



Technical Submittal
Hotel Smoke Extract Stairwell CFD

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Executive Summary

The purpose of this technical submittal is to provide the reader with an overview of the smoke ventilation scheme CFD

Appendix A - Basis of Design

- NSE-MEE-NS-XX-TS-Z-008002, MCFC Redevelopment Mechanical & Public Health Services Specification, P01
- NSE-MEE-ZZ-XX-TS-E-008002, MCFC Redevelopment Electrical Services Specification P01

Appendix B - Manufacturers Details

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Appendix C - Technical Literature

As per technical data attached - see appendix H.

Appendix D - Compliance

In line with the mechanical specification and equipment schedule:

NSE-MEE-NS-XX-TS-Z-08001

NSE-MEE-NS-XX-LS-M-008312

Appendix E - Non -Compliance

N/A

Appendix F - Programme

The Purpose of this technical submission is to inform the Etihad client team and professional team of SES intent regards to procurement of systems and equipment to enable input into the MEP design and therefore complete the systems MEP design.

The Technical submission is by no means intended to show full systems design by the way of MEP design drawings and schematics.

Drawings and Schematics will follow once technical submissions have reached A or B status and the technical information from within the approved submission has been inputted into the MEP design.

Appendix G - Drawing Reference

N/A

Appendix H - Attachments

Etihad Hotel SMOKE EXTRACT SYSTEM CFD Technical
Submission Technical Submission NSE-SEE-HT-ZZ-TEC-M-
601002 -P01



CFD Report

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Report for a CFD Analysis of a Smoke Control System in Fire-fighting Lobbies

Etihad

Hotel

NSE-SEE-HT-ZZ-TEC-M-601002

Revision P01

Prepared For:
SES

28th March 2025

Gavin Walker BEng (Hons)
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Issue	Date	Reason	By	Approved
P01	28 th March 2025	First Issue	G. Walker	R. Diaper

1. Introduction

This report describes the Computational Fluid Dynamics (CFD) analysis that has been carried out of the smoke control system to be installed within the Hotel fire-fighting lobbies of the Etihad development in Manchester. The development is a stadium to host sports and concert events. The Hotel building extends from ground to 5 upper floors.

Approved Document B (Fire Safety) to the Building Regulations (ADB) recommends that buildings with an occupied floor 18m or more above or 10m below fire service access level should be provided with a fire-fighting shaft ^[1]. In the event of a fire in the building, a fire-fighting shaft allows quick and safe access for firefighters to enter the building and conduct fire-fighting activities. Normal protocol is for the firefighters to set up a bridgehead, typically one or two floors below the fire floor, and tackle the fire from the fire-fighting lobby on the fire floor. According to the Fire Strategy, Stair 2 and Stair 3 will be the fire-fighting shafts.

Further guidance within BS 9999:2017 recommends that measures are put in place to ensure that the use of fire-fighting shafts is not restricted by smoke ^[2]. Therefore, a smoke control system is required to provide protection against smoke entering the stairwell. Four types of smoke control system are described in BS 9999:2017; pressure differential systems, mechanical smoke ventilation systems, natural ventilation using shafts and natural ventilation using Automatic Opening Ventilators (AOVs). It is proposed to use a mechanical smoke ventilation system in this building. BS 9999:2017 recommends that the performance of mechanical smoke ventilation systems is proven through CFD analysis ^[2].

The CFD modelling has assessed the temperature and visibility conditions in the stair and lobbies during the escape and fire-fighting phases. Acceptance criteria were determined after review of guidance and recommendations contained within the ADB, British Standards, Smoke Control Association publications and project specific specification documents.

2. Modelling Approach

2.1 Acceptance Criteria

The performance requirements of mechanical smoke ventilation systems that are used to protect fire-fighting shafts are described within BS 9999:2017. It recommends that the mechanical smoke vent system should provide conditions that are as good as, if not better, than the conditions that would be provided by a natural shaft as described in BRE Project Report 79204^[2]. Further guidance suggests that “The primary objective of the system should be to maintain smoke-free conditions in the staircase during both means of escape and fire-fighting operations.”

Therefore, the acceptance criterion for the system is that the conditions provided by the mechanical smoke ventilation system should be at least equivalent to, if not better than, those provided by the natural shaft system.

Conditions were measured in terms of visibility and temperature within the fire-fighting lobby and stairwell. Temperatures were measured at 1.5m above floor level as recommended in the Smoke Control Association (SCA) guide ^[3].

The performance objective of the system is to prevent smoke entering the stair. However, it is possible for the system to not meet this performance objective but still meet the minimum acceptance criteria. There is no defined limit on visibility within stairwells so the SCA guidance of 10m visibility as being an acceptable lower limit. The stair is approximately 2.6m wide by 5.2m long. If any smoke does enter the stairwell a lower limit of 10m visibility will ensure that occupants can still see the entire stairwell and should not hinder their movement throughout the building.

To ensure that occupants of the building are still able to open doors to make their escape it is essential that door opening forces are kept to a suitable level. BS EN 12101-6:2005 recommends that the maximum door opening force for a pressure differential system is 100N ^[4]. This is based on systems where the maximum pressure differential across a door is 55Pa. Therefore, at no point during the simulation should the pressure differential between the fire compartment and the fire-fighting lobby and between the fire-fighting lobby and the stairwell exceed 55Pa.

2.2 Scenario Selection

In order to ensure that the simulation is representative of a real scenario that could occur within the building it is necessary to evaluate all possible scenarios to determine which are the ‘worst case’ scenarios. If the smoke control system can meet the acceptance criteria when subjected to the ‘worst case’ scenario it can be determined that it would meet the acceptance criteria in any other, less onerous scenario.

When considering a smoke control system that is used to provide protection to the fire-fighting stairwell, the ‘worst case’ scenario is the scenario in which it is most difficult to prevent smoke from entering the stairwell. There are a number of factors to be considered which may make a fire in a particular location more or less onerous than fires in other locations. Factors to be considered include;

- The location of fire compartment doors in relation to the stairwell door.
- The volume of the fire compartment.
- Proximity to the head of stairwell ventilator.

It is essential to ensure that the smoke control system can prevent smoke from entering the stairwell during the fire-fighting phase. When the firefighters open the door to the fire compartment smoke and heat that has built up in the compartment between the escape and fire-fighting phases is released into the corridor,

often at high velocity. To prevent the heat and smoke from entering the stair the smoke control system must counter this before it reaches the stairwell. The 'worst case' scenario for protecting the stair will be a fire located in a compartment that is closest to the stairwell as it provides the least opportunity for the smoke control system to prevent smoke entering the stairwell.

The design fires used for CFD simulations of smoke control systems do not vary with compartment size, unless the compartment is too small to accommodate a fully developed fire. The volume of smoke and heat generated by the fire will be the same. This is to ensure repeatability and also to allow comparisons to be made between different scenarios. Smaller fire compartments will fill with smoke more rapidly than larger compartments and can result in larger volumes of smoke entering the corridor. It is therefore important to consider fire compartment size as smaller fire compartments can provide more onerous conditions than larger fire compartments.

A fundamental operating principle of mechanical smoke extract systems is that fresh air is drawn from the stairwell when the door to the stairwell is opened. This is achieved by depressurising the corridor in relation to the stairwell so that when the door is opened fresh air can be drawn into the corridor via the stairwell and the AOV at the head of the stairwell. It is therefore necessary to consider the distance between the fire affected floor and the head of stairwell AOV. On floors which are more remote from the head of stairwell AOV the smoke control system will have to overcome greater resistance to airflow due to the stairwell than on floors which are closer to the head of stairwell AOV.

A study of the building was carried out to assess the worst case scenario. One location has been identified. A fire located in GR Twin Room A1 2.055 on Level 02 was modelled because:

- Level 02 is the furthest level from the head of stair vent containing hotel rooms.
- Apartment 2.055 is the apartment most directly opposite a lobby door across the hotel development and the most opposite a stairwell door, making it the most onerous to keep smoke out of the stairs.

The layout of Level 02 is shown in Figure 1. The stairwell is shown in green, corridor in orange fire-fighting lobby in blue, the hotel room in red and the smoke extract shaft in pink. The fire was positioned in the location of the beds as these are the most likely fire source within a hotel room.



Figure 1: Level 02

3. Model Details

3.1 Background Information

The simulations must be representative of a real scenario that could occur within the building. It is therefore important that the 3D model that is produced for the simulation reflects the geometry of the building that it is intended to represent. A number of sources of information were used to obtain data for producing the 3D model, including architects layout drawings and sections and the project specific fire strategy. This information was then incorporated into the 3D model to reflect the actual geometry of the building following the interconnecting grids as a guide.

Information and details were obtained from the following sources:

- Artec Fire:
 - Fire Strategy Report:
 - 00258_MCFC Hotel_ Stage 5 Fire Safety Strategy_Rev.01_240718
- Populous:
 - General Arrangement Plan:
 - NSE-POP-HT-02-DP-A-000122_C02
 - Section:
 - NSE-POP-HT-ZZ-DR-A-000244_Proposed Hotel Sections N-S & E-W_A5_C01

3.2 Modelling Software

The CFD software used for this analysis was Fire Dynamics Simulator (FDS 6.7.9) from the National Institute of Standards and Technology, United States Department of Commerce (See Appendix A).

The model consists of a number of interconnecting grids which define the extent of the simulation domain. The grids cover areas of the building which are key to the outcome of the simulation such as the stairwell, lobbies and smoke extract shafts. Additionally a single floor was included as the location of the fire.

