COLT

MECHANICAL VENTILATION OF FIRE-FIGHTING SHAFTS:

PERFORMANCE AND DESIGN

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1. INTRODUCTION

The recommendations for design of smoke control in fire-fighting shafts are given in Approved Document B to the Building Regulations, BS 5588-5 and BS 5588-4.

These recommendations cover several acceptable designs, specifically openable vents, shafts and pressurisation.

It is generally recognised that openable vent and shaft designs, while well established, are unreliable due to the possibility of adverse wind effects. Pressurisation systems overcome this problem but are avoided by designers due to their cost and complexity.

In 2002 the BRE published project report 79204, introducing a new, simplified shaft design. Due to its simplicity and effectiveness the BRE shaft has become a popular design option which has been accepted by many Building Control Authorities and Approved Inspectors as being an acceptable alternative to the recommendations of ADB and BS 5588-5.

The BRE shaft is a $3m^2$ shaft, open at the top and closed at the bottom, with inlets from the fire-fighting lobbies at each storey, closed off by automatic smoke dampers. In the event of fire, the damper on the fire floor is opened to provide natural ventilation to keep the lobby reasonably clear of smoke and prevent smoke entry into the stairs.

While the BRE shaft is an improvement over openable vents and previous shaft designs, the loss of over $3m^2$ floor area on each storey is a concern to building designers. There is therefore pressure to reduce the size of the BRE shaft. This has been achieved on an ad hoc basis for particular buildings either by using CFD analysis to demonstrate acceptable effectiveness or by providing mechanical ventilation by the addition of a fan at the top of the shaft.

The purpose of this project is to develop a standard design of mechanically ventilated shaft with a demonstrated effectiveness equal to the BRE shaft. This has the twin benefits of avoiding the need to re-invent the wheel for each project and of making it easier for Building Control to assess and approve designs.

2. Methodology

The BRE report provides a standard set of design requirements and provides some information on performance.

The starting point for this project was therefore to model a typical building (as used by BRE) with a BRE shaft. This was carried out using the FST CFD code, a freely available and widely used code developed for smoke control applications by NIST (National Institute of Standards and Technology, USA).

The building modelled was a 6 storey building with a straight 20m long corridor from the bottom of the stairs to the final exit door. Each storey had a simple fire-fighting lobby to the accommodation. An ultra fast growing fire with 2MW peak output was

used, occurring on the 1st floor. A shaft complying with the BRE design requirements was linked to the lobbies and an open $1m^2$ vent was fitted at the head of the stairs. The doors from the accommodation to the lobby, from the lobby to the stairs, from the stairs to the corridor and from the corridor to the exterior were all open and sized at $1.6m^2$.

The CFD code is time based. The model was therefore run for a period of 15 minutes on each run, providing sufficient time for conditions to stabilise. The results provided were taken from the final second of each run.

Initial modelling with doors open showed different results to those produced by BRE. Discussions with BRE staff led to modifications to the model and results consistent with the BRE report were achieved. These results then became the benchmark for performance requirements for alternative designs.

The model was then modified by reducing the size of the shaft to a nominal $0.6m^2$ and adding a fan to the top of the shaft. Extract rates equalling and exceeding the extract rate achieved by the BRE shaft were modelled, the aim being to achieve an optimum design. Lower extract rates were not comprehensively modelled since the BRE had already considered lesser designs and concluded that they were not sufficiently robust.

While the door open condition is the most critical, the system of course has to deal with conditions with the lobby doors closed as well. An obvious concern was whether the mechanical extract would tend to draw excess smoke into the lobby through gaps around the closed door to the accommodation. This condition was therefore also modelled, with the addition of a pressure relief damper in the shaft to limit lobby depressurisation to 25 Pa. The model took a worst case condition of a double door with $0.03m^2$ leakage area (from table D.1 of BS 5588-4). Due to the considerable leakage that occurred, a condition using a smoke seal door was also modelled, with a leakage area of $0.0007m^2$. All leakage was modelled as a single opening at the threshold. The adoption of a single opening was due to the difficulty CFD systems have of accurately dealing with slots that are significantly smaller than the grid size, such as the very small gaps that occur around the door.

3. Modelling results

The results of modelling five conditions are presented here:

a) BRE shaft
b) Mechanically ventilated shaft at [redacted], door open condition
c) Mechanically ventilated shaft at [redacted], door open condition
d) Mechanically ventilated shaft at [redacted], door closed condition, no smoke seals
e) Mechanically ventilated shaft at [redacted], door closed condition, with smoke seals

Figures 1 and 2 show the basic model in BRE shaft configuration.

3.1 BRE shaft

This was modelled in the door open condition only. The BRE report did not consider the door closed condition since under natural ventilation negligible flow up the shaft would be expected.

Figures 3 and 4 illustrate conditions and ventilation flows through the system.

Overall flow rates predicted by the model are:

Accommodation to lobby:	1.3 kg/s
Stair to lobby:	1.9 kg/s
Extract through shaft:	[redacted]

It should be noted that there is a degree of recirculation occurring at the accommodation to lobby door. The flow rate given is the overall net flow.

In common with the results from the BRE report, it can be seen that in the open door condition the system does not keep the lobby totally free of smoke but does largely contain the smoke in the upper region of the lobby.

3.2 Mechanically ventilated shaft at [redacted], door open condition

Figures 5 and 6 illustrate the conditions and flows through the system.

Overall flow rates predicted by the model are:

Accommodation to lobby:	2.0 kg/s
Stair to lobby:	1.4 kg/s
Extract through shaft:	[redacted]

In this case there is no recirculation through the accommodation to lobby door.

The overall extract flow rate is greater than that provided by the BRE shaft. The results show, however, that this increase is not beneficial. The system draws more smoke out from the accommodation and makes conditions worse in the lobby, with a deeper smoke layer and higher temperatures.

3.3 Mechanically ventilated shaft at [redacted], door open condition

Figures 7 and 8 illustrate the conditions and flows through the system.

