THE USE OF A FIRE ENGINEERING BRIEF TO JUSTIFY THE OMISSION OF SPRINKLERS

Chris Chennell
Buro Happold FEDRA

INTRODUCTION

A Fire Engineering Brief (FEB) following the guidance set out in the International Fire Engineering Guidelines [1] was adopted to justify the removal of fire sprinklers from the MAN Diesel distribution and storage warehouse in Stockport.

The warehouse is be a single storey double height space with a maximum floor to ceiling height of 13 metres at the apex, and a floor area of 7,670 m^2. The warehouse is used for the receipt, storage, and distribution of marine and vehicle plant equipment. The warehouse contains a variety of sections consisting of major unit storage areas (A), variable beam racking (B), with vehicle loading areas (C) and delivery bays (D) (both internal and external), as shown in Figure 1 below.

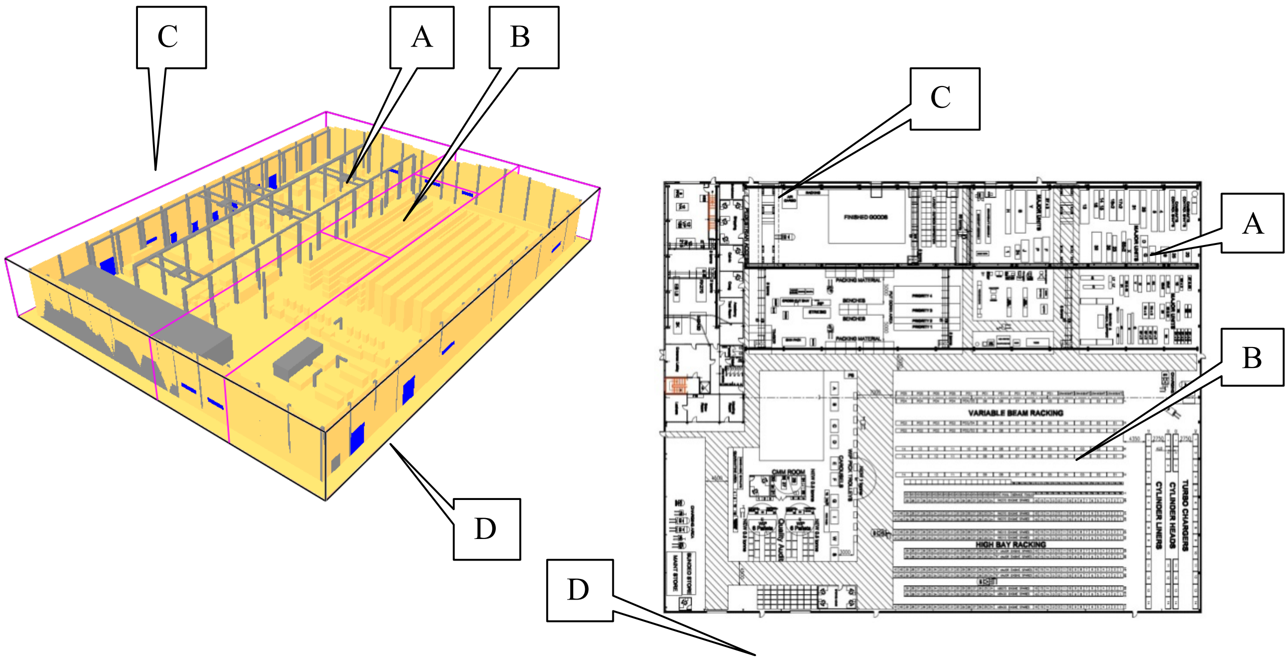


Figure 1. 3D model and plan view of the warehouse.