3.3 Mesh Resolution

It is widely acknowledged that mesh and cell sizes have a significant effect on the accuracy of the results of a CFD simulation. One that uses a finer mesh with a smaller cell size will produce more detailed results than a simulation that uses a much coarser mesh with a larger cells. It must also be recognised that using a smaller cell size increases the number of cells in the model so will increase the time taken to complete the simulation.

Therefore it is important that a cell size is used that allows for an appropriate level of detail within the results and also does not result in unnecessary long run times. A recommendation is made within the FDS User's Guide that a 100mm cell size may be "adequate" for assessing the spread of smoke through a building^[5]. The suitability of cells of this size can be assessed using the calculations for Plume Resolution Index given within the FDS Validation guide^[6].

$$\text{Plume Resolution Index} = \frac{D^*}{\delta x}$$

Where: D^* is the characteristic fire diameter in metres.
 δx is the cell size in metres.

The characteristic fire diameter is given by the equation in the FDS User's Guide^[5]:

$$D^* = \left(\frac{\dot{Q}}{\rho_{\infty} c_p T_{\infty} \sqrt{g}} \right)^{\frac{2}{5}}$$

A range of values of D^*/dx between 4 and 16, where 4 represents a coarse mesh and 16 a fine mesh, are commonly regarded as acceptable.

When calculated based on a cell size of 100mm D^*/dx equals 4.174132, if the heat release rate of the fire is 125 kW. As the value D^* increases as the total heat output of the fire increases it can be concluded as long as the heat output of the fire is at least 125 kW a 100mm cell size is appropriate for the simulation.

In areas of the model that are remote from the fire and are less significant to the outcome of the simulation, a coarser cell size of 200mm shall be used.

3.4 Input Parameters

The building will be fitted with a sprinkler system. Therefore a sprinkler controlled fire was used for the simulation. The fire was modelled with a heat release rate per unit area of 250 kW/m² in accordance with BR368 recommendations. However, the total area of the fire is limited to the area when the sprinklers around the fire have operated. The fire was modelled as a growing fire, following a medium growth rate t^2 curve. The overall heat release rate will continue to follow the t^2 curve until two sprinklers have activated. If the sprinklers do not activate, the fire will reach peak heat output at 208s.

As sprinkler information was not available at the time of modelling, sprinklers were positioned in the model 4m apart as far from the centre of the fire as possible. The sprinklers included within the model had volume flow rate of 50 litres/minute and activated at 72°C, with an RTI of 80. The second sprinkler to be activated was activated at 143 seconds therefore the heat release rate of the fire was limited to approximately 240kW. Figure 2 shows the resultant heat release rate.

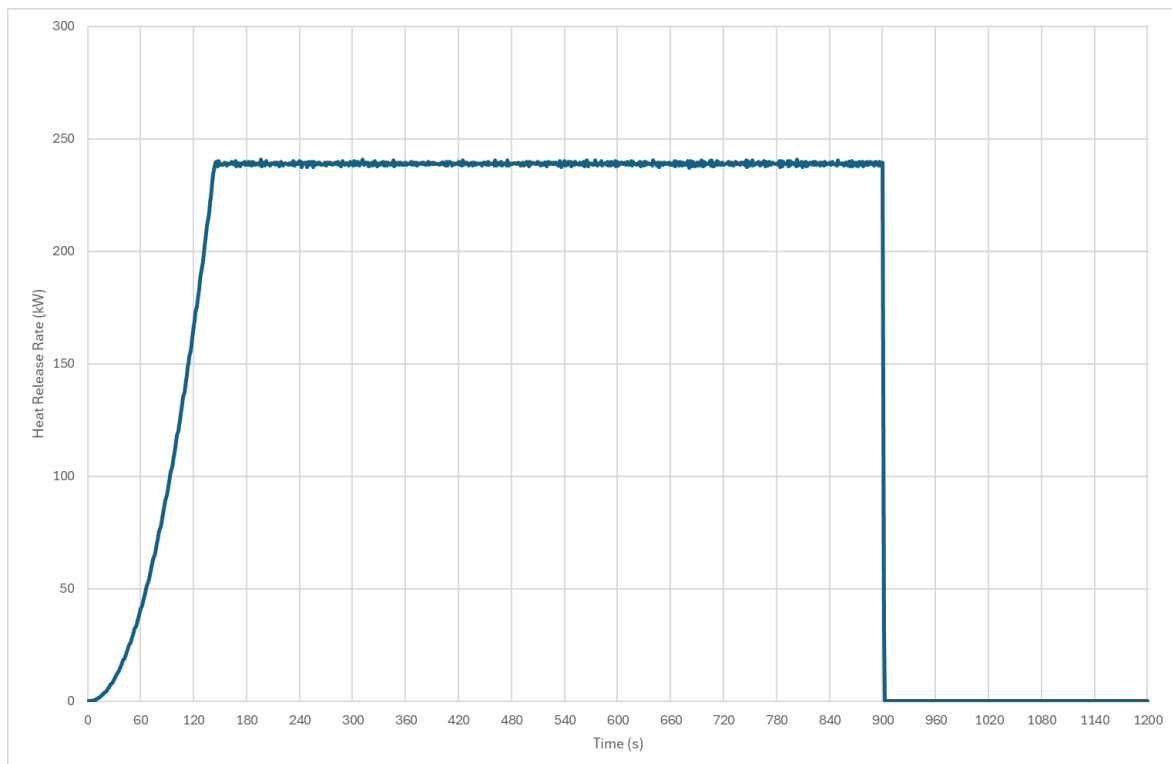


Figure 2: Resultant Heat Release Rate

A polyurethane fire with a soot yield of 0.1 (10%) was used. Visibility factors are based on distances to light reflective signage. By default, FDS assumes that soot is transported just like all other gaseous species. That is, the soot particles are small enough that their settling velocity is small compared to the fire-driven flows of the gas containing the soot. Deposition cannot be defined using the mixture fraction model.

Single-Step Mixing-Controlled Combustion was enabled. This approach to combustion considers a single fuel species that is composed primarily of C,H,O, and N that reacts with oxygen in one or more mixing-controlled steps to form H₂O, CO₂ and soot.

3.5 Fire Compartment Ventilation

In order to sustain combustion within the CFD model it is necessary to provide ventilation to the fire compartment outside to ensure that combustion continues without the fire being completely starved of oxygen. Due to this, a low level vent was provided from the fire compartment to outside to ensure that combustion continues without the fire being completely starved of oxygen.

3.6 Leakage

It is expected that the lobbies on-site will not be perfectly sealed. There is likely to be leakage from a number of sources including other fire doors, lift doors and general leakage through the construction. To account for this leakage areas were specified for the fire doors and lift doors. Following the guidance within BS EN 12101-6:2005^[4], the following leakage areas were set:

- Single leaf door opening into the corridor – 0.02m²,
- Single leaf door opening out of the corridor – 0.01m²,
- Double leaf doors – 0.03m²,
- Lift shaft doors – 0.06m².

3.7 Ventilation System

Two models are presented, a model of a BRE natural smoke shaft representing the code compliant solution and a model of a Colt Shaft Variable representing the proposed mechanical solution.

BRE Natural Smoke Shaft – Code Compliant Smoke Control System

The BRE natural smoke shaft consists of a single 3m² vertical shaft, connected to the fire-fighting lobbies on each floor via a 1.5m² free area lobby ventilator. The shaft has a 2m² free area ventilator at the top. In event of a fire the lobby ventilator on the floor where the fire was detected will open as well as the ventilator at the top of the shaft. Fresh air will be drawn from the stairwell when the door to the stairwell is opened.

The stairwell is provided via a 1.0m² ventilator from the top storey to outside.

Colt Shaft Variable - Proposed Mechanical Smoke Control System

The proposed mechanical smoke control system consists of a single vertical shaft, connected to the fire-fighting lobbies on each floor via a 0.6m² free area lobby ventilator. The shaft has a set of run and standby axial fans to extract smoke from the lobbies. In event of a fire the lobby ventilator on the floor where the fire was detected will open and the fans will begin to ventilate the lobby. The extract rate used for the simulation was 3m³/s. Fresh air will be drawn from the stairwell when the door to the stairwell is opened. To ensure that the lobby does not become over-depressurised the smoke extract fans will slow down when the door to the stairwell is closed. A differential pressure sensor monitors the pressure difference between the lobby and stairwell and adjusts the speed of the fan accordingly.

The stairwell is provided via a 1.0m² ventilator from the top storey to outside.

3.8 Simulation Timeline

From the initiation of the fire through to completion, the simulation follows a set timeline. The events in the timeline, represent the ignition of the fire and evacuation of the occupants of the fire compartment. Guidance has been taken from PD 7974-6:2019 with respect to the travelling speed of occupants ^[7]. It has been assumed that occupants will travel at 1 m/s whilst escaping from the fire compartment.

The distance between the hotel room door and the door to the lobby is 2m, therefore the lobby door will open 2 seconds after the hotel room door opens. The distance between the lobby door and the door to the stairs is 5m, therefore the stair door will open 5 seconds after the lobby door opens ^[7].

During the fire-fighting phase it is expected that the firefighters will access the hotel room from the stairwell and fire-fighting lobby closest to the fire. Where there are doors that consist of more than one leaf, only the single largest leaf is open during the fire-fighting phase, following the guidance within BS EN 12101-6:2005 ^[4]. It is expected that the firefighters will run their hoses through the doors between the stairwell and location of the fire and allow the doors to close. The doors will not completely due to the hoses running through. However, to provide a more onerous scenario, the doors will be simulated as fully open throughout the fire-fighting phase.