Overall flow rates predicted by the model are:

Accommodation to lobby:	1.2 kg/s
Stair to lobby:	1.9 kg/s
Extract through shaft:	[redacted]

The flow rates match those provided by the BRE shaft. The results show that providing a mechanical extract rate to match the natural air flow rate of the BRE shaft provides virtually identical conditions.

3.4 Mechanically ventilated shaft at [redacted], door closed condition, no smoke seals

Figures 9 and 10 illustrate the conditions and flows through the system.

Overall flow rates predicted by the model are:

Accommodation to lobby	0.27 kg/s
Stair to lobby:	0.21 kg/s

In this condition the smoke leakage around the doors is sufficient to smoke log the lobby, even with the depressurisation limited to 25 Pa. The temperature within the lobby remains tenable.

3.5 Mechanically ventilated shaft at [redacted], door closed condition, with smoke seals

Figures 11 and 12 illustrate the conditions and flows through the system.

Overall flow rates predicted by the model are:

Accommodation to lobby:	negligible
Stair to lobby:	negligible

As a worst case smoke seals were modelled to all doors to the lobby, reducing the clean air intake from the stairs as well as the smoke intake from the accommodation. In this condition the smoke leakage around the doors is significantly reduced, keeping the lobby substantially smoke free.

4. Discussion

It is clear from the results that it is possible to provide a smaller mechanically ventilated shaft that provides equivalent performance to the BRE shaft and operates effectively under both door open and door closed conditions.

It is important that the mechanically ventilated shaft is not overrated since an increase in the design extract rate tends to draw excess smoke from the accommodation into the lobby, making conditions in the lobby worse.

Use of a mechanically ventilated shaft allows a significant reduction in the size of the shaft. The shaft modelled was 1/5 of the area of the BRE shaft. Although other shaft sizes were not modelled, it is not considered that the actual shaft size is critical, provided that the pressure drop down the shaft does not lead to significantly different flow and pressure conditions between lobbies.

For a mechanically ventilated shaft to also protect the lobby during the escape period prior to fire service arrival it is essential that the door between the lobby and the accommodation be fitted with smoke seals (S rated)

Wind effects were not modelled. However, BRE did model wind effects during development of the BRE shaft and concluded that the BRE shaft is less wind dependent than openable vents or alternative shaft designs. A mechanically ventilated shaft would be expected to have the same exhaust location as a BRE shaft and mechanical systems are generally less affected by wind. There is therefore no reason to presume that wind effects would be worse than for the BRE shaft.

For modelling purposes, the lobby depressurisation in the door closed condition was limited by pressure relief from the shaft. In practice use of this method requires large grille area to the lobbies and severely limits the number of storeys to be ventilated unless the shaft is oversized. Since the aim of pressure relief is simply to limit the depressurisation of the lobby a more practical method is to control the fan speed based on the lobby pressure.

The model showed maximum smoke temperatures in the lobby of less than 120°C. Since there is no current standard for this type of mechanical ventilation system there is no specific time/temperature rating for the fans. The nearest requirements, in BS 5588-4, are for fans used for accommodation air release. The specification therein is 300°C for 2 hours in a sprinklered building and 600°C for 2 hours if no sprinklers are fitted. However an accommodation air release system is designed to deal with undiluted smoke and heat extracted directly from the accommodation. The mechanical ventilation shaft deals with a mixture of smoke and heat from the accommodation and fresh air from the stairs. This dilution decreases the temperature the fans need to withstand, hence the low smoke temperature shown in the model. A time/temperature rating of 300°C is therefore considered suitable for this system.

5. Conclusions

A properly designed mechanically ventilated shaft system, following the design requirements specified in Annex A, is suitable for ventilation of fire-fighting shafts and is equal to or better than the openable vent or shaft systems recommended in Approved Document B and the BRE shaft.

Acknowledgements

Thanks to Ron Diaper and Geoff Whittle for their considerable input into the development of this report.