Compliance with The Greater Manchester Act 1981 [2] was required to be demonstrated, specifically as the building was used *for the purpose of storage or depositing goods or materials where more than 7,000 cubic metres of the building are so used.* As such the building was required to be installed with an a*utomatic fire alarms,* and *fire extinguishing systems,* along with providing *effective means of removing smoke in case of fire,* and, *adequate means of access for fire brigade appliances and personnel.*

The objective of the brief was to demonstrate compliance with the intention of The Greater Manchester Act (GMA) by demonstrating that the omission of sprinklers would not impact on the operational procedures of attending fire crews. To achieve this, a Quantitative Assessment was conducted of the projected fire load within the warehouse and compared with typical fire loads for a number of other occupancies which did not fall within the jurisdiction of the GMA. To substantiate that this deviation from the GMA did not impede fire fighting operations a deterministic analysis of smoke movement was conducted with the use of Computational Fluid Dynamic (CFD) modelling.

METHODOLOGY

The intention of the FEB is to outline the scope of work for the engineering analysis, correspond with the relevant stakeholders and develop an agreed acceptance criteria within which the analysis will be undertaken.

The FEB model was developed to heighten communication between fire engineering practitioners and building regulators. It was recognised that although fire engineering analysis are often complex and require extensive use of engineering judgements, guidance was required to improve the standard of the fire engineering applications. In turn this would increase the understanding of the fire engineering process, and importantly what constitutes an acceptable analysis, by those required to assess the output, i.e. the building regulators. For this project the building regulators were The Great Manchester Fire and Rescue Service and Stockport Building Control.

Analysis Parameters

As agreed between Buro Happold FEDRA and the building regulators the intention of the GMA is the protection of attending fire crews in the event of a fire. Life safety of the building occupants was not considered within this scope of works as the building was in compliance with the functional requirements of Part B (Fire Safety) The Building Regulations 2000 [3]. Therefore, it was discussed and agreed as to what hazard the heat and smoke from a likely fire scenario in the warehouse would pose to fire fighters with the omission of sprinklers and how this risk to their safety could be mitigated. The following acceptance criteria were set out for the analysis.

- The smoke control system will maintain a reasonable clear layer height above the heads of attending fire crews.

A smoke control system was installed to maintain a clear smoke layer at 2.5 m above floor level, i.e. above head height of attending fire crews, at a visibility of 10 m beneath the smoke layer. This ensured that the location of the fire can be determined quickly by the attending fire crews. The seat of the fire will be visible from the periphery of the warehouse when fire crews are committed, assumed to be of the region of 20 – 30 minutes post fire ignition.

- The smoke layer temperature will be such that it will not subject attending fire crews to a radiant heat density such that operational procedures are impeded.

Smoke layer temperature was controlled such that it will not subject fire crews to a radiant heat density of 2.5 kW/m^2 or greater, translating to no greater than 200 °C. By the adoption of this limit a conservative tenability criteria has been chosen, as, any fire fighter committed to the warehouse will be wearing full Personal Protective Equipment (PPE) and thus afforded a greater level of protection. It is typical to expect that fire fighters can withstand greater temperatures whilst in PPE. The Australian Fire Brigade Intervention Model (FBIM) manual states that received radiation up to 4.5kW/m^2 [4] can be withstood by fire fighters donned in full PPE, translating to an upper smoke layer temperature of 280 °C.

- Air flow rates that prevent movement through the building access routes should not be generated.

At no time will an air velocity greater than 5 m/s [5] exist at the fire service entry point, to ensure that access for the attending fire crews is not impeded. By the adoption of this limit a conservative tenability criteria has been chosen, as, any fire fighter committed to the warehouse is assumed to be of a given physical fitness. The 5 m/s parameter is commonly used in buildings for egressing occupants, of all ages and mobility, with an upper limit of 11 m/s [5] adopted within passenger tunnel escape scenarios

COMPARITIVE ASSESSMENT

The predominant load within the warehouse is large metal machine parts for vehicles and marine engines, which do not constitute a great fire load density. The wooden crates and cardboard packing material forms the bulk of the potential fire load. On average cellulose material (wood and paper) such as these have a calorific value between 13 – 18 MJ/kg. Palletised units are stored in the variable beam racking using wooden pallets on racks up to 10 metres above floor level (4 levels). High bay racking is used to store metallic items only with no packaging. Packing materials will be stored prior to use in the warehouse, potentially stacked to maximise floor space. Packed units in wooden crates are stored temporarily prior to shipping. A number of types of both pallets and crates were researched and the figures in Table 1 are taken from this study.