The smoke control system was initiated at the beginning of the escape phase of the simulation.

Phase	Time (S)	Action	Notes
Pre-movement	0	Fire Starts	t ² medium growth rate
Escape	300	Hotel room door opens, smoke control system initiated	First occupants of hotel room escape into corridor
	302	Lobby door opens	First occupants reach lobby
	307	Stairwell door opens	First occupants reach stairwell
	320	Hotel room door closes	Last occupants reach corridor
	322	Lobby door closes	Last occupants of office reach lobby
	327	Stairwell door closes	Last occupants reach stairwell
Fire-fighting	600	Stairwell door opens and is held open	Firefighters enter fire-fighting lobby
	615	Lobby door opens and is held open	Firefighters enter corridor
	630	Hotel room door opens and is held open	Firefighters enter hotel room
	900	Fire extinguished	
Clearance	1200	End of Simulation	

Table 1: Timeline for Simulation

4. Results

4.1 Model 1 – BRE Shaft

Figure 3 shows the CFD model created for the BRE Shaft simulation. The stairwell and fire-fighting lobby is modelled completely, with the AOV at the head of the stairwell approximately 21m above the fire floor.

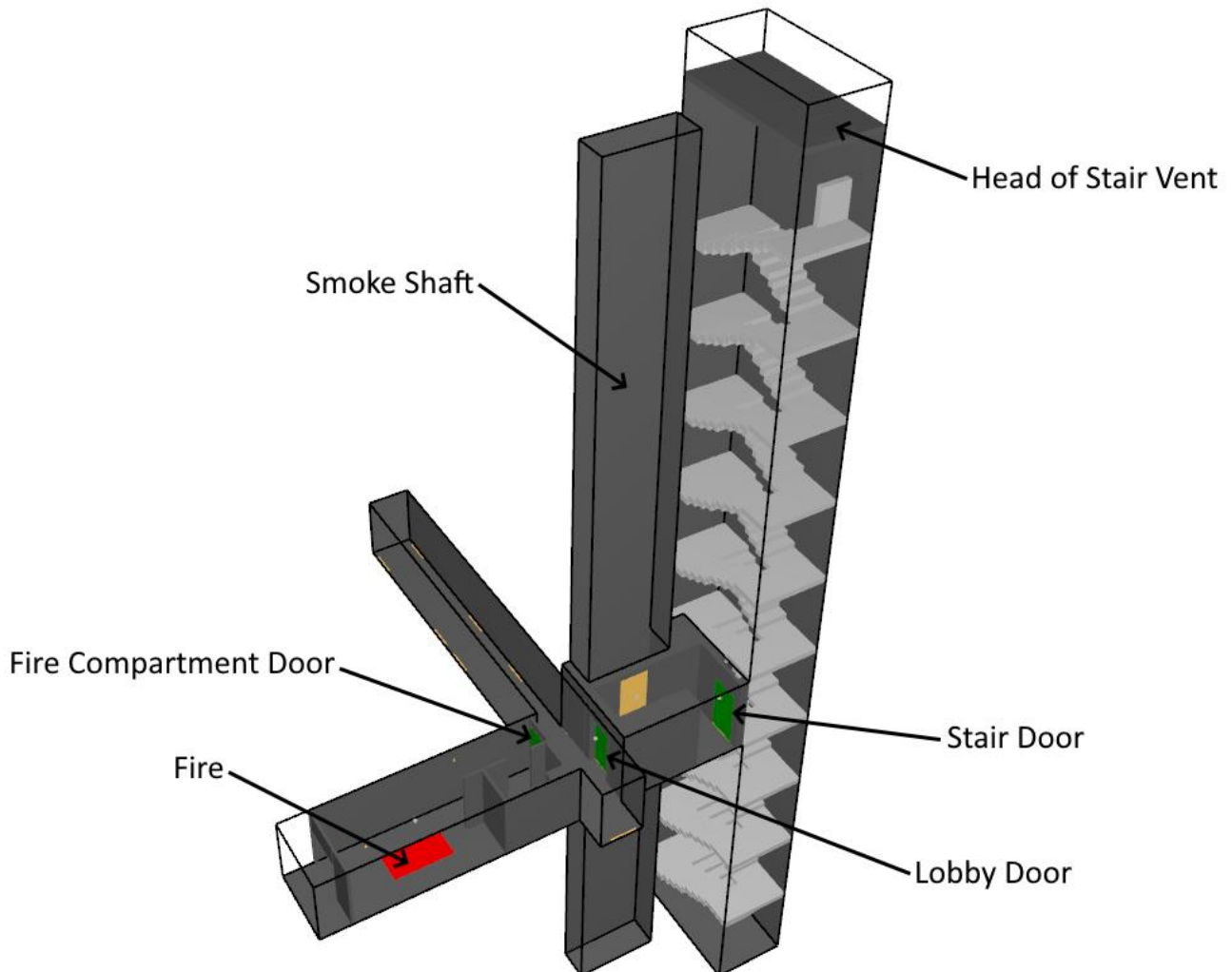


Figure 3: Model 1 – BRE Shaft

4.1.1 Temperature

The following peak temperatures detected by the sensors in the model were recorded during the simulation.

Location	Escape [°C]	Fire-fighting [°C]
Stair Door	21.8	32.5
Fire Compartment Door	26.2	52.4

Table 2: Peak Recorded Temperatures

4.1.2 Visibility

The following figures show the visibility throughout the model at key intervals during the simulation. The data is truncated at 30m displaying as transparent within the simulation.

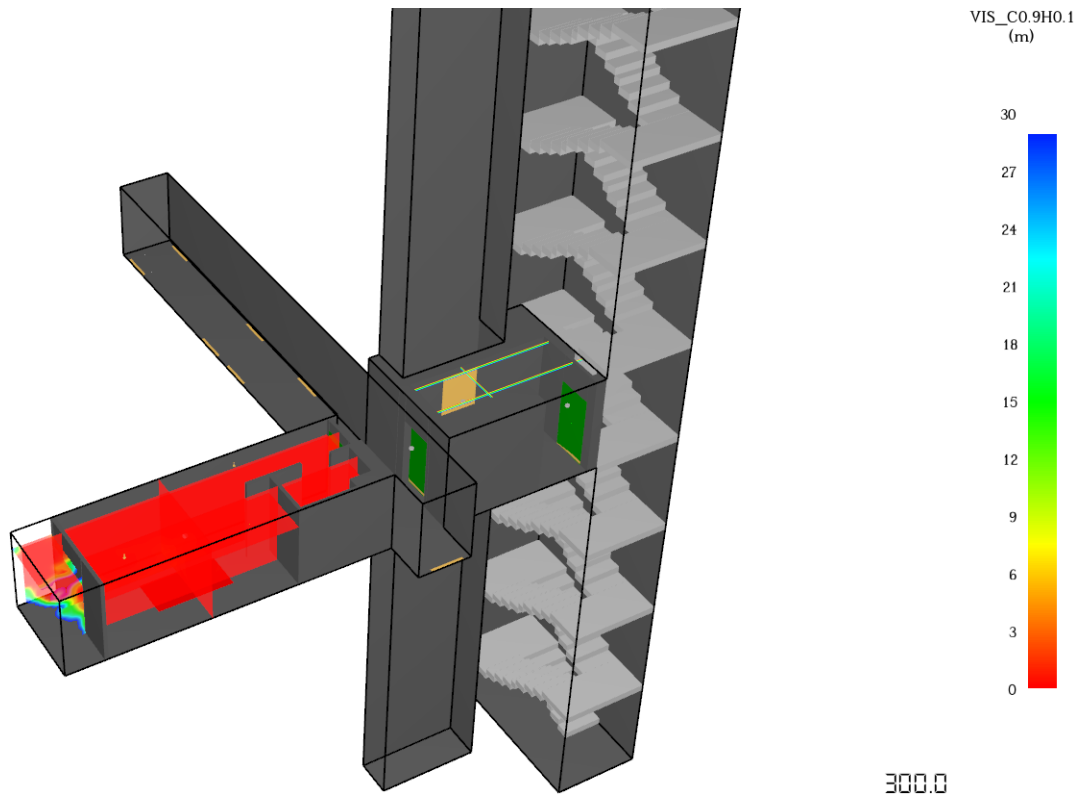


Figure 4: Visibility at 300s

Figure 4 shows conditions at the beginning of the escape phase, immediately prior to the doors between the fire compartment and the corridor opening.