Figure 1 Isometric view of CFD model with BRE shaft

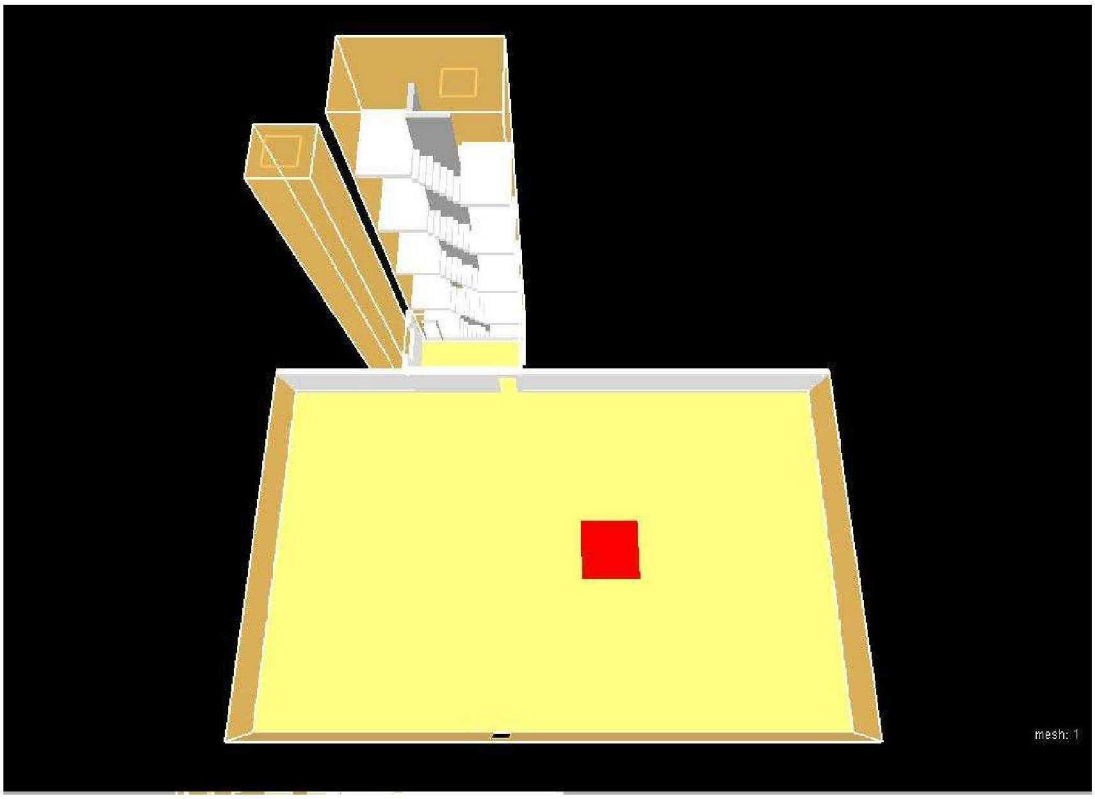


Figure 2: Isometric view of lobby and stairs

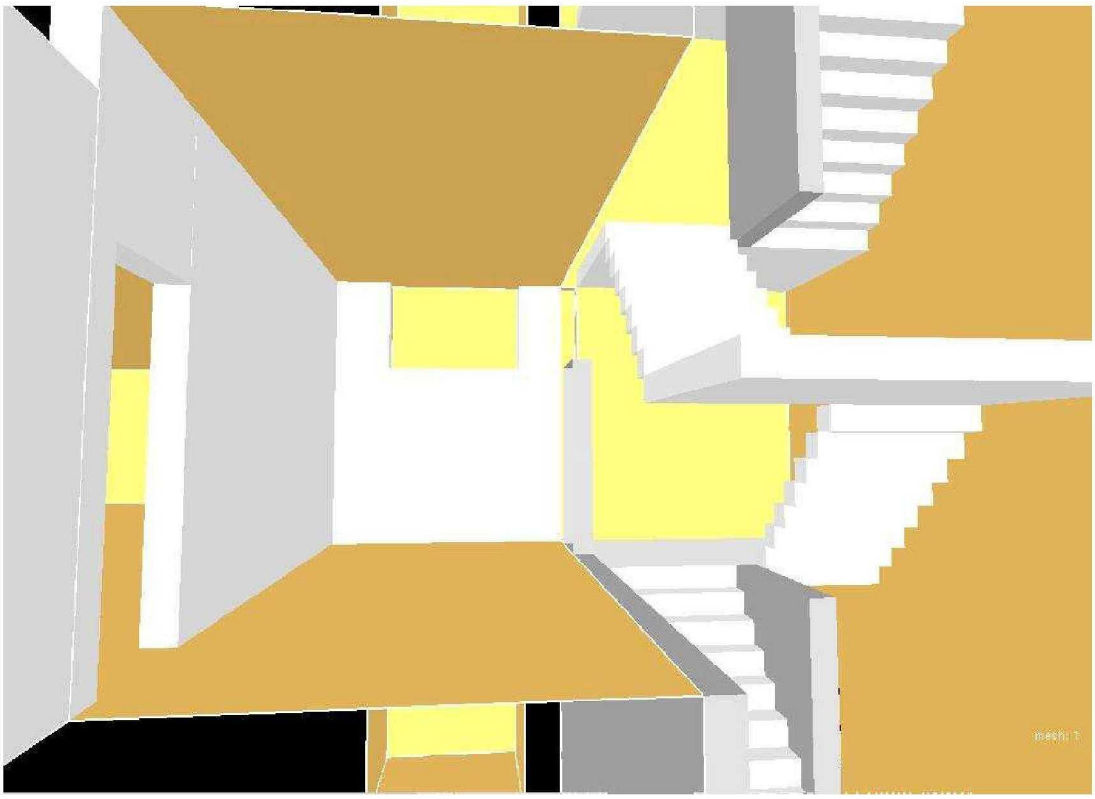


Figure 3: Slice through lobby showing visibility (BRE shaft, door open)