Fuel	*Weight*	*Calorific Value*	*Fire Load*	*Area (sqm)*	*Fire Load Density*
Pallet (small)	20 kgs	15 MJ/kg	300 MJ	1.2 sqm	250 MJ/sqm
Pallet (large)	33 kgs	15 MJ/kg	495 MJ	2.2 sqm	225 MJ/sqm
Crate	25 kgs	15 MJ/kg	375 MJ	0.7 sqm	536 MJ/sqm
Crate	51 kgs	15 MJ/kg	765 MJ	1.2 sqm	638 MJ/sqm

Table 1. Fuel types and respective fire loads

From the furniture layout, shelving arrangements, packing and storage operations and fire loadings, a fire load density for each area of the warehouse was calculated incorporating the packing materials, pallets and packing crates.

Variable Beam Racking
2 small pallets per shelf, 14 shelves per rack, 4 levels of racks per high bay racking, 7 rows of racks;
2 small pallets x 14 shelves x 4 levels x 7 rows = 784 pallets.
784 pallets x 300 MJ per pallet = 235,200 MJ (Total fire load)
Total fire load / Floor area; 235,200 MJ / 710 m^2 = ***331 MJ/m^2***.

Ground Floor Palletised Storage (Cylinder Heads)
1 pallet per shelf, 14 shelves per rack, 4 rows of racks;
1 pallet x 14 shelves x 4 rows = 56 pallets
56 pallets x 495 MJ per pallet = 27,720 MJ (Total fire load)
Total fire load / Floor area; 27,720 MJ / 334 m^2 = ***83 MJ/m^2***.

Crate Storage
Major Units 1 – (Floor area = 756 m^2)
Total measured area of fire load x fire load of average crate; 295.5 m^2 x 600 MJ = 177,300 MJ

Fire load / floor areas; 177,300 MJ / 756 m^2 = 235 MJ/m^2.

Major Units 2 – (Floor area = 399 m^2)
Total measured area of fire load x fire load of average crate; 85 m^2 x 600 MJ = 51,000 MJ
Fire load / floor areas; 51,000 MJ / 399 m^2 = 128 MJ/m^2.

Quality Audit – (Floor area = 810 m^2)
Total measured area of palletised fire load x pallet fire load; 53 m^2 x 300 MJ = 15,900 MJ
Total measured area of crated fire load x fire load of average of crate; 38 m^2 x 600 MJ = 22,800 MJ.
Fire load / floor areas; (15,900 + 22,800) MJ / 810 m^2 = 48 MJ/m^2.

As can be seen from the above a variety of fire loads are present throughout the warehouse. As part of the comparative approach, these varying fire loads were compiled and an overall average fire load density calculated;
Total fire load / Total warehouse floor area; 529,920 MJ / 7662 m^2 = ***69 MJ/m^2.***

The average fire load across the warehouse (69 MJ/m^2) was then compared with the fire load densities of occupancies taken from BS 7974 Part 1 [6] Table 19A

- Office space = 420 MJ/m^2
- Retail space = 600 MJ/m^2
- Manufacturing and Storage = 1180 MJ/m^2

The fire load density for the warehouse is 69 MJ/m^2, a sixth of the typical fire load found in an office, and 5 % of the fire load found in a typical manufacturing and storage occupancy. By comparison this demonstrates that the warehouse does not present the same risk as a typical storage occupancy would, and as such the limitations stated in the Greater Manchester Act do not apply to this building.

DETERMINISTIC ANALYSIS

The analysis was conducted in two stages; the first consisting of a series of scoping calculations; the second comprising of CFD models to simulate the flow behaviour of smoke from a fire scenario.