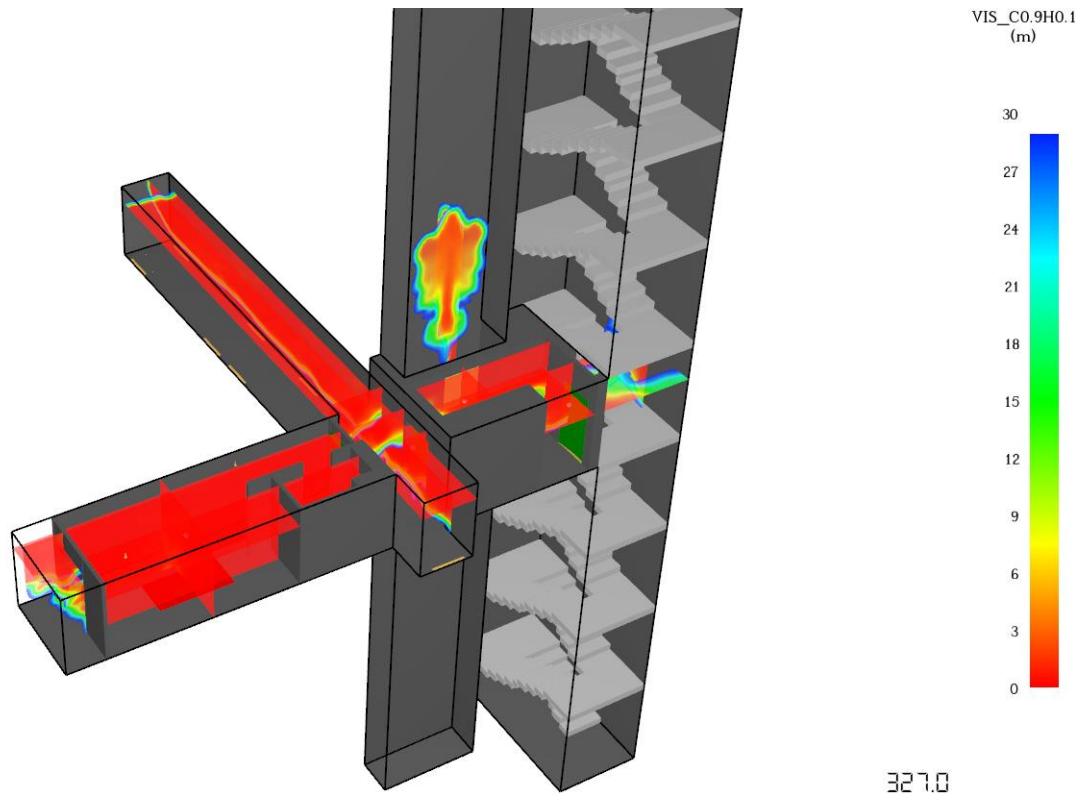
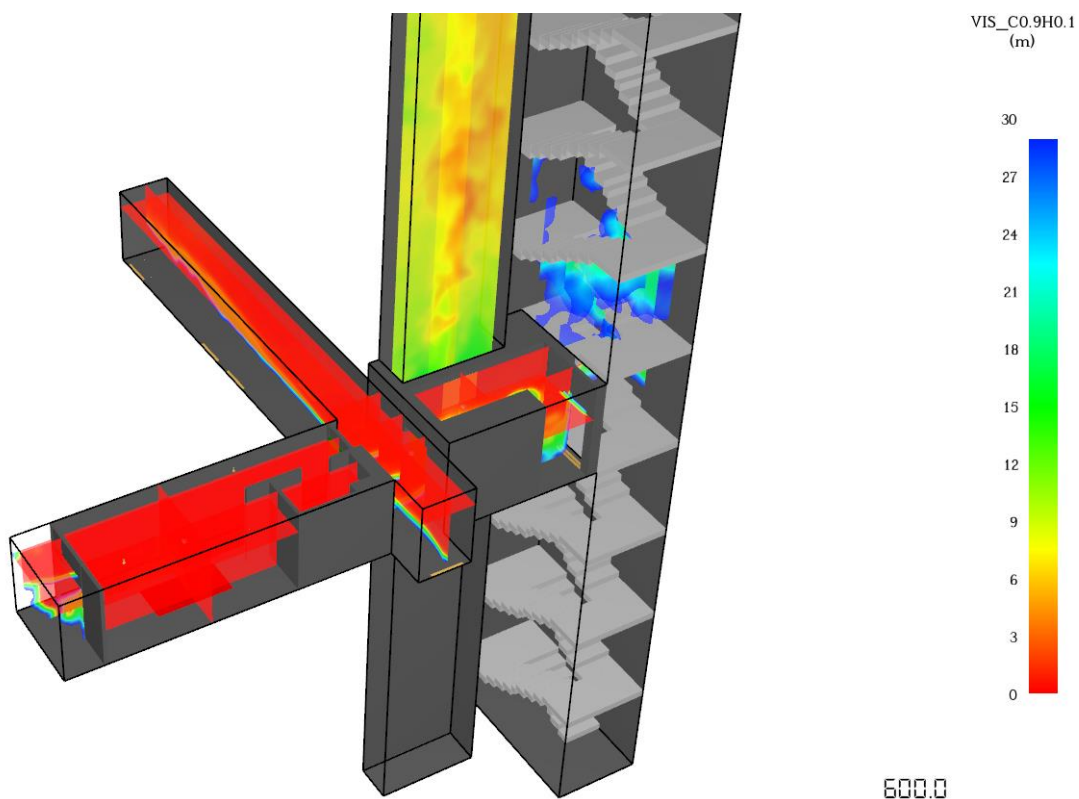
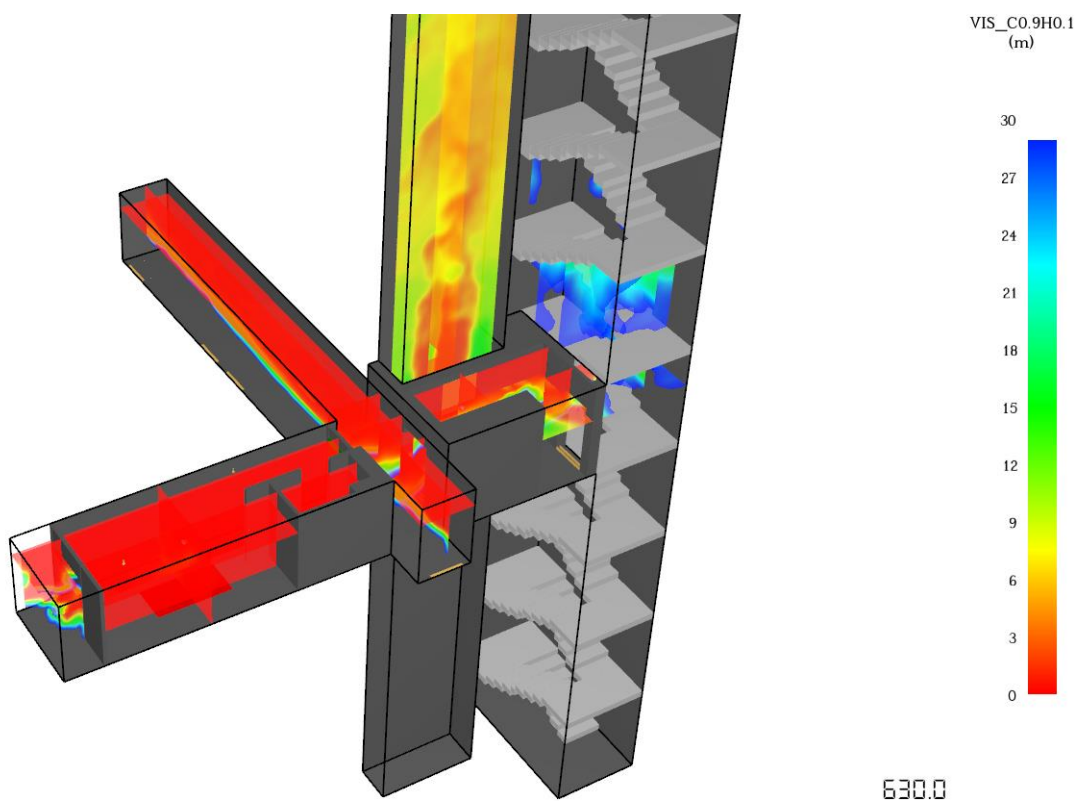


Figure 5: Visibility at 327s

Figure 5 shows conditions at the end of the escape phase, immediately prior to the doors between the fire-fighting lobby and stairwell closing. Smoke has entered the stairwell.

Conditions with the fire compartment continue to worsen as the fire grows with time. The fire door between the fire compartment and the corridor remains closed until the fire service arrive and open the fire door during the fire-fighting phase.

At 540 seconds, the fire and rescue service arrives to carry out fire-fighting operations. They will have gained access to the building by opening the lower stair exit door within the stairwell, ascending and opening the door into the fire-fighting lobby. At 600s the fire and rescue service opens the door between the stairwell and fire-fighting lobby. The stairwell door is held open as hoses pass from the rising main to the fire-fighting lobby.



At 630s the fire and rescue service open the door to the fire compartment and smoke spills into the fire-fighting lobby. Figure 7 shows conditions as the door to the fire compartment is opened.