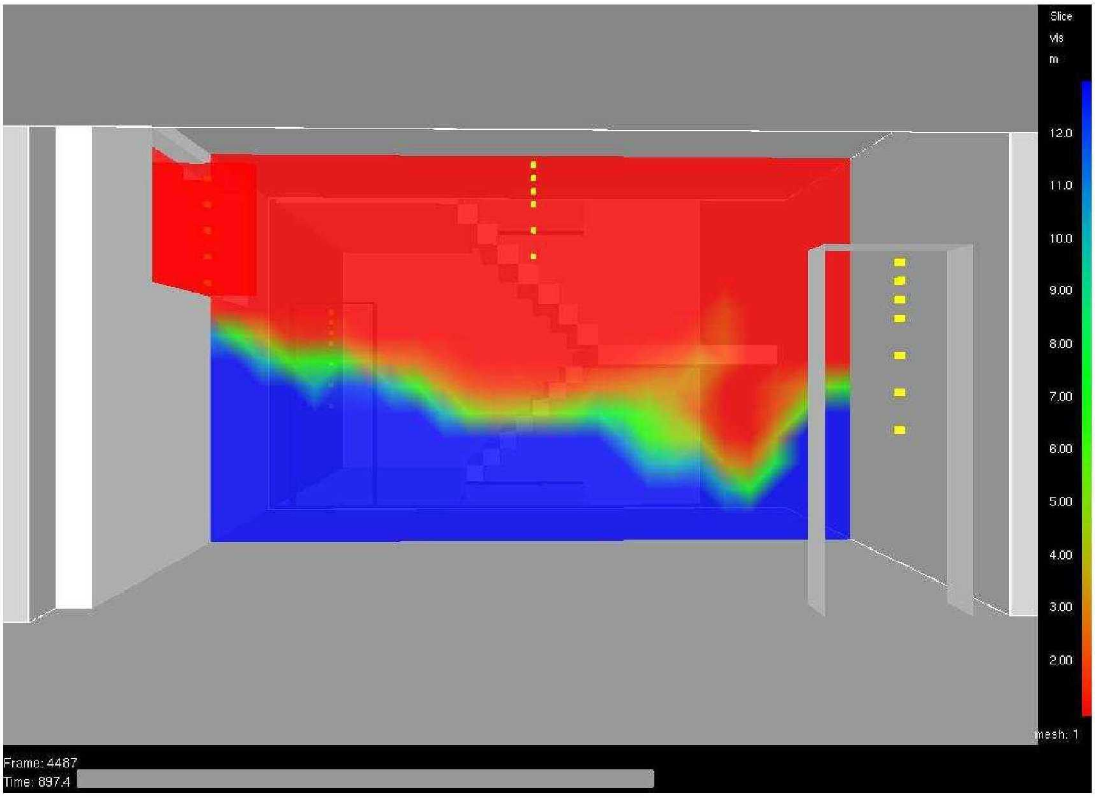


Figure 4: Slice through lobby showing temperature (BRE shaft, door open)

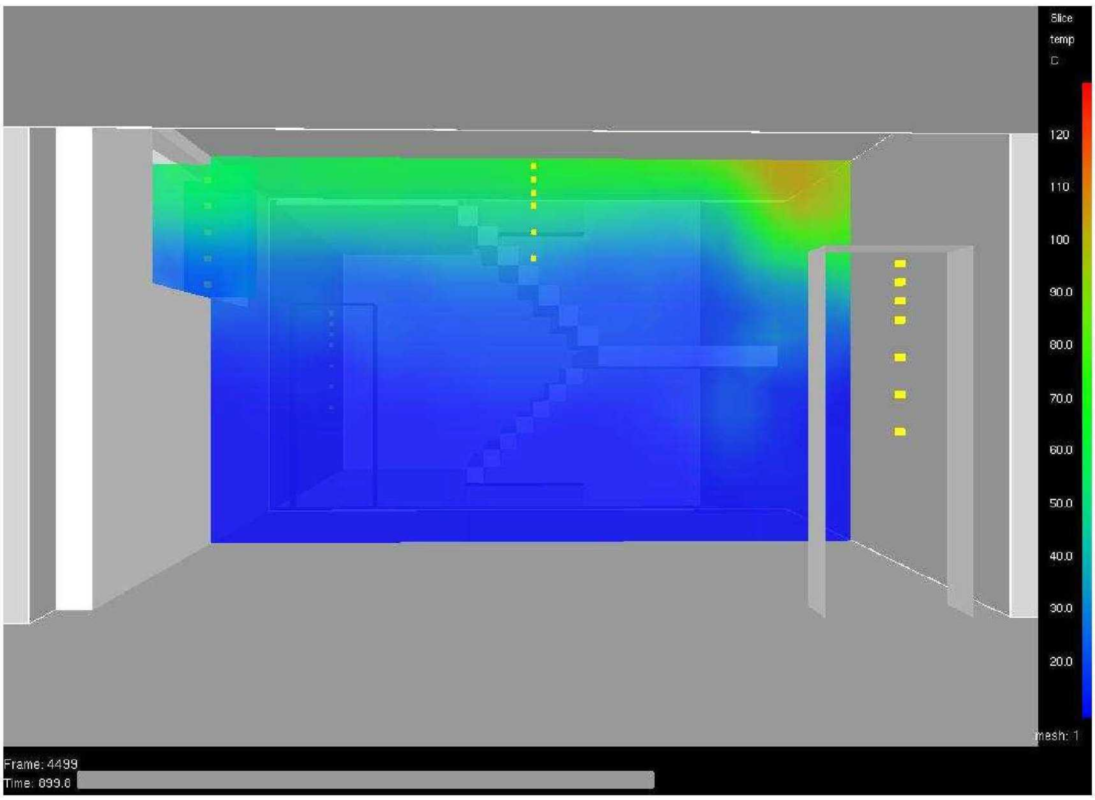


Figure 5: Slice through lobby showing visibility ([redacted] mech vent, door open)