Fire Scenarios

The Comparative Assessment concluded where the worst case fire scenarios would be within the warehouse, based on fire load density and orientation of combustibles. Therefore, two fire scenarios where proposed and agreed upon as the worst cases. Fire area (47 m^2), perimeter (24 m), heat release rate density (255kW/m^2) and total heat release rate (12 MW) used for the scenarios were those provided in BRE 368 [7], Table 3.3 for an un-sprinklered fuel bed controlled fire as this had the closest fire load density (420 MJ/m^2) to that of the two fire scenarios;

Scenario 1, Variable Beam Racking

The variable beam racking is used to store palletised units that have been delivered to the site. The major fire load on the racking system will be the pallets. Each shelving level and projected number of palletised units has been assessed and maximum of four shelf levels assumed. The area of 47 m^2 will be applied to the racks and involve two racks back to back and twenty shelf units in total. Over the given floor area that this racking system will be located a fire load density of 331 MJ/m^2 has been calculated. This figure includes all four levels of racking, adjacent cylinder and turbo charger storage and the high bay racking areas. To represent the height of the fire load all four levels were assumed involved and up to twenty shelf units in two racks back to back where included at each level.

Scenario 2, Major Units 1

Crated units are stored prior to shipping adjacent to the vehicle loading areas. This scenario consisted of wooden packing crates stacked in pairs in close proximity with other crates, producing a fire load density of 235 MJ/m^2. The 47 m^2 fire area was situated in a corner to replicate reduced entrainment into the smoke plume and thus increase flame height and smoke temperature.

Stage 1 – Scoping Calculations

Prior to the CFD simulation a number of scoping calculations where conducted using the CIBSE Guide E [7] calculation method. This empirical calculation method assesses conservation of mass and energy, predicting how the smoke layer would descend. The design fire parameters were discussed and agreed with the regulators based on the two scenarios listed above assuming a fast growth rate fire within the geometry of the warehouse. The model was run over 30 minutes to include roof vent operation after 180 seconds to simulate time to smoke detection and define a critical smoke layer height of 2.5 m, and a reduced critical smoke layer temperature of 185 °C.

The results from Scenario 1 deterministic analysis are presented graphically in Figure 2 below highlighting smoke layer height (a) and smoke layer temperature (b).