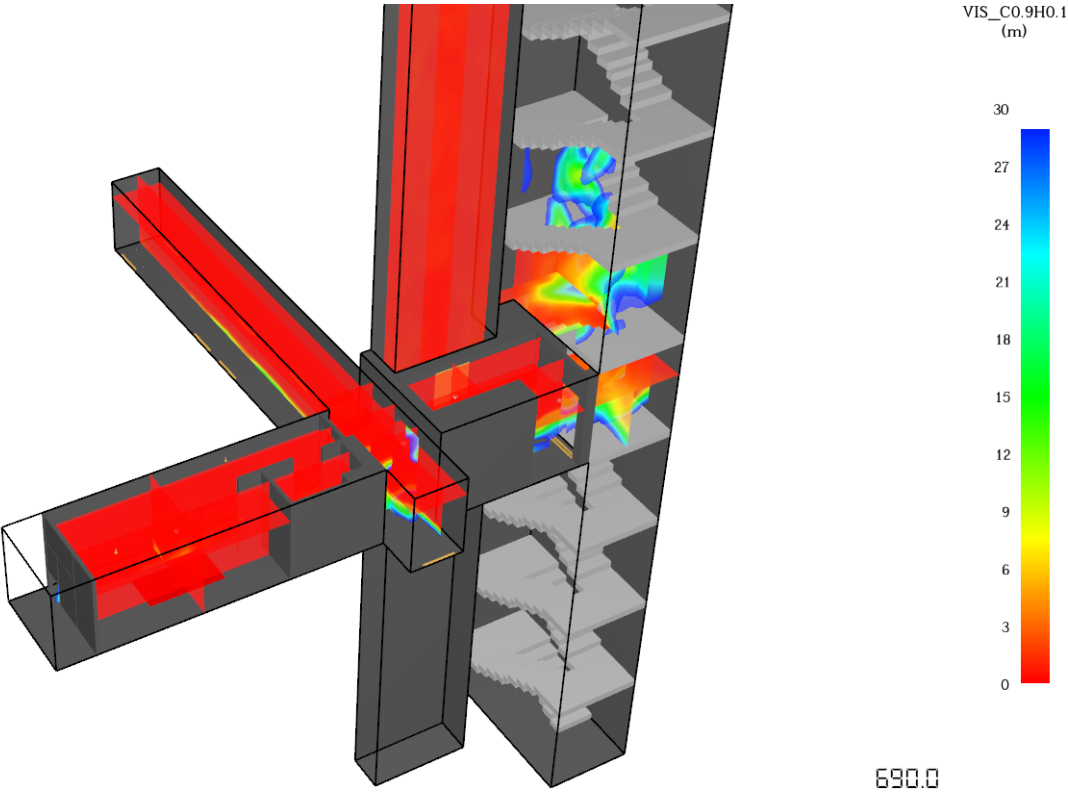


Figure 8: Visibility at 690s

Figure 8 shows conditions 1 minute after the door to the fire compartment was opened. Significant smoke has entered the stairwell.

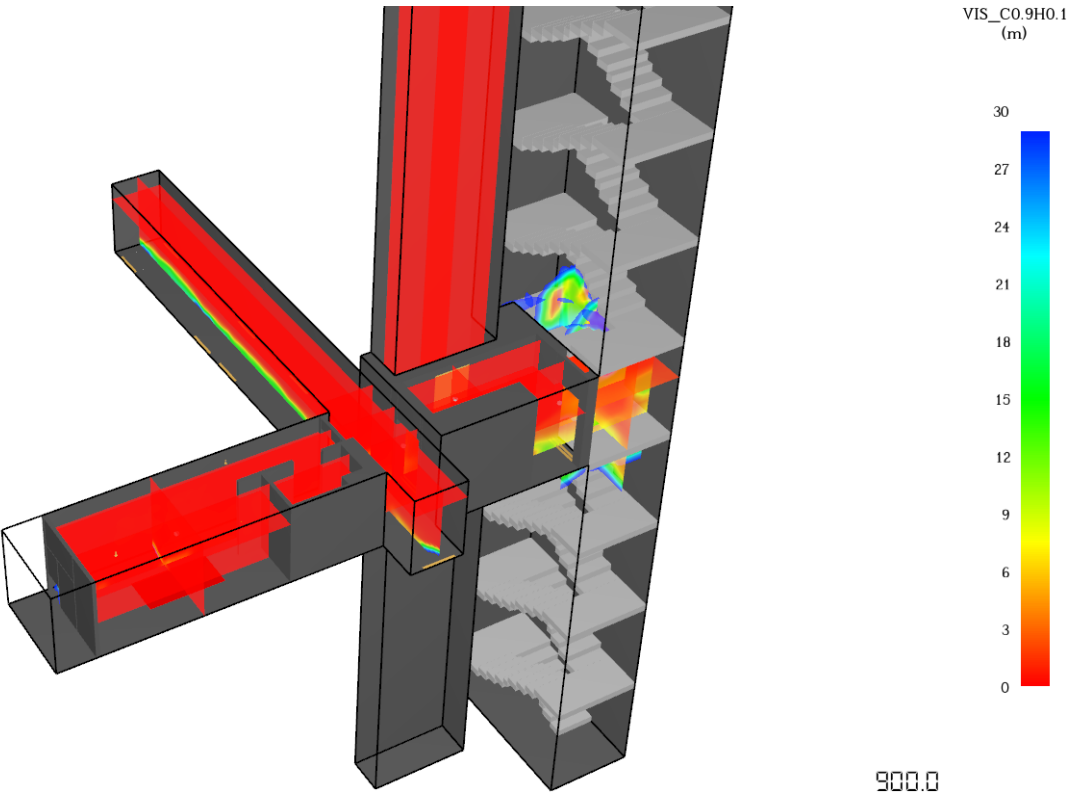


Figure 9: Visibility at 900s

The firefighters extinguish the fire at 900s. Smoke has not been cleared from the fire-fighting stairwell. From this point of the simulation conditions within the lobby do not become worse.

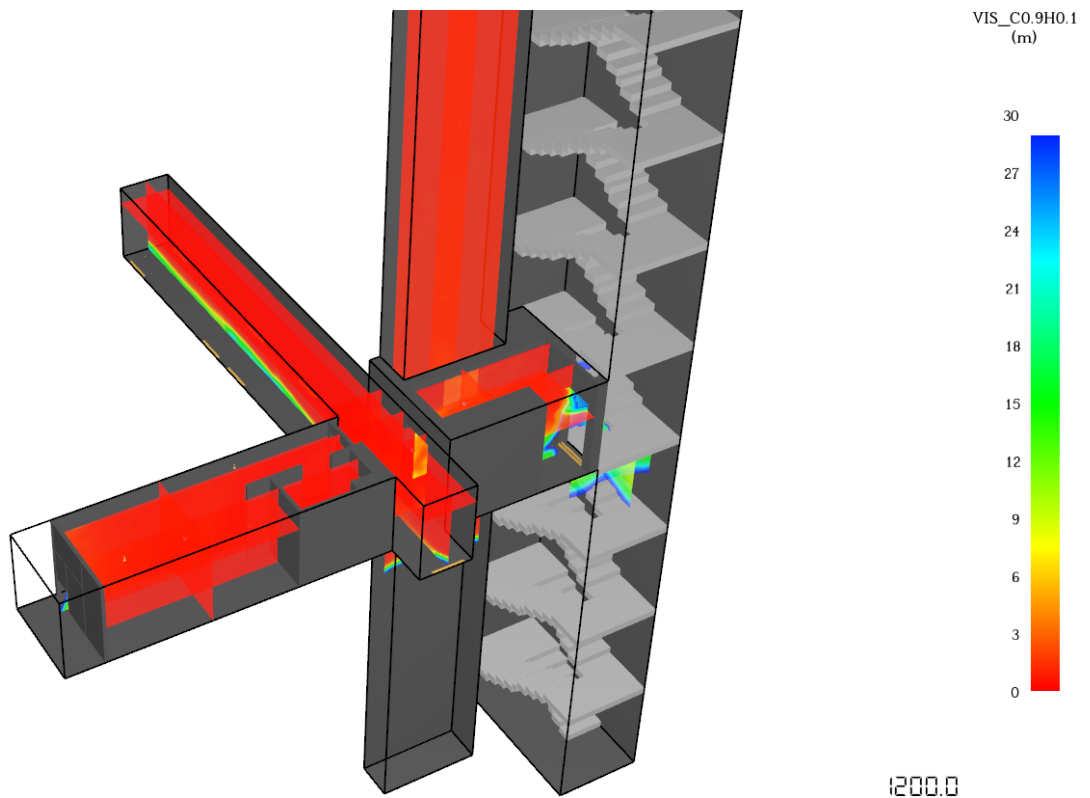


Figure 10: Visibility at 1200s

Five minutes after the fire was extinguished the building retains high volumes of dense smoke. Had the simulation continued beyond this point the smoke would gradually be removed from the model.

4.2 Model 2 – Colt Shaft Variable

Figure 11 shows the CFD model created for the Colt Shaft Variable simulation. The stairwell and fire-fighting lobby is modelled completely, with the AOV at the head of the stairwell approximately 21m above the fire floor.