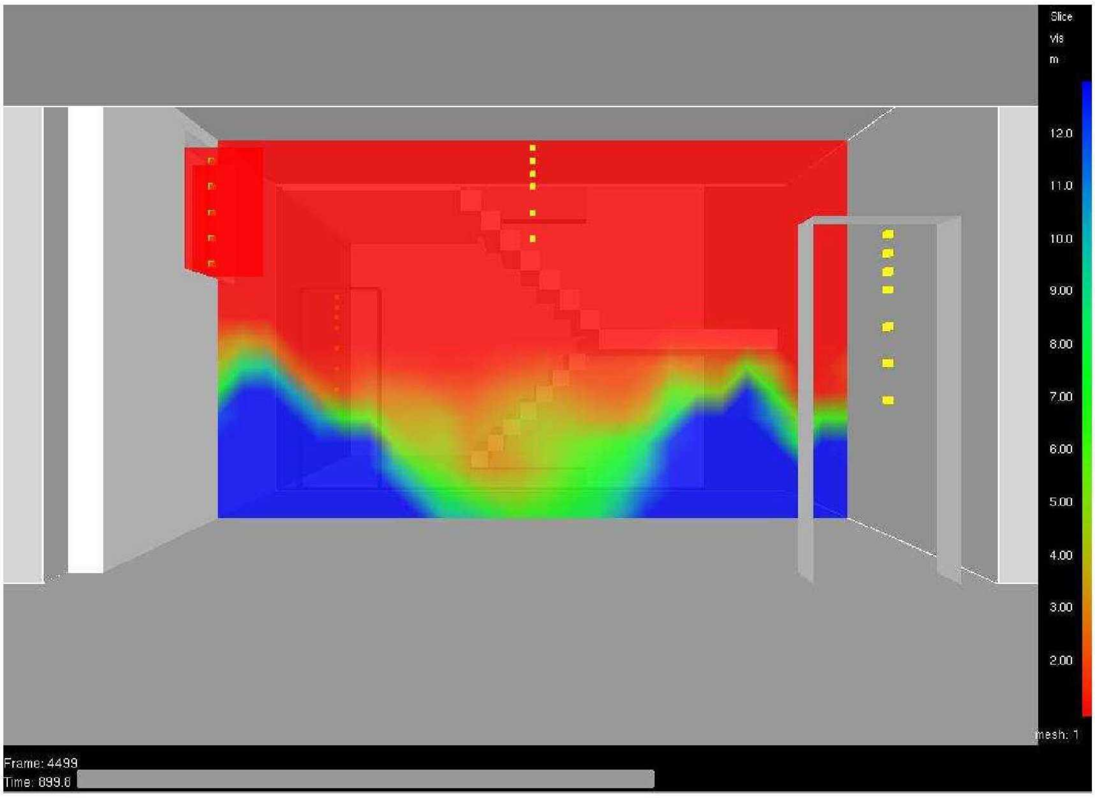


Figure 6: Slice through lobby showing temperature ([redacted] mech vent, door open)

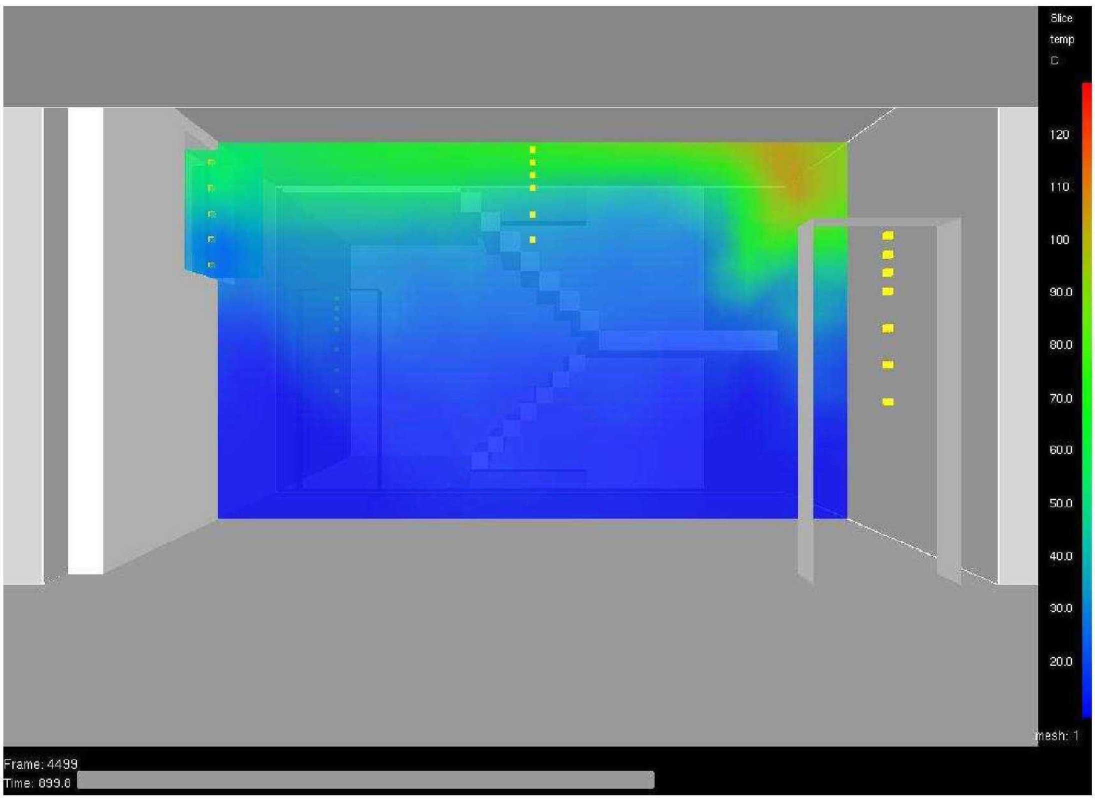


Figure 7: Slice through lobby showing visibility [redacted] mech vent, door open)

