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MODELLING SMOKE MOVEMENT - THE PRACTITIONERS REQUIREMENT

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Introduction

In 1987 there were over 100,000 fires in occupied buildings, resulting in 900 fatal casualties and 12,000 non-fatal casualties (see [1]). In the majority of fatal casualties the cause of death was attributed to asphyxiation by smoke. Good building design and the use of fire protection systems minimise the hazard from a fire in a building. This is done by reducing fire and smoke spread with compartmentation; sprinkler systems and smoke control systems and maintenance of escape routes during a fire for a sufficient length of time to allow evacuation.

Modelling of smoke movement can be used to design and validate smoke control systems, predicting times to life threat given a fire scenario. Computer modelling of smoke movement can also be used to find the optimum locations for smoke detectors and sprinklers for early detection and extinguishing of a fire. At the early stages of fire growth, when detection should occur the problem is identical to modelling air movement within the building.

The Practitioners and the Law

The people most interested in modelling smoke movement can be divided into two groups:

(i) Fire safety engineers designing smoke control systems and
(ii) Building Control Officials who need to be satisfied that designs meet the requirements of the appropriate legislation.

The requirements of a building as regards fire safety are dependent on the type of buildings and are specified by the building regulations[2] in the form of "approved documents" and in certain circumstances by the Fire Precautions Act[3]. These may call apon documents such as BS

5588: Part 2 [4] and Part 3 [5] and CP3: Chapter 4: Part 1 [6] which deal with means of escape from shops, offices and some residential buildings respectively. The usual approach in these documents is to specify maximum travel distances allowed from any point in the building to the exterior of a fire and/or smoke resisting door protecting the next stage of the escape route.

Some building types are not covered by approved documents. A common reason being that a compartment exceeds the maximum allowed volume. In this case the building regulation stipulates the building designers must seek a "variation" or "relaxation" by showing an equivalent standard of safety to the usual rules by using other or additional methods of smoke control.

Models used to Analyse Smoke Movement

The models currently being used by fire protection engineers can be divided into two types:

(i) Zone Models and
(ii) Field Models

(i) Zone Models

Zone models are derived by assuming that the compartment and fire can be subdivided into zones, where each zone represents a particular feature of the fire. For example a fire in a compartment could in many circumstances be divided into the fire, thermal plume, homogeneous smoke layer, smoke outlets and air inlets (see Appendix A1). Links between zones are identified and simple models for interactions between zones are derived using correlations calculated from experiments, simplifying assumptions and conservation principles. A consequence of the simplifying assumptions and the subdivision of the compartment into zones is that zone models must be used with caution. The low accuracy of zone models is accommodated in the design of smoke control systems by overdesigning the system. Zone models vary in complexity from simple "back of envelope" expressions collected together in the form of a fire engineers calculator such as ASKFRS[7] or FIREFORM[8] to transient multi-compartment models such as FAST[9] and HARVARD VI[10].

(ii) Field Models

The application of field models to practical design problems is a comparatively recent development in the fire safety industry and represents the state of the art in smoke movement models. Field models are computer models based on the solution of partial differential equations derived from physical laws governing the conservation of mass, momentum, energy and chemical species. There are no assumptions necessary concerning air entrainment or smoke movement and no fire specific experimental correlations used. As there are no simplifying assumptions field models are more universal than zone models, being applicable to scenarios where zone models fail ie compartments with large floor areas and tall atrium type buildings. See Appendix A2 for an example of the application of a field model to a practical design. The advantages of field models over zone models are their universal applicability, accuracy and their ability to predict quantities locally throughout the compartment giving a realistic overview of smoke movement within a building. The disadvantage of field modelling is the computational cost. There are a number of field models commercially available, JASMINE[11] and CINA[12] being two models developed specifically for fire applications.

Conclusion

In this report a brief account of the practitioners and their requirements with respect to modelling smoke movement in buildings has been given. The two distinct modelling approaches used by the practitioners has been stated. Currently few smoke control system designers exploit computational methods of either type, being content with tables and simple expressions of the form given in appendix A1. However the more inovative are moving in that direction. The choice of which modelling approach to use depends on the type of building under construction and the computer facilities available. Where zone models apply they are probably the most cost effective. In situations where zone models fail the only option is to use a field model. The cost of using field models has reduced considerably with the increase in performance of computer hardware. The on going reduction in cost of using field models, and the increasing awareness of fire safety engineers of the application of field models suggests their use will increase within the fire safety industry.

