filing cabinet on the ground floor near one of the spiral staircases and a person on the uppermost walkway near that stairway. The occupant(s) would then have to travel the full 25m distance between the stairways before moving downwards. It should be noted that for all positions of fire and occupant there is always at least one escape route available where the person can turn his or her back on the fire to escape safely, thus the important principle embodied in fire precautions codes of practice (such as the BS 5588 series for instance) is satisfied in this project.

Assuming that a fire occurred by ignition of papers in a cabinet on the ground floor, the smoke plume will rise up the front of the cabinet and will be deflected by the imperfo-



1. Ignition. (Small fire, smoke plume rises and is deflected laterally, smoke beam detectors operate, alarm sounded, occupants escape).

2. Small fire. (Smoke plume reaches second level and actuates beam detectors at that level).

3. Plume reaches ceiling.

4. Smoke begins to build downwards from ceiling.

Figure 5. Likely smoke flow pattern for fire in files

rate steel plate forming the floor of the walkway above. It will then rise vertically, expanding in v-shaped plumes as it does so, until it meets the underside of the ceiling of the hall 10m above floor level, as in figure 5. Indeed it should be noted that an incipient fire anywhere (whether it be anywhere on plan and anywhere vertically, such as ground floor level or first or second elevated levels) ll produce a smoke plume which will rise until it contacts the hall ceiling. Here, it will spread laterally/longitudinally until it meets the walls and will then begin building downwards. The time taken for smoke to build down to a level sufficient to place people on the second level walkway at risk (a distance of 3m from ceiling to head level) is greater than for conventional single storey office office accommodation where the corresponding distance is often approximately 1m, and the smoke reservoir is correspondingly smaller. Despite this qualitative-based conclusion showing adequacy, it was decided to quantify two severe (worst case) fire scenarios.

Scenario A assumes that a fire occurs in a filing cabinet at ground floor level as shown in figure 5.

Scenario B assumes that, against all the fire safety management rules, paper waste in a bag(s) has been placed or temporarily stored at ground floor level and has been ignited accidentally or maliciously.

For both scenarios it is assumed that: (a) there is a person on the highest level walkway vertically above the fire source who has to walk the 25m length of the walkway before the smoke builds down to impare his or her escape, thereafter it is assumed that the occupant can walk down the stair and exit through a doorway faster than the smoke can build down; and (b) smoke detection is not provided or is ineffective. [Note: Smoke beam detection formed part of the final design on which building approval was given.]

QUANTITATIVE ANALYSIS

This comprises two stages:

- calculation of time required for escape from time of ignition (time = zero) which, for this case, is the time for an occupant to reach one of the spiral staircases, assuming the other staircase is unusable;
- calculation of time available for escape from time of ignition which, for this case, is the time it takes for smoke to build down to head height for a person on the uppermost walkway, i.e. 3m below the ceiling.

Assumptions

1. The Heat Release Rates (HRR) for an open-fronted filing cabinet 3m wide by 2.2m high filled with paper files is not known to the author. It is assumed to be far less than for a 1.2m high stack of timber pallets which is known from calorimeter tests to produce HRRs of 300 and 3000kW at 200 and 330 seconds respectively after ignition. A burning bag of paper refuse is adopted as a design fire caused by malice.
2. A rough approximation of smoke fill times can be obtained using the smoke fill program in ASKFRS (a suite of micro-computer programs for fire calculation prepared by Fire Research Station, BRE). Although sub-system 2 of DD 240 provides some plume equations, it gives, at present, no guidance on the calculation of smoke fill times, and most practitioners resort to the use of computer programs designed for the purpose. The smoke fill program assumes an undisturbed axi-symmetric plume but the plume rising from a filing cabinet would be bifurcated (see figure 5), leading to greater entrainment of air and shorter smoke fill times. The choice of severe design fires is assumed to compensate for this effect.
3. The trapezoidally shaped roof can be represented by a rectangular shaped smoke reservoir having a length of 30m and an equivalent width of 10m.

Time required for escape

The components of escape time are shown in figure 6.