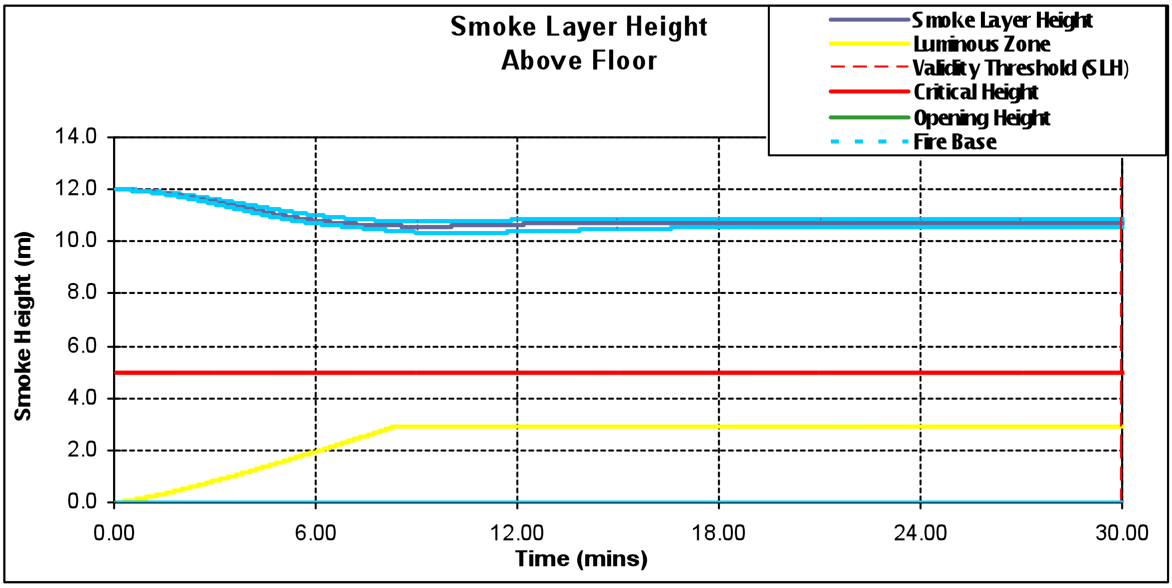


Figure 2 (a). Smoke layer height, Scenario 1

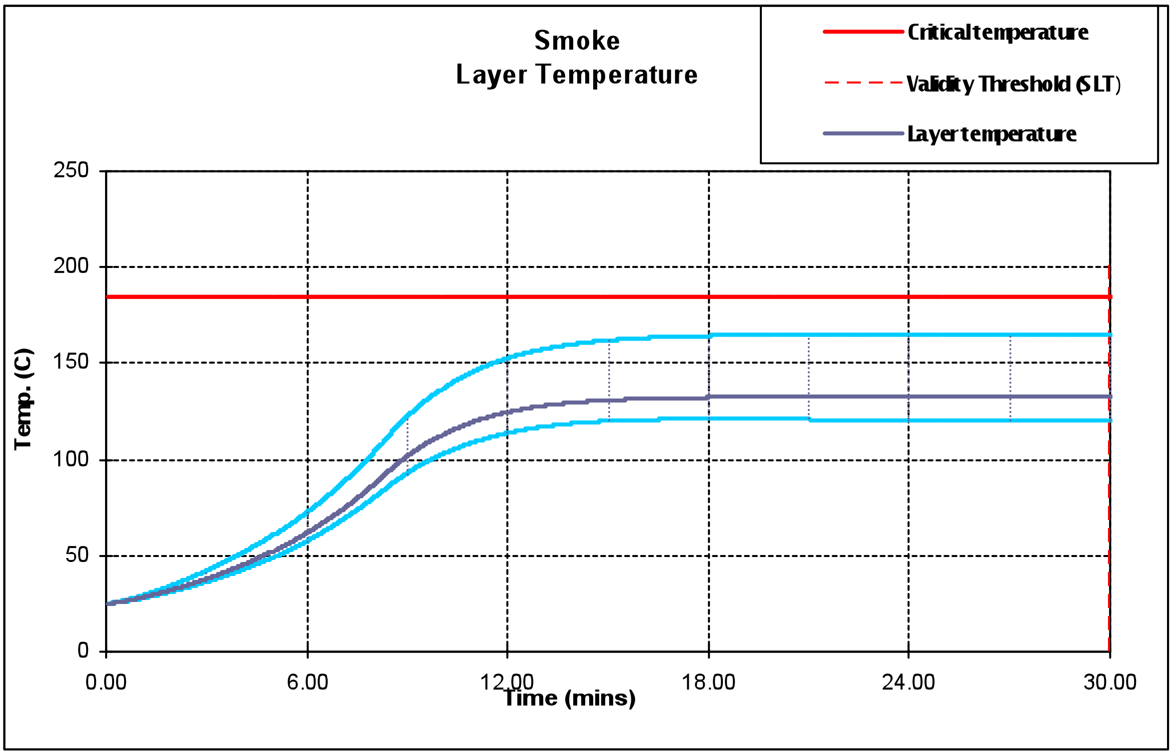


Figure 2 (b). Smoke layer temperature, Scenario 1

The results from Scenario 2 deterministic analysis are presented graphically in Figure 3 below highlighting smoke layer height (a) and smoke layer temperature (b).