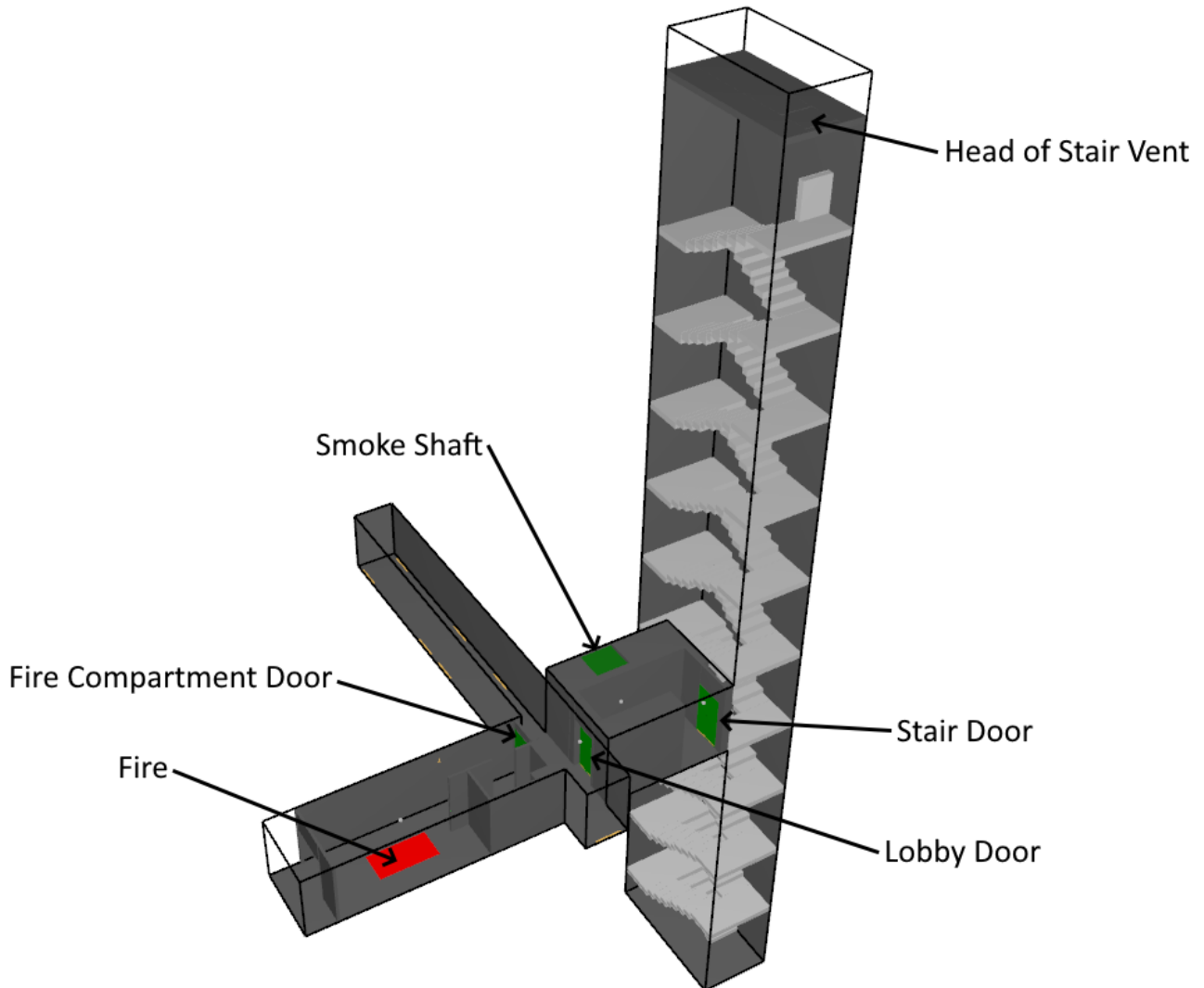


Figure 11: Model 2 – Colt Shaft Variable

4.2.1 Temperature

The following peak temperatures detected by the sensors in the model were recorded during the simulation.

Location	Escape [°C]	Fire-fighting [°C]
Stair Door	20.2	20.1
Fire Compartment Door	25.9	40.7

Table 3: Peak Recorded Temperatures

4.2.2 Visibility

The following figures show the visibility throughout the model at key intervals during the simulation. The data is truncated at 30m displaying as transparent within the simulation.

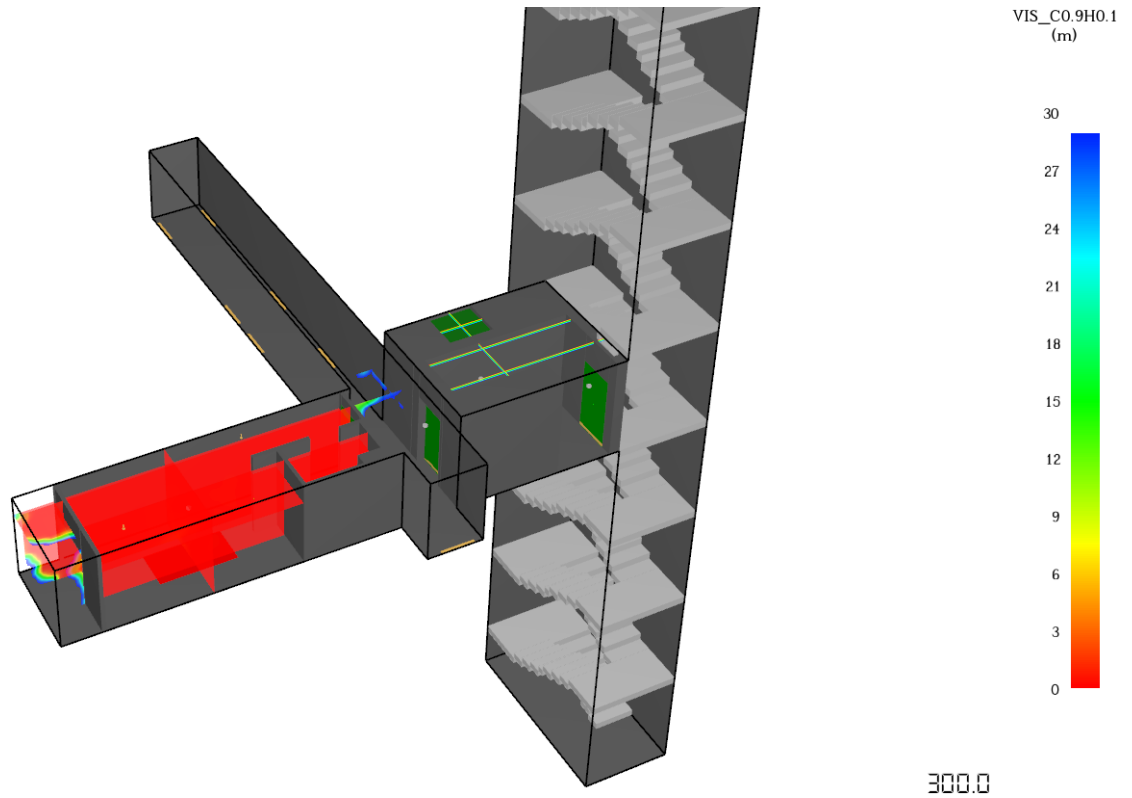


Figure 12: Visibility at 300s

Figure 12 shows conditions at the beginning of the escape phase, immediately prior to the doors between the fire compartment and the corridor opening.

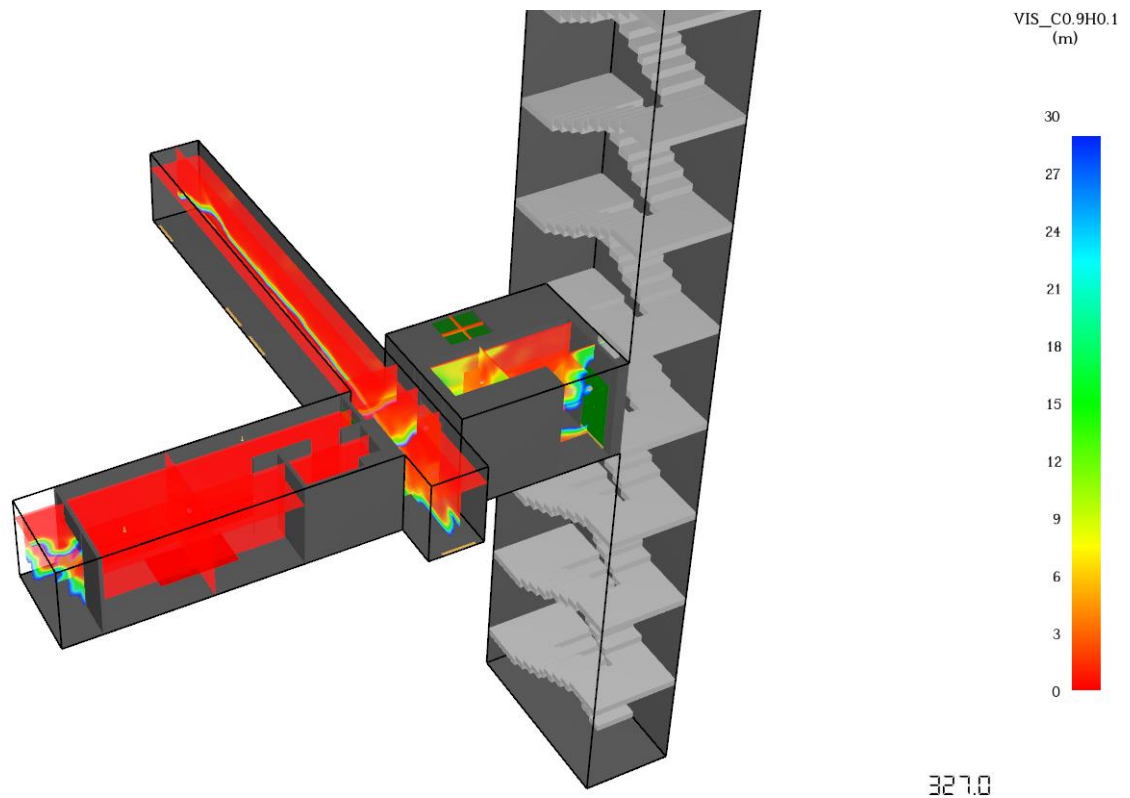


Figure 13: Visibility at 327s

Figure 13 shows conditions at the end of the escape phase, immediately prior to the doors between the fire-fighting lobby and stairwell closing. Smoke has not entered the stairwell.

Conditions with the fire compartment continue to worsen as the fire grows with time. The fire door between the fire compartment and the corridor remains closed until the fire service arrive and open the fire door during the fire-fighting phase.

At 540 seconds, the fire and rescue service arrives to carry out fire-fighting operations. They will have gained access to the building by opening the lower stair exit door within the stairwell, ascending and opening the door into the fire-fighting lobby. At 600s the fire and rescue service opens the door between the stairwell and fire-fighting lobby. The stairwell door is held open as hoses pass from the rising main to the fire-fighting lobby.