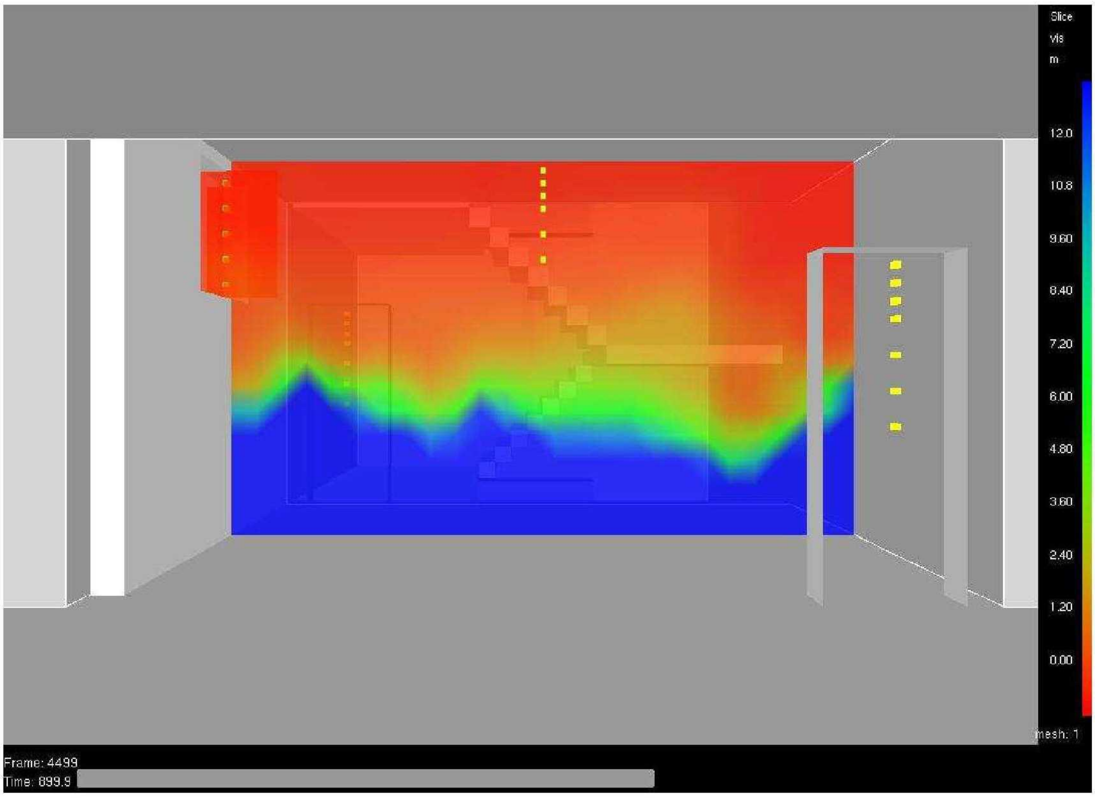


Figure 8: Slice through lobby showing temperature [redacted] mech vent, door open)

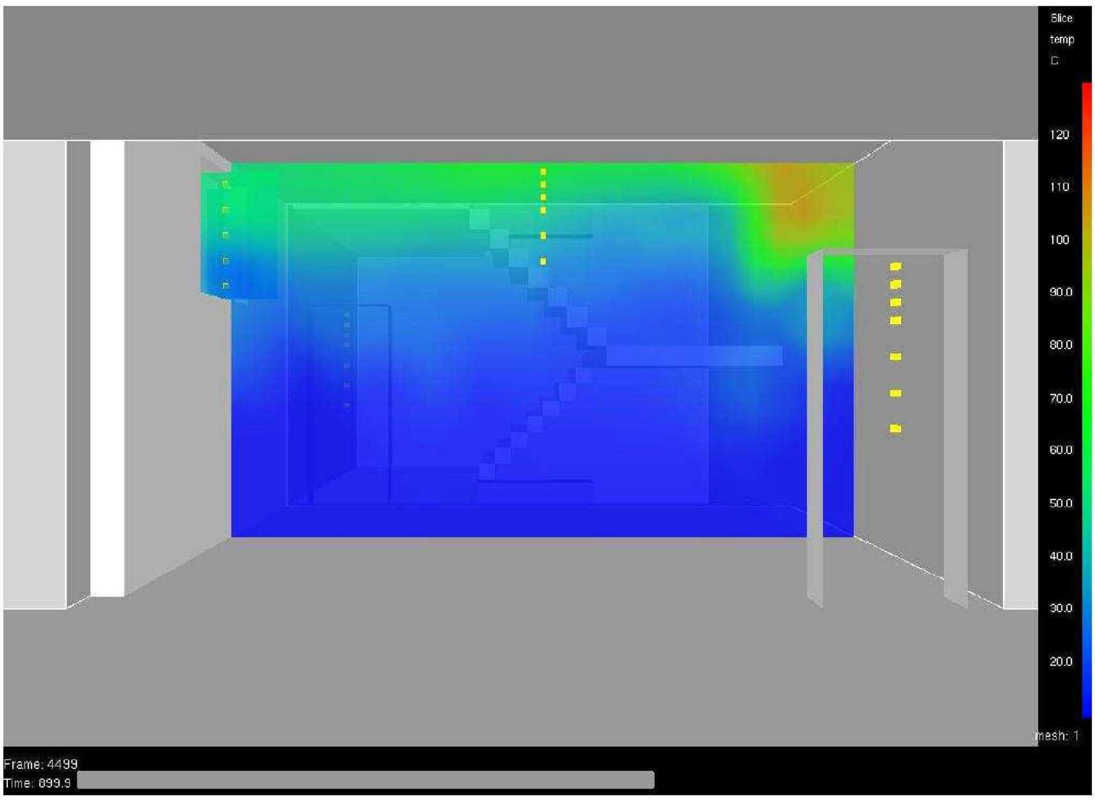


Figure 9: Slice through lobby showing visibility ([redacted] mech vent, door closed, no smoke seal)