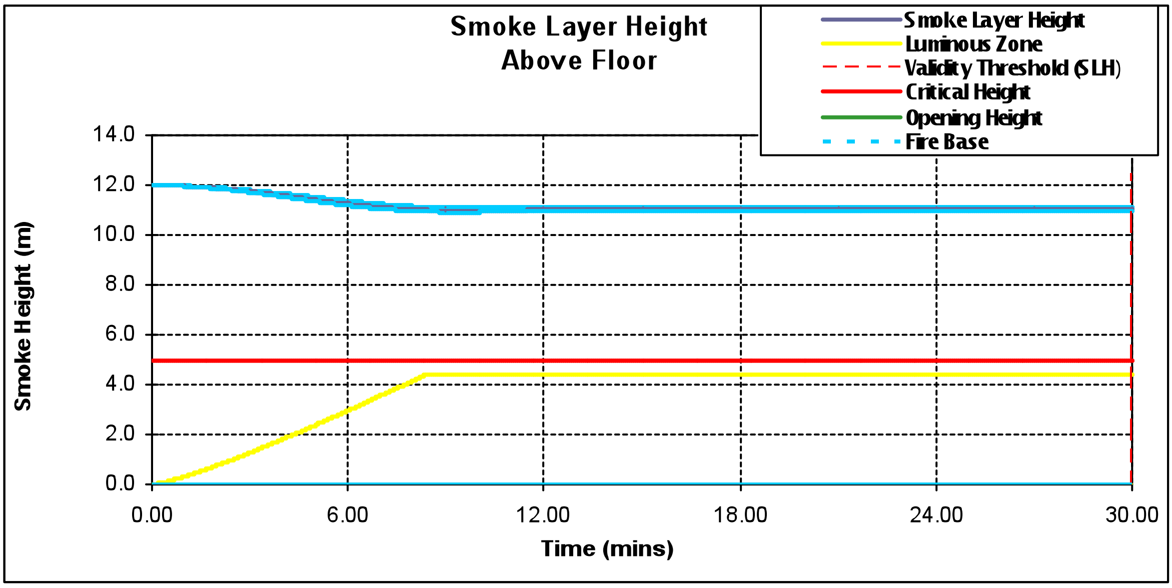


Figure 3 (a). Smoke layer height, Scenario 2

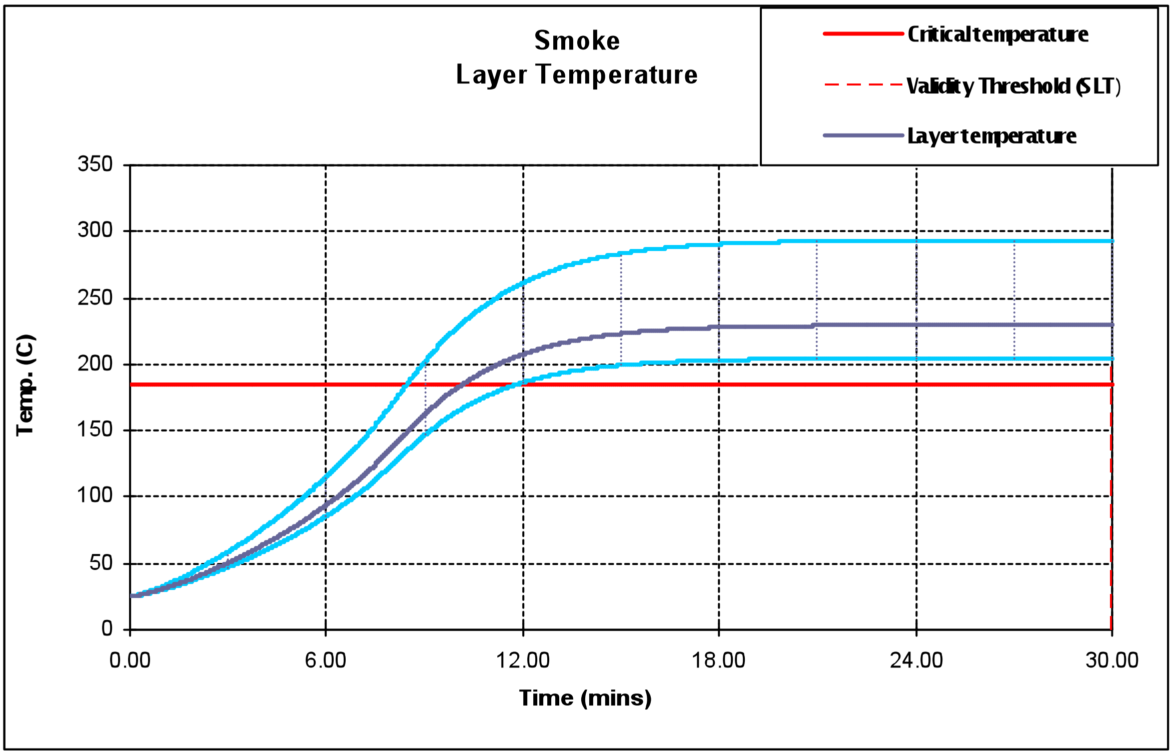


Figure 3 (b). Smoke layer temperature, Scenario 2

Note: The blue variance on the above graphs indicate the ranges through which the smoke layer height and temperature may alter, with the purple line defining an average.

The results from the two scenarios both produced clear layer heights above 2.5 m, with Scenario 1 having a greater smoke volume due to radial air entrainment into the smoke plume. Scenario 2 produced a smoke layer temperature in excess of 185 °C, where as Scenario 1 did not, but as the smoke layer height was approximately 11 m above floor level the radiant heat flux at 2.5 m was concluded to be within the acceptable criterion. As the volume of smoke produced was greater in Scenario 1, Scenario 2 was discounted and Scenario 1 was used within Stage 2 of the deterministic analysis. This decision was taken as it was agreed that the Stage 1 results showed that visibility through the smoke layer to the seat of the fire was of greater concern than the heat flux from the smoke layer.