References

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7. Chitty R and Cox G. ASKFRS BRE Microcomputer Package AP46 1988.

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10. Emmons H W. The Prediction of Fires in Buildings. 17^{th} Symposium (International) on Combustion. The Combustion Institute 1979, pg101

11. Cox G and Kumar S. Field Modelling of Fires in Forced Ventilated Enclosures, Combustion Science and Technology 52, pg7 1987

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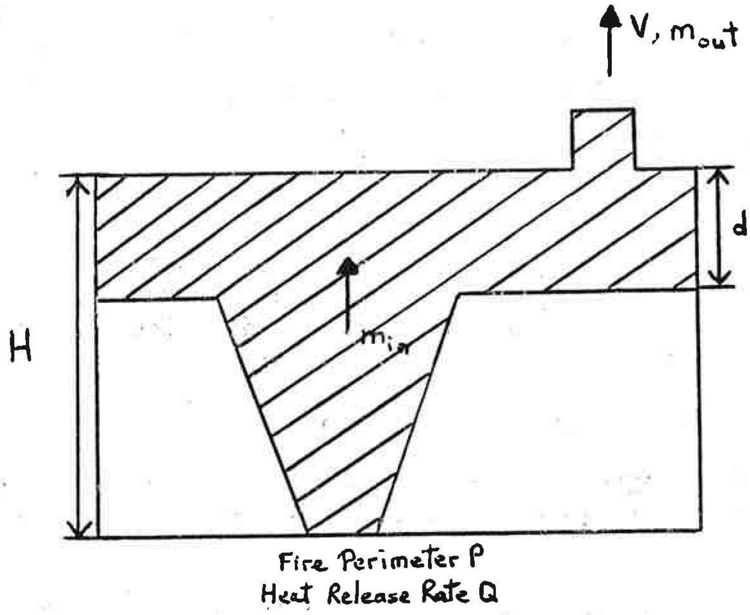
APPENDIX A1 - Example of a Simple Zone Model

Consider a small room with mechanical smoke extraction and a good supply of replacement air. The fire has a constant heat release rate Q and perimeter P. The fan providing the mechanical extract has a volume flow rate V. Heat losses to the boundaries and by radiation are neglected and the steady state has been reached.



Let the mass flow rate from the plume to the smoke layer be

$$m_{in} = 0.188P\,(H-d)^{1.5} \quad (1)$$

The mass flow rate extracted

$$m_{out} = V\rho\, T_{amb}/T_{lay} \quad (2)$$

where ρ is the density of air at ambient temperature T_{amb} and T_{lay} is the temperature of the smoke layer.

As there are no heat losses from the layer

$$T_{lay} - T_{amb} = \frac{Q}{m_{in}\, C_p} \quad (3)$$

where C_p is the specific heat capacity of air at steady state conditions. As the fire has reached steady state, conservation of mass gives

$$m_{out} = m_{in} \quad (4)$$

Using equations (1), (2), (3) and (4) the equations

$$V = (0.188P\,(H-d)^{1.5}\,C_pT_{amb} + Q)/(\rho T_{amb}\,C_p)$$

$$T_{lay} = Q/(0.188P\,C_p\,(H-d)^{1.5}) + T_{amb}$$

can be derived giving expression for the extraction rate V and the layer temperature T_{lay}. Clearly given a design fire and the maximum depth of smoke layer allowed the extraction rate required can be calculated

APPENDIX A2 - An Application of JASMINE

This appendix is a brief summary of an assesment of a smoke control system in a large atrium using the field model JASMINE. The shape and dimension of the building can be seen in figure 2 and 3. The assesment comprised a number of fire scenarios modelling the smoke detection system and the smoke extract system. Figure 2 and 3 show the location and final area of the fire in the simulation presented here. Initially the doors at ground level are closed and the smoke extract system is off. On detection of the fire the doors are opened and the extraction system is activated. The fires initial heat release is 0.1Mw with the heat release doubling every minute until the heat release reaches 3.2Mw after five minutes. The simulation then continues for several minutes with the heat release constant. The fire area increases as a function of heat release, growing in discrete stages.