The time required for escape comprises the following times obtained by consideration of factors in sub-system 6 of DD 240:

- detection time. Assumed to be, at mor one minute after ignition. Detection by occupant via sight, smell or hearing. Note that detection and alarm are coincident;
- recognition time. Assumed that occupant carries on working for 15 seconds (e.g. carries on filing);
- response time. Assumed that occupant

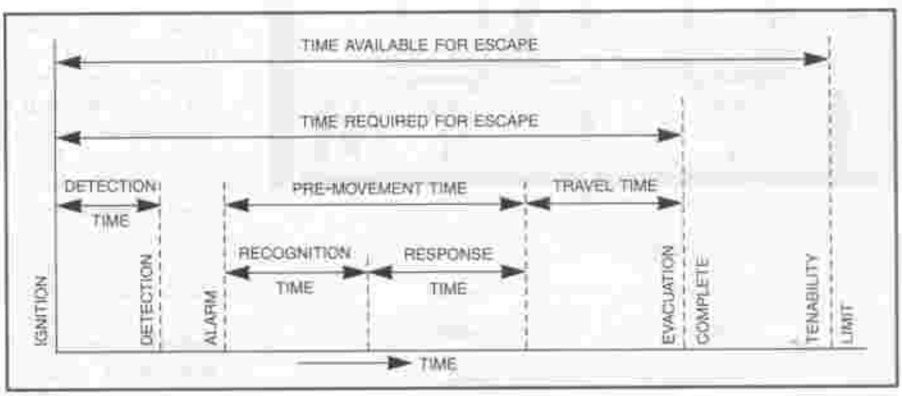


Figure 6. Components of escape time

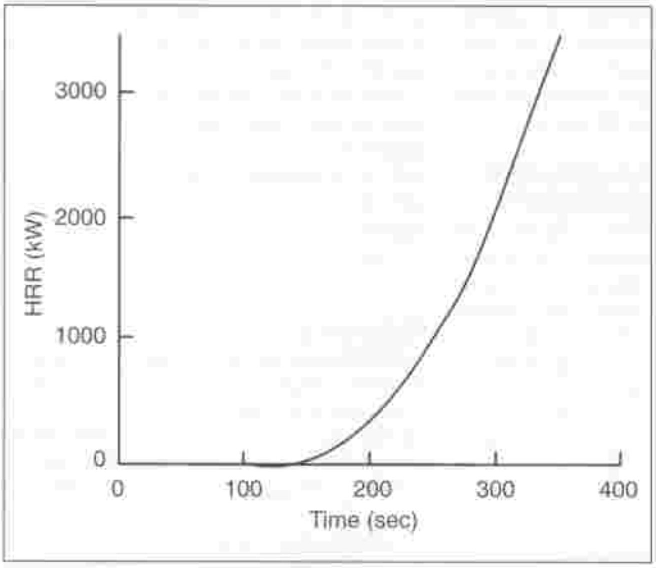


Figure 7. HRR's for timber pallets

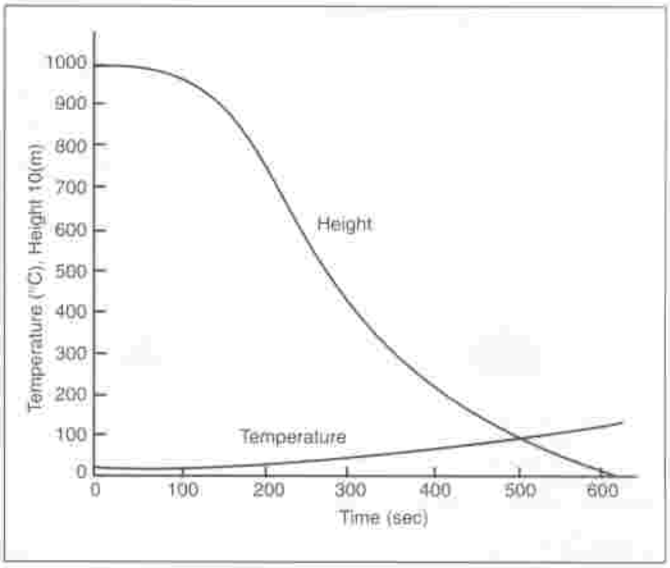


Figure 8. Clear air layer depth and smoke temperature, timber pallets

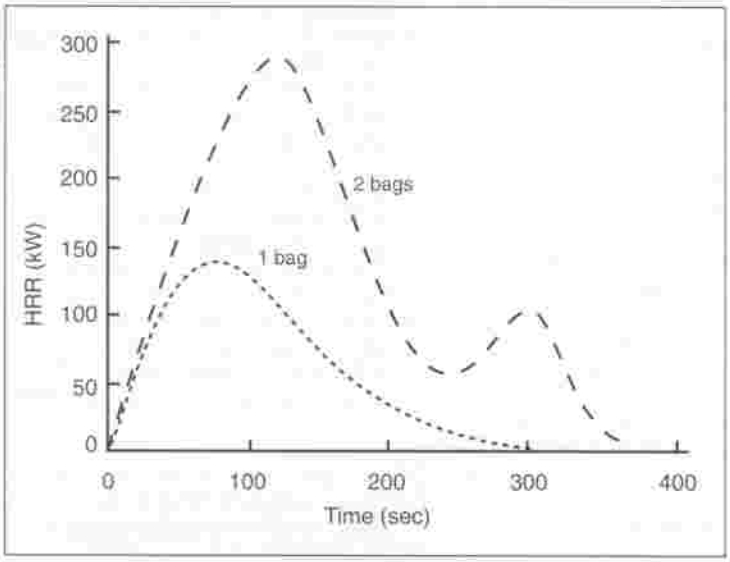


Figure 9. HRR's for bags of paper refuse

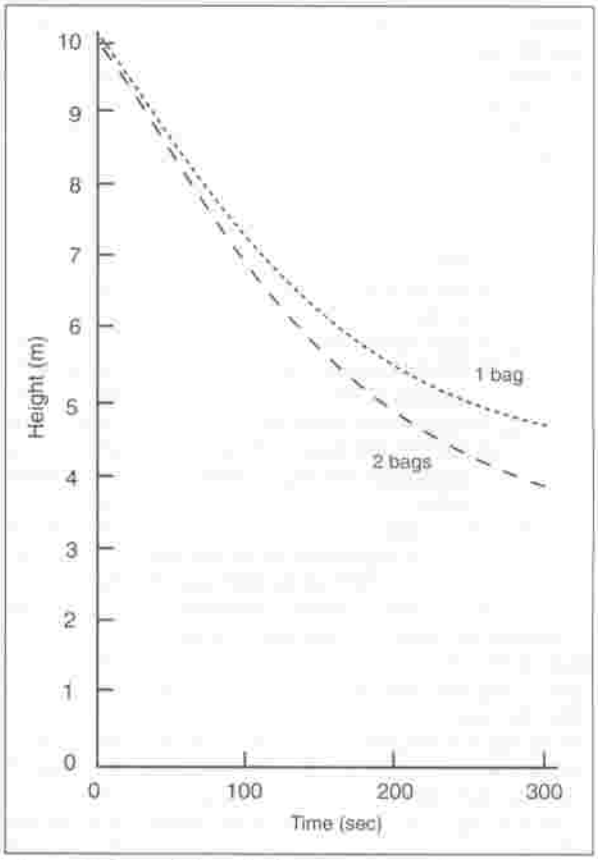


Figure 10. Clear air layer depth, bags of paper refuse

investigates (looks over handrail) to see where smoke is coming from and this takes 15 seconds before beginning to move along the escape route;

- travel time. Assumed that occupant walks the full length of the walkway (25m) at a speed of 1m/s to reach the spiral stairway, i.e. travel time is 25 seconds. The small number of occupants present means that queuing does not occur.

Time required for the critical part of the escape is therefore nominally two minutes.

Time available for escape

Design fire scenario A

The HRR versus time for the 1.2m high stack of timber pallets is shown in figure 7.

Figure 8 shows that for a smoke layer thickness of 3m (i.e. a clear air layer of 7m), ASKFRS gives a fill time of 235 seconds.

Design fire scenario B

The HRR versus time for one and two bags of paper refuse are shown in figure 9.

Again, for a smoke layer thickness of 3m, ASKFRS gives fill times of 100 and 126 seconds for the burning of one and two bags of paper refuse respectively, figure 10.