Note: The fire is located in the variable beam racks. The upper-most surface of the fire is located 1.5m above ground floor level. The 2.5m of shelf space directly above the fire has been removed to facilitate air flow to the fire.

Stage 2 – CFD Analysis
After discussion with the regulators the parameters for the CFD analysis were agreed upon. Scenario 1 was agreed to be the worst case fire, and the fire load, density, orientation, building geometry and ventilation provisions were all discussed and agreed prior to running the computer models, as listed below;

- Building plan area = 105.0m x 80.5m ≈ 8450m².
- Building height = 12.0m. (To lowest point of roof structure – conservative.)
- Maximum fire total heat release rate = 12MW (48m² at 250kW/m²).

- Radiative fraction = 0.33.
- Maximum convective heat release rate = 8MW.
- 'Fast' t^2 growth rate (= 0.04689kW/s^2).
- Fuel – predominantly timber – with limited plastic content.

Typical properties for timber are:

- Heat of combustion = 13,000 kJ/kg;
- Soot yield = 0.01 – 0.025kg/kg.

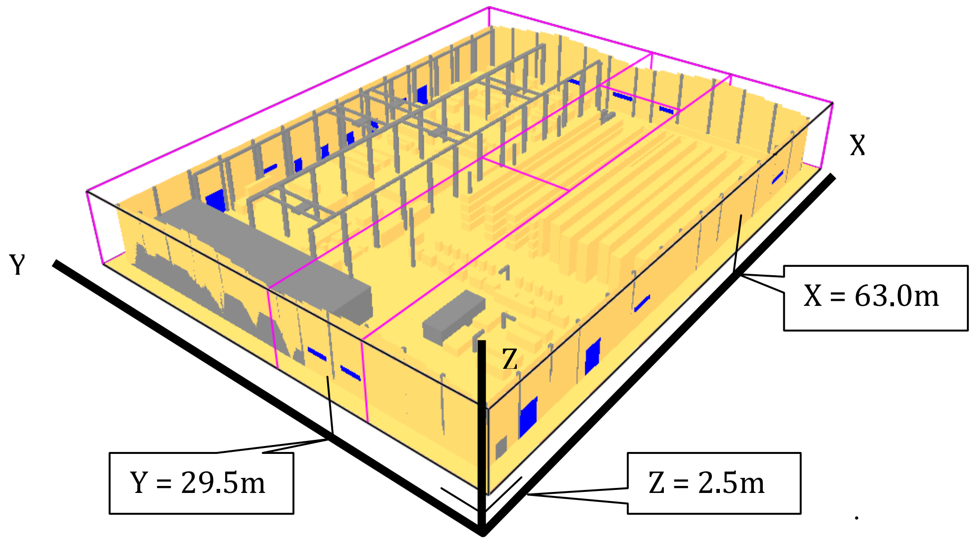
To allow for the presence of a limited plastic content, the following properties are adopted.