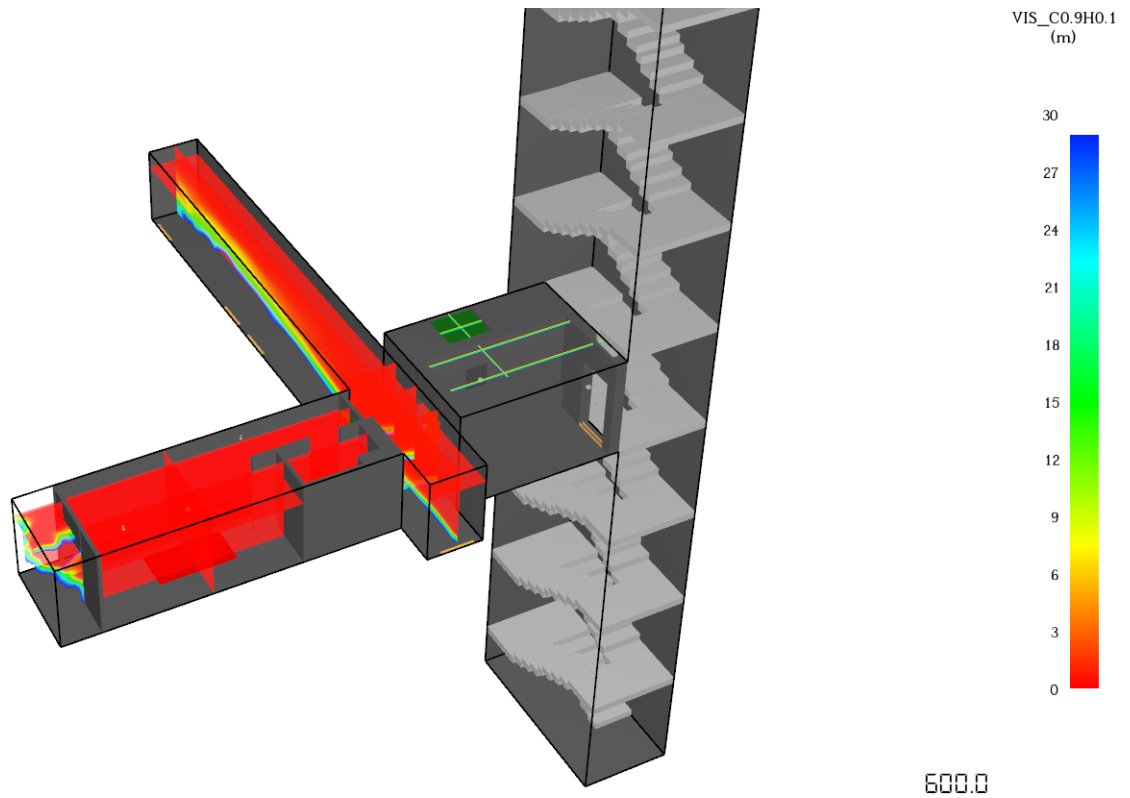


Figure 14: Visibility at 600s

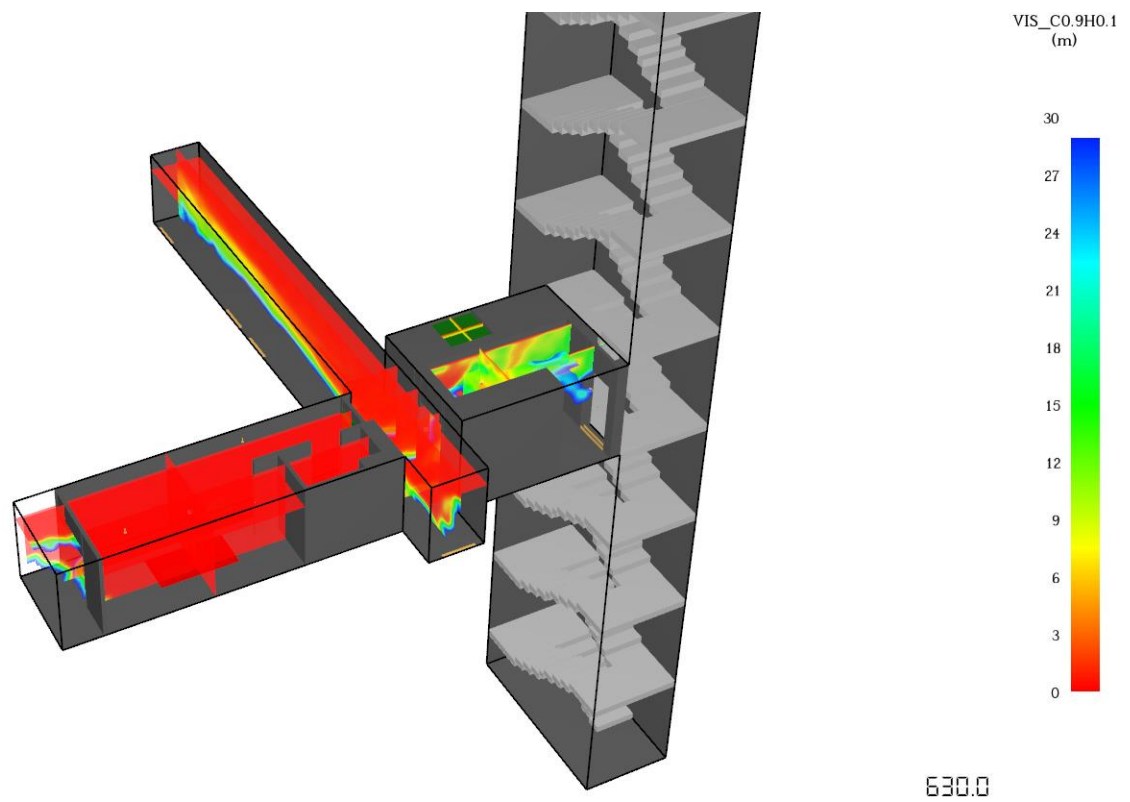


Figure 15: Visibility at 630s

At 630s the fire and rescue service open the door to the fire compartment and smoke spills into the fire-fighting lobby. Figure 15 shows conditions as the door to the fire compartment is opened.

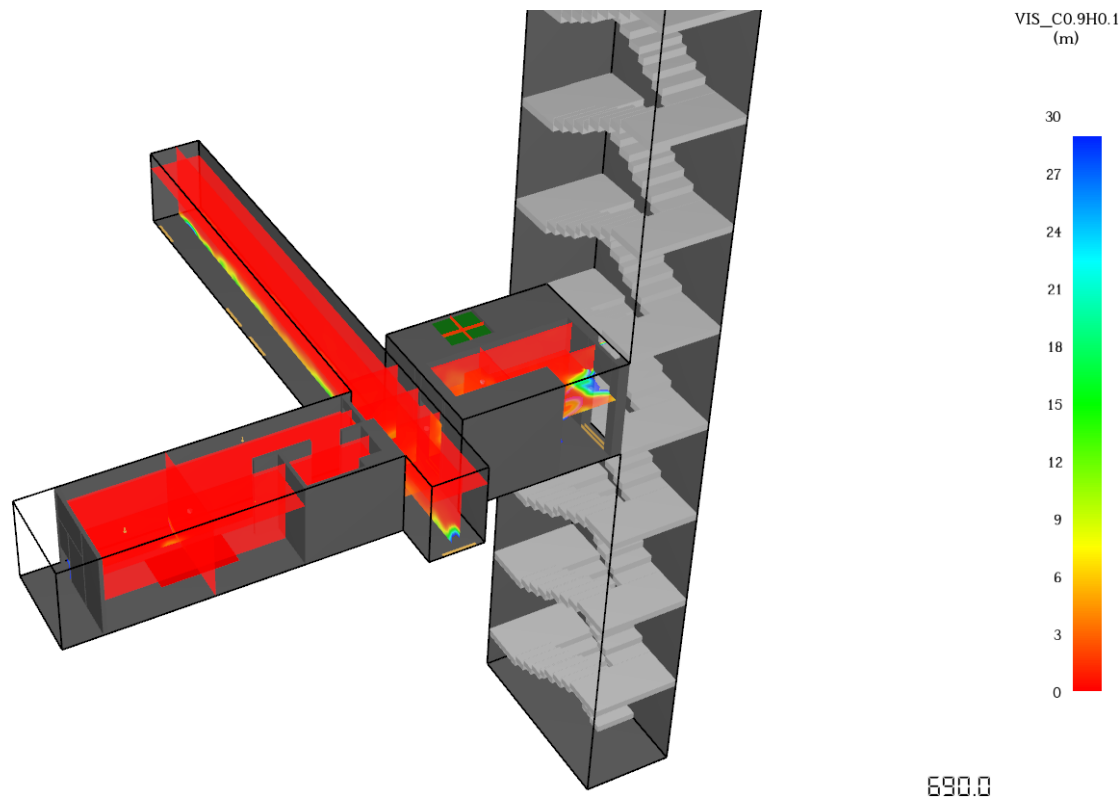


Figure 16: Visibility at 690s

Figure 16 shows conditions 1 minute after the door to the fire compartment was opened.