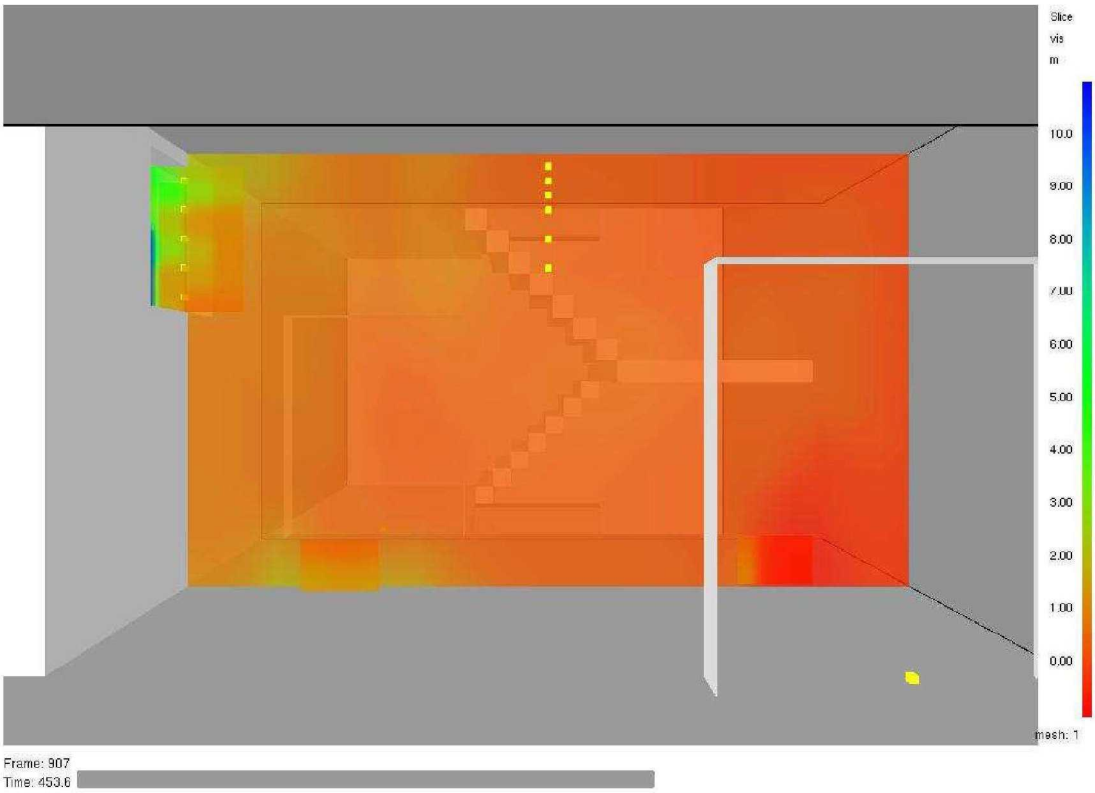


Figure 10: Slice through lobby showing temperature ([redacted] mech vent, door closed, no smoke seal)

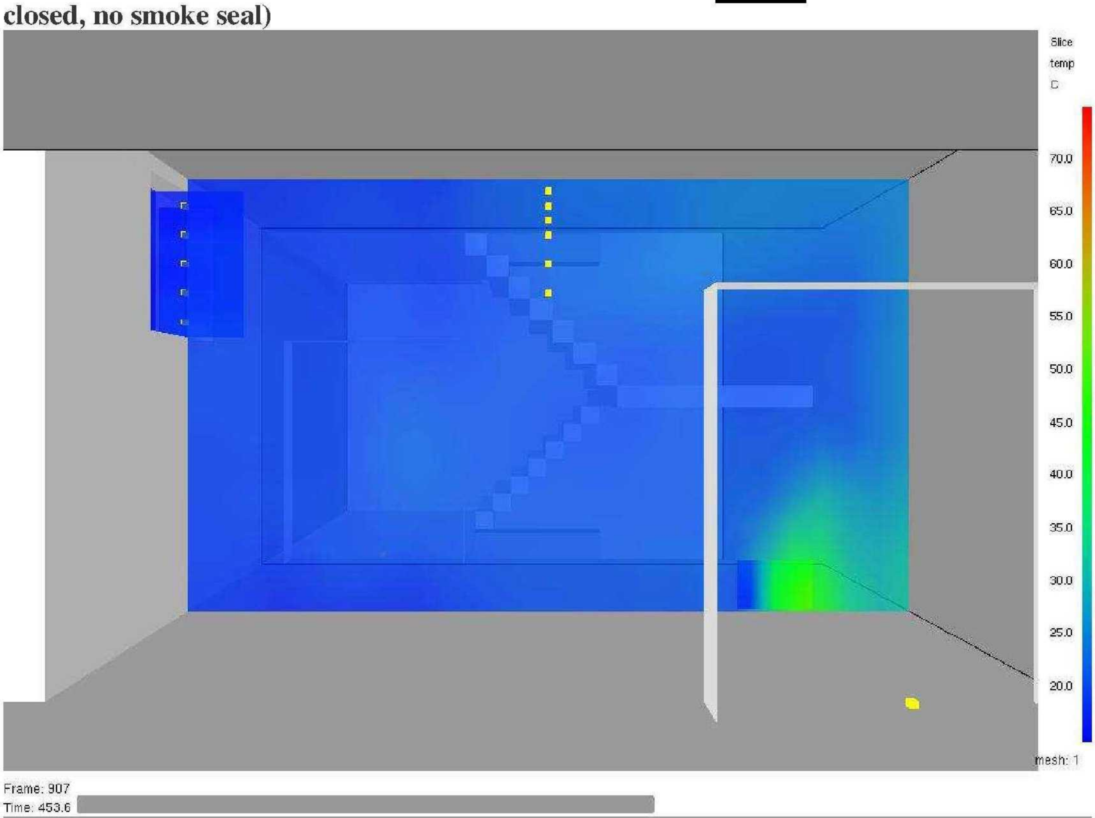


Figure 11: Slice through lobby showing visibility ([redacted], door closed with smoke seal)