Simulating fires in this way enables prediction of time to detection and time to hazardous conditions and hence time for evacuation. During this simulation the smoke detection system is activated after 65 seconds of the simulation. Results are restricted to the evolution of contours of temperature in figure 4 and optical density in figure 5 on the symmetry plane. Figure 4 and 5 show the deflection of the fire plume after activation of the smoke extract system and opening of the doors at ground level at t=65 seconds. The plume is deflected by the momentum of air entrained through the ground level doors.

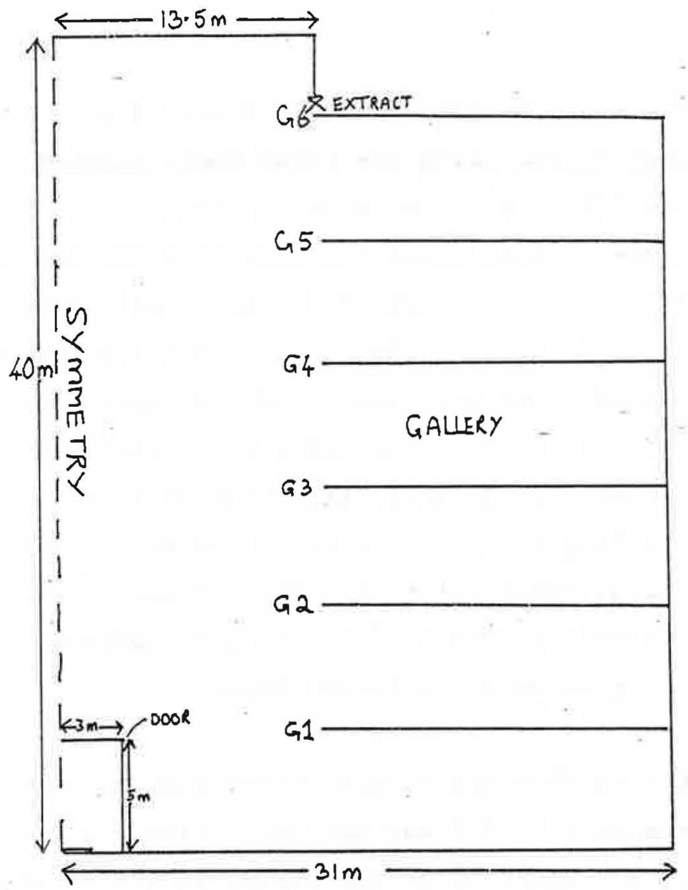


Figure 2 - Half cross-section of the atrium

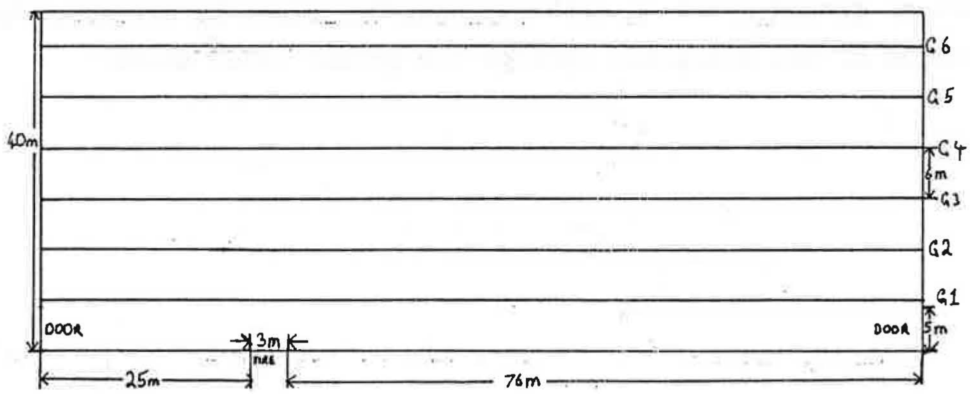


Figure 3 - Side view of the atrium

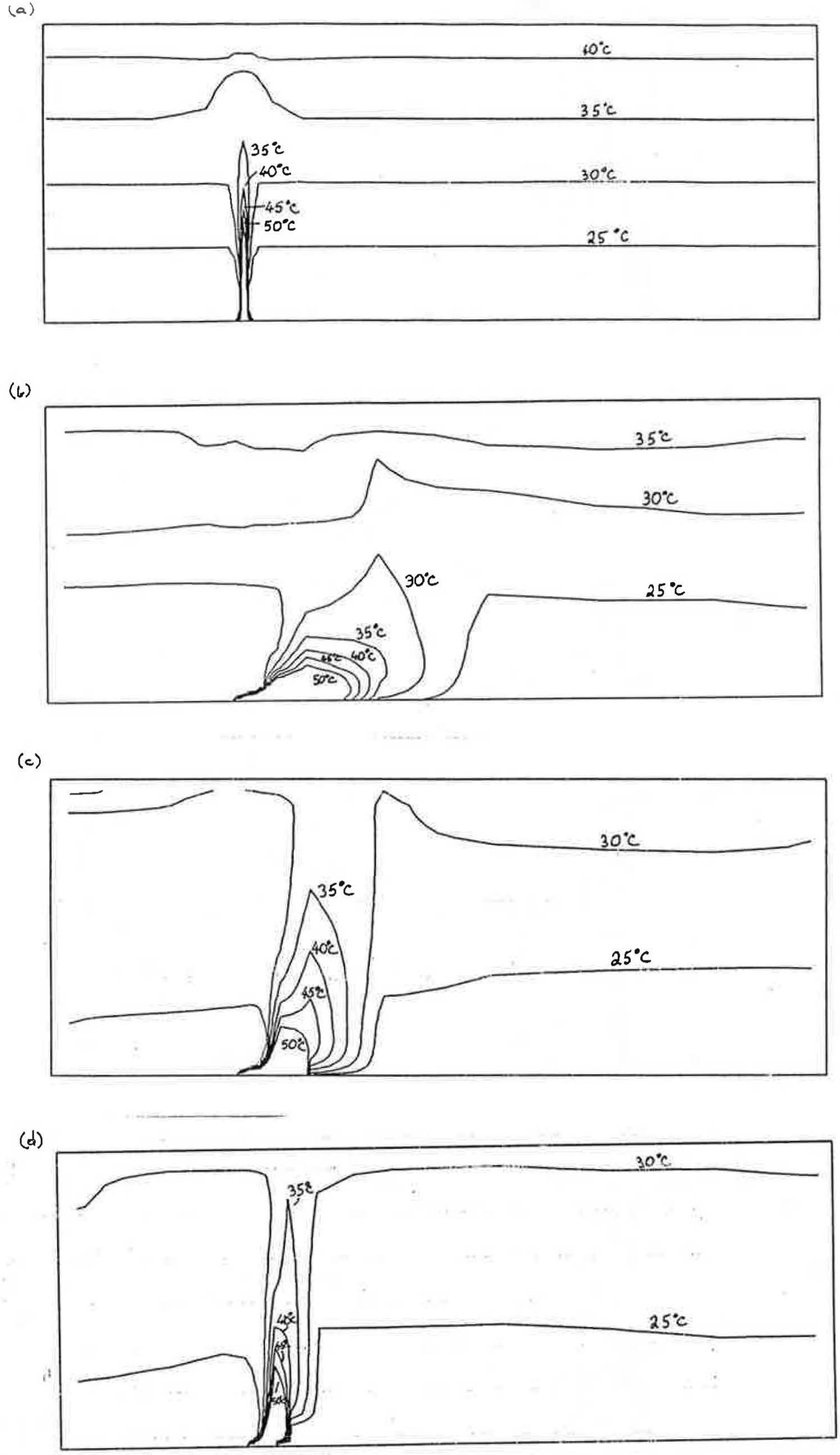


Figure 4 - Evolution of the gas temperature(C) on the vertical plane through the fire along the length of the atrium a)65 sec, b)270 sec, c)450 sec and d)600 sec.