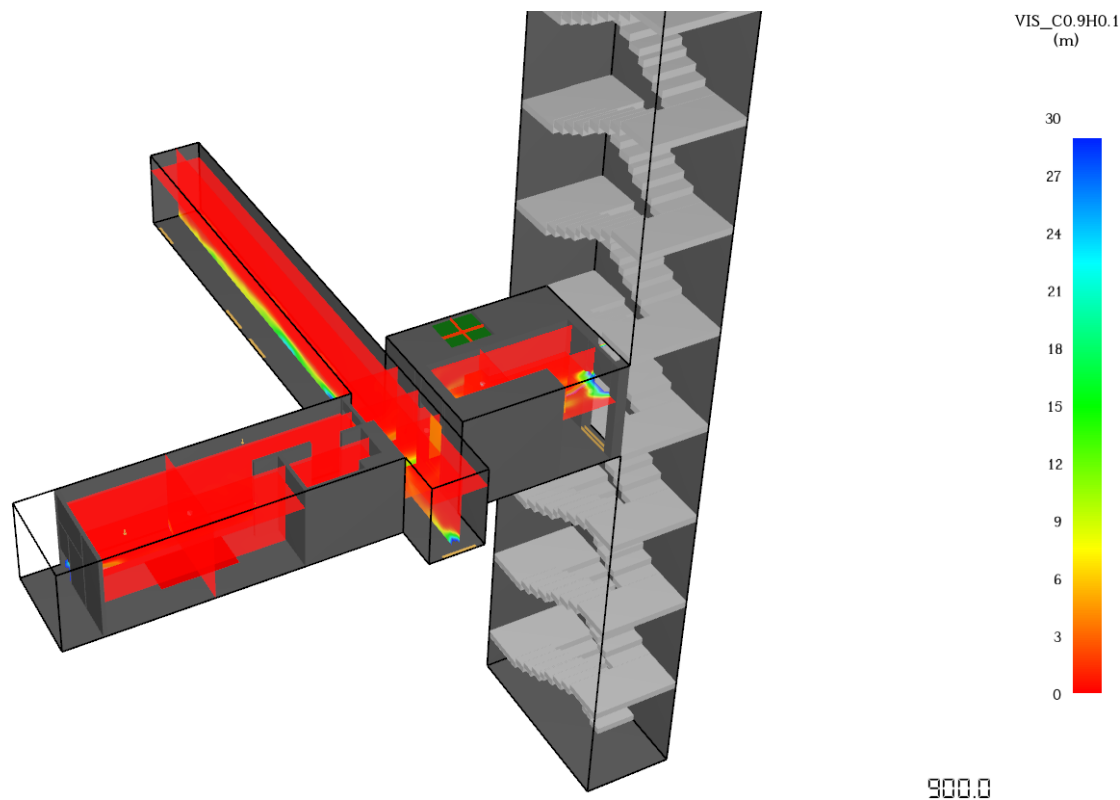


Figure 17: Visibility at 900s

The firefighters extinguish the fire at 900s. Smoke has not entered the fire-fighting stairwell, despite the doors between the fire compartment and the stairwell being open for the duration of the fire-fighting phase. From this point of the simulation conditions within the lobby do not become worse.

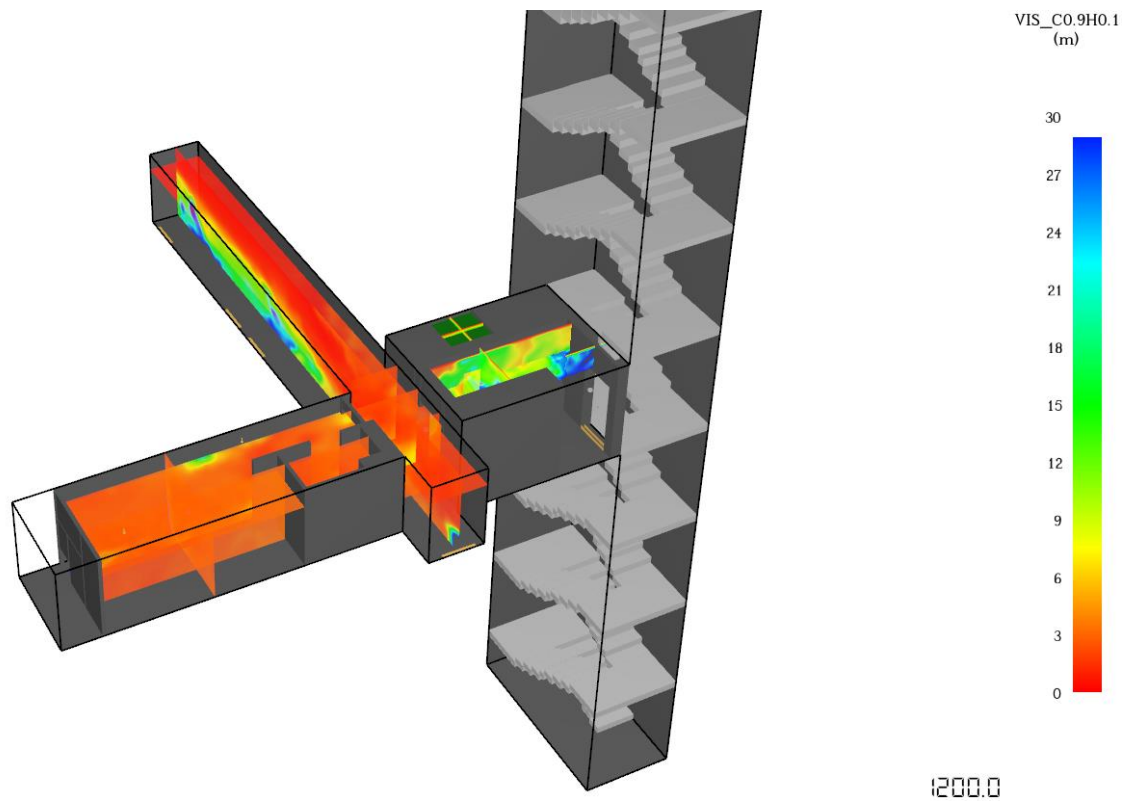


Figure 18: Visibility at 1200s

Five minutes after the fire was extinguished the building retains high volumes of dense smoke. Had the simulation continued beyond this point the smoke would gradually be removed from the model.

5. DISCUSSION AND CONCLUSION

CFD modelling has been used to assess the temperature and smoke visibility within the Hotel fire-fighting shaft at Etihad, Manchester. One configuration was modelled and assessed with the results analysed against the acceptance criteria.

The primary objective of the system is to provide equivalent or better conditions than the prescriptive natural BRE Shaft. The goal of the system is to maintain the stairwell free of smoke during both means of escape and fire-fighting phases. Smoke free conditions are considered to be conditions where visibility is 10m or greater.

The model simulated the Colt Shaft Variable in the event of a fire located in a hotel room opposite a fire-fighting lobby. A sprinkler controlled fire was used for the simulations. The fire reached a maximum size heat release rate of 240kW. A soot yield of 10% was used and visibility factors have been based on distances to light reflective signage.

The results show that:

- The BRE shaft was unable to prevent smoke entering the stairwell during both means of escape and fire-fighting phases.
- The Colt Shaft Variable was able to prevent smoke entering the stairwell during both means of escape and fire-fighting phases.
- Recorded temperatures were similar in both simulations.

The simulation was run for 1200 seconds. Past this point if the simulation was to continue, visibility conditions within the building would continue to improve until the building has been emptied of smoke or the smoke control system is manually shut off.

From these results, it can be concluded that, under the conditions modelled, the proposed Colt Shaft Variable smoke control system exceeds the performance of the natural BRE shaft and satisfies the acceptance criteria as set out within section 2.1 of this report.

6. References

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Appendix A: CFD Modelling

Convectional Computational Fluid Dynamics (CFD) software programs operate by computing the Reynolds-averaged formulation of the Navier-Stokes Equations (RANS) over a discretised domain. The decomposition of the governing equations into a mean and fluctuating part leads to a closure problem. This is overcome by the introduction of turbulence models. The limitation of such time-averaged solutions is that they cannot show the development of the flow field over time. To obtain such solutions Large Eddy Simulations (LES) are usually employed. These solvers solve the unsteady Navier-Stokes equations directly at large scales of motion, while modelling the smaller eddies.

The CFD software used for this analysis is Fire Dynamics Simulator (FDS) from the National Institute of Standards and Technology, United States Department of Commerce. Whilst FDS was developed primarily for fire and smoke modelling in buildings, it is also applicable to air movement and ventilation studies. It is well-documented with a substantial quantity of testing and validation data available^{3, 4}.

FDS is a structured mesh CFD code that uses an explicit time-marching solution procedure and incorporates LES. Geometric shapes are defined and represented in Cartesian coordinate system by blocking cell-volumes or cell-faces.

Steady state fire results can be obtained through continuing time-dependent simulation, but because of non-linearity's in the equation-set the calculations take many hours to reach a meaningful solution. However, the advantage of a CFD analysis is that of generating detailed predictions of likely flow conditions based on rigorous numerical analysis techniques.

The simulation was carried out using a number of interconnecting grids defining approximately 210,350 cells for the complete lobby system. The simulation used a mixture of 200mm & 100mm grid resolutions in the X, Y & Z axis.

Tests of grid sensitivity have been carried out in other models of shaft systems. Based on this experience the results shown above are not expected to show significant sensitivities. It is concluded that the grid used above is satisfactory.

The default mixture-fraction combustion model was used for the simulation.

FDS operates only in transient mode and solves an explicit formulation of the governing equations (the X, Y & Z components of velocity, pressure, and temperature etc.). The time-step is automatically selected within FDS based on the CFL stability condition. A direct solver for the pressure equation is employed solving mass continuity within each grid to machine accuracy at each time step.