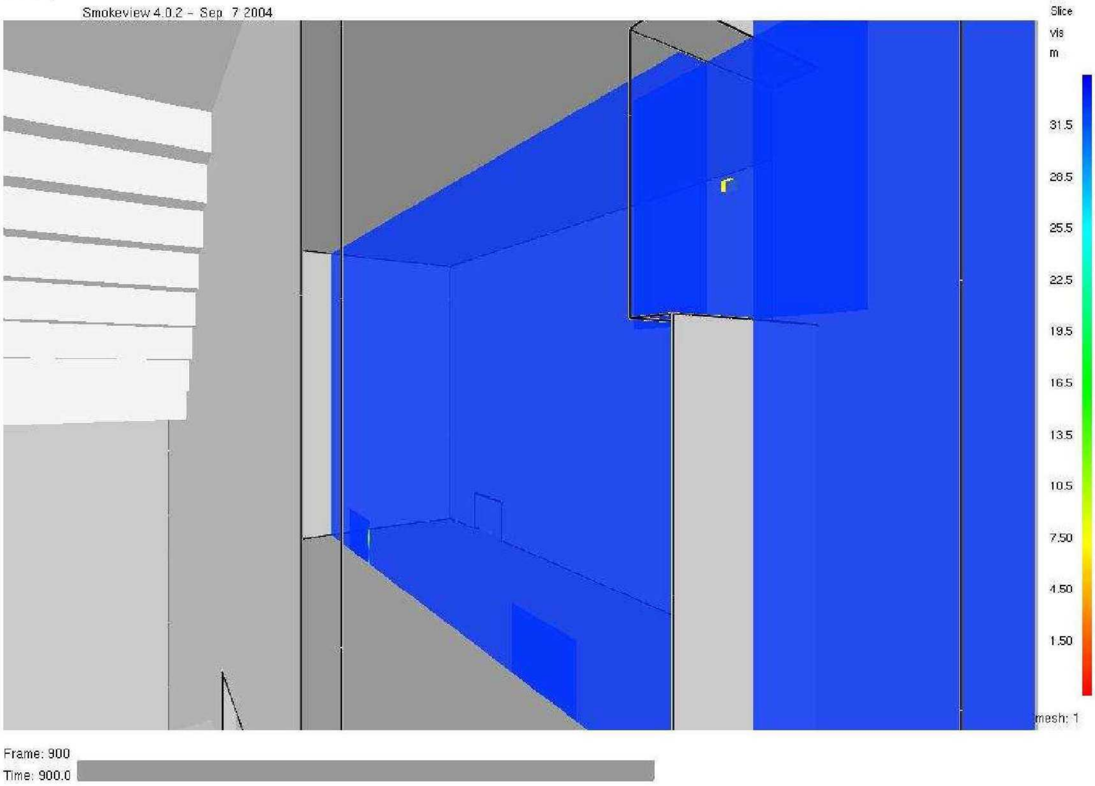
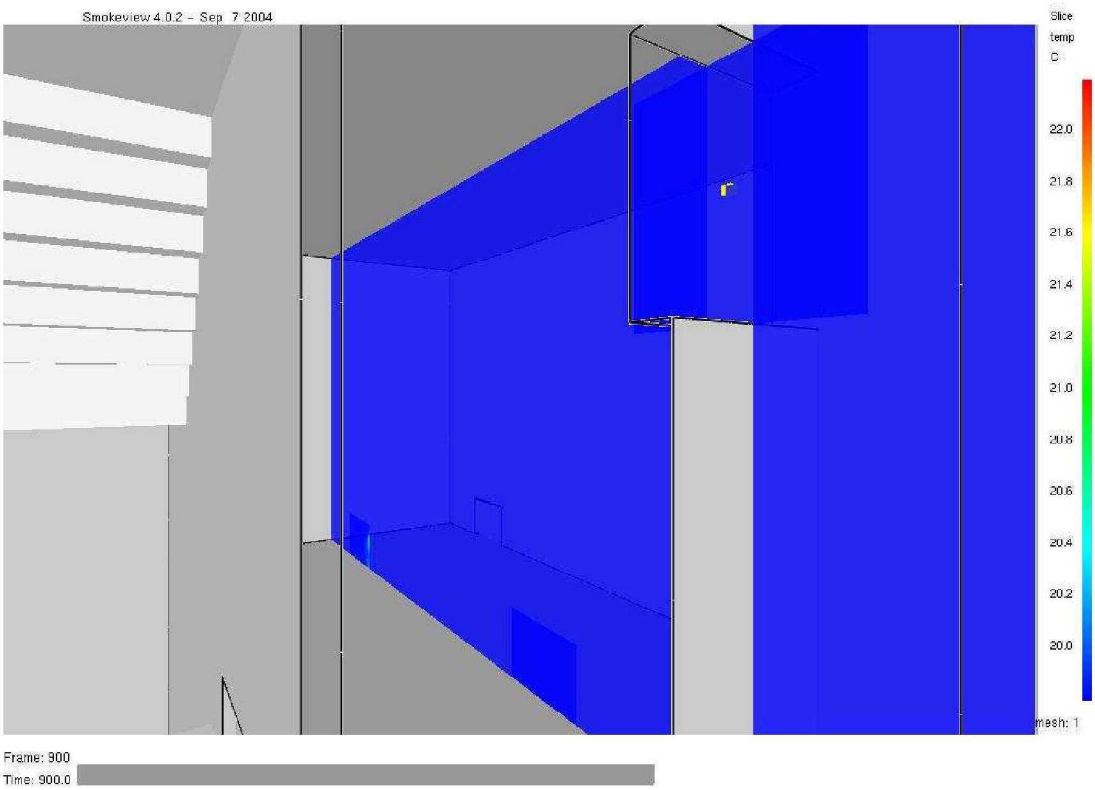


Figure 12: Slice through lobby showing temperature ([redacted] mech vent, door closed with smoke seal)



Annex A Design specification

The Colt mechanically ventilated shaft system comprises:

1	Vertical shaft located adjacent to fire-fighting lobbies. To be of fire rated construction. To be sized for a maximum pressure drop of 50Pa between highest and lowest storey served. Nominal size 0.6 m^2 for buildings up to 30 m tall.
1	Extract fan set comprising duty and standby fans with automatic changeover. Fans to be rated to operate at 300°C for 2 hours. Extract flow rate to be [redacted].
1	Seefire smoke ventilator as weatherproof termination to shaft. Alternative ventilators conforming to the requirements of BS 7346-1 or BS EN 12101-2 may be used.
1/storey	Automatic smoke damper, drive open / drive closed or fire door with Colt Doorman control. Minimum geometric area 0.8m^2. To be located in the shaft wall to the lobby, as high as possible in each lobby.
1	Stairwell ventilator with a geometric area of 1m^2, located at the head of the stairs.
1	Control system incorporating pressure sensing and smoke detection on each storey, with pressure sensors and smoke detectors located in the lobby. In the event of fire the system will open the stairwell ventilator, the shaft termination ventilator and the damper/door on the fire floor and start the extract fan. If the pressure in the lobby on the fire floor drops below –25Pa the fan slows on inverter control. Fireman's override to be installed at the base of the stairs, or other location agreed with the Fire Authority.

A maintained power supply is required in accordance with the requirements of BS5588-5.

The fire door between the lobby and the accommodation is required to be smoke sealed (S rated).