Assessment of toxic hazard and visibility

The temperature of the smoke for the design fires considered was very low – still only 3°C above ambient for fire scenario A at 235 seconds, and even less for the other fire scenarios – which is indicative of a high level of dilution and low buoyancy.

To check if the smoke produced would impair escape the method of toxic hazard assessment given in DD 180[2] is used. In the following simplified calculation of the hazard associated with the partial burning of one 1.7kg bag of paper refuse it is assumed that: the smoke layer is 3m thick giving a smoke volume of $30 \times 10 \times 3 = 900m^3$, the products of combustion are uniformly dispersed in the smoke volume, paper is the only material burning so that the toxic potency factor is 1.0, and that paper is a material of 'usual toxicity' which it is. Since the total mass loss is proportional to the area under the HRR-time curve, it can be seen from figure 8 that at two minutes after ignition approximately 1kg paper will have been burnt.

The toxic potential concentration is $1000 \div 900 = 1.11g.m^{-3}$. The exposure dose is 200 and $500g.m^{-1}.\ min^{-1}$ for escape impairment (e.g. asphyxiation) and death respectively and it is therefore clear that an occupant could remain unimpaired for 180 minutes in the smoke assuming that the concentration remained constant. In our example, an occupant would have reached the top of the staircase two minutes after ignition when the smoke reached head level so the occupant

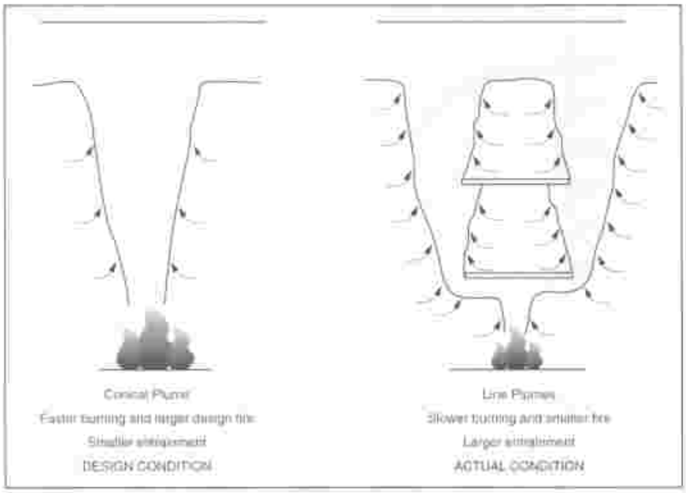


Figure 11. Plume conditions – design versus actual

would not be exposed to any smoke. Even if an occupant had been exposed to smoke, it is clear that the burning of one bag of paper refuse is not a threat although at concentrations over 1 to $2g.m^{-3}$ stinging in the eyes and irritation to the throat may occur. It is therefore concluded that the time available for escape would be considerably greater than the smoke fill times calculated by ASKFRS.

From DD 240 the visibility distance (m) is given by:

$$S = V \div (D_m . f_b)$$

where V = volume of smoke (m^3)
= 900 for a smoke layer depth of 3m
D_m = mass optical density (m^2/kg)
= 400 for flaming cellulosic material (Table 15 of DD 240)
f_b = mass of fuel burnt (kg)
= 1.0 after two minutes from ignition for one bag of paper refuse.

Therefore S = 2.25m

This value seems intuitively to be far too small and it throws doubt on the BSI quoted value of smoke optical density ($400m^2/kg$).

Babrauskas, who has done much work on rate of heat release, smoke and soot production using the cone calorimeter[3], believes that the value of $D = 400m^2/kg$ is incorrect by an order of magnitude[4] and this confirms the author's suspicion. A value of 40 is considered more appropriate and would give a visibility of 22m in the example given above.

This visibility calculation assumes that the smoke particulates are uniformly distributed in the smoke volume. In practice the smoke obscuration will be higher near the ceiling if the plume is buoyant. In the example scenarios the smoke temperature is low so that a coherent layer cannot be assumed and the visibility would be expected to vary from point to point.