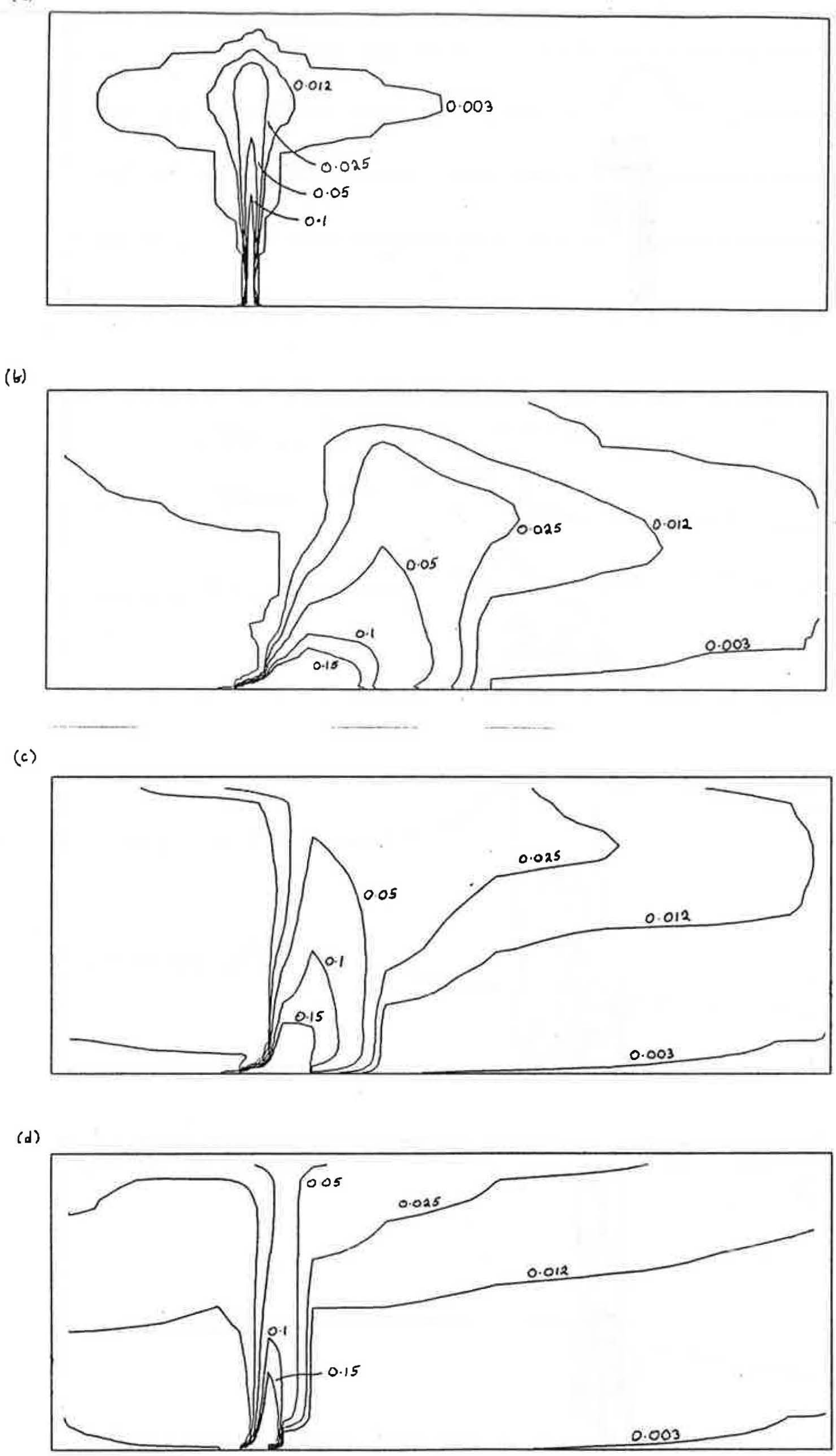


Figure 5 - Evolution of the optical density (OD/m) on the vertical plane through the fire along the length of the atrium a)65 sec, b)270 sec, c)450 sec and d)600 sec.