Assessment of results against criteria

The acceptance criterion was that time available for escape should be greater than the time required for escape. The calculated time available for escape was in the range of 96 to 210 seconds for highly diluted smoke and would be greater before the smoke reached untenable conditions. The time required for escape was approximately 120 seconds assuming a pre-movement time of 95 seconds.

ENGINEERING JUDGEMENT

The choice of design fire is usually a contentious issue. The author believes that the most appropriate of the three considered is the burning single bag of paper refuse since, in the early stage of a fire spreading upwards on a 2.2m vertical face of paper files, a peak HRR of more than 140kW within one minute is difficult to imagine – pilot flame ignition of paper refuse generally leads to a very fast HRR because the fuel is porous, unlike paper in files. As noted however, a sensitivity analysis has been made for the burning of two bags of paper refuse which also allows for arson or accident.

Another matter of judgement is the decision to use a smoke fill program based on an axi-symmetric plume. The comparison between the actual condition and the design condition is shown in figure 11. A rigorous analysis should arguably be based on line plumes but this is more complicated and cannot be justified for a project where it is almost self evident from a qualitative assessment that the design is safe. The author has deliberately chosen severe design fires which feature initial high heat release rates to counterbalance the use of a conical plume and to avoid the use of safety margins implied in Part 2 of DD 240.

The use of pre-movement times in a British Standard fire precautions document is a new idea. There is as yet little information on pre-movement times and this is understandable when considering the range of factors affecting them. The recognition and response times adopted by the author in this paper were therefore chosen simply on the basis of what he considered to be reasonable and not on any scientific data. The same may be said of the detection time chosen. This is an illustration of the transparent honesty which the document encourages.

CONCLUSIONS

There is adequate time for escape of occupants for the severe fire scenarios considered.

It should be recalled that the original design included eight automatic smoke beam detectors, viewing from one end of the hall to the other, linked to an alarm. Each detector would be sited to 'beam' through aligned holes in the webs of the lateral steel beams which support the elevated floor panels. In this way, the smoke from a fire on the face of a filing cabinet would rise until it contacted the underside of the floor panel immediately above then spread laterally to interrupt the detector beam: thus the fire alarm would be given in the shortest possible time which would further reduce the pre-movement time and provide more time for escape.

The example calculations have indicated areas of uncertainty and the need for further appplication-led research which, it is hoped, will be undertaken as part of the review of DD 240 over the next two to three years. The author has indicated elsewhere[5] the kind of changes needed.

REFERENCES

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2. BSI. Draft for Development 180. Guide for the Assessment of Toxic Hazards in Fire in Buildings and Transport. BSI. 1989.
3. Babrauskas V and Mulholland G. 'Smoke and soot data determinations in the cone calorimeter', Mathematical Modelling of Fires, ASTM STP 983, ed Mehaffey J R, 1988. USA.
4. Babrauskas V, Private Communication, 18/1/1998.
5. Cooke G M E. 'So DD 240 has been published – what next?', Fire Safety Engineering, December 1997, p20-21.

FURTHER READING

1. SFPE 'Handbook of fire protection engineering, 2nd edition. Society of Fire Protection Engineers. Boston, Mass. 1995.
2. Cooke G M E. 'Developments in fire safety engineering', Proc of the Assoc of Building Engineers, Annual Conference, Buxton, 26-28 April 1995.

APPENDIX. SUMMARY OF THE DD 240 FIRE SAFETY DESIGN PROCESS

Conduct qualitative design review

- Establish fire safety objectives;
- review architectural design;
- characterise building, environment and occupants;
- establish evacuation strategy;
- identify acceptance criteria;
- identify fire hazards and possible consequences;
- establish trial fire safety designs;
- specify fire scenarios for analysis; and
- indicate appropriate methods of analysis.

Conduct quantitative analysis

- Use sub-systems (SS) as appropriate:
  - SS 1 fire growth/suppression
  - SS 2 smoke spread
  - SS 3 fire spread
  - SS 4 detection
  - SS 5 intervention
  - SS 6 evacuation;
- undertake sensitivity analyses; and
- apply engineering judgement.

Assess results against criteria

- if satisfactory, report and present results; and
- if unsatisfactory, repeat quantitative analysis using new trial fire safety design.