- Heat of combustion = 15,000 kJ/kg;
- Soot yield = 0.045kg/kg.

The key parameters, for this study, are the height and temperature of the smoke layer. Assessment of the results took place with respect to the anticipated time at which the Fire Service commences fire-fighting operations: taken to be 20 – 30 minutes after fire ignition. (In this model, ignition is considered to represent the post-smouldering phase of fire development.). A sensitivity study into varying natural ventilation inlet and outlet arrangements was conducted resultant in the design ventilation provisions required to meet the acceptance criteria. Also, a study into variations in the model geometry, vent orientation, fire growth rates and fire time lines was conducted to ensure the analysis results had considered a number of eventualities and the results were sufficiently robust to be considered representative of a real fire scenario.

Deterministic Analysis Results

Slice files through the model where used to visually illustrate smoke layer height and temperature along with flow rates at varying elevations. The co-ordinates of each of the slice files are represented indicatively in the diagrams below.



The modelled dimensions are as follows.

-3.00m ≤	X	≤	108.00m
-3.00m ≤	Y	≤	83.50m
0.00m ≤	Z	≤	15.00m

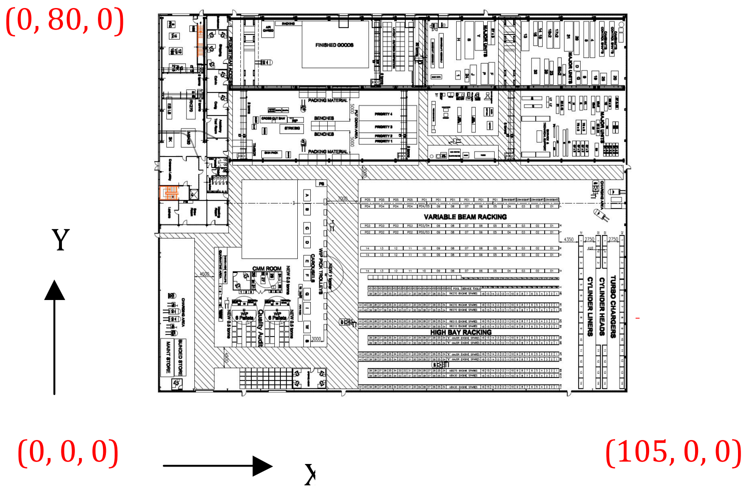


Figure 4. Model orientation and slice file co-ordinates

These dimensions include a 3 metres external zone around the building to ensure external effects are taken into account. The results from the CFD simulations, as illustrated in Figure 5 (a), (b), (c) and (d) below (X 63.0 m), defined that the agreed acceptance criteria for the models had been met; the smoke temperature did not exceed 185 °C; the visibility at 2.5 m was greater than 10 m.

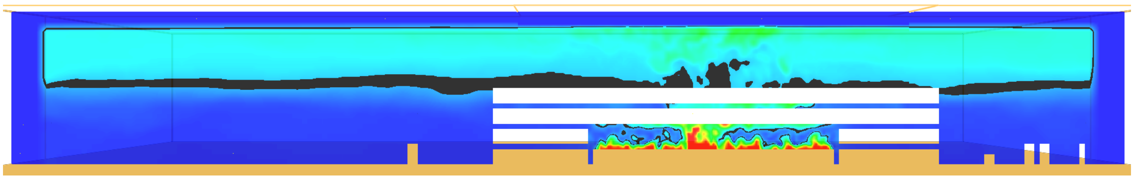


Figure 5 (a). 60ºC Black Contour at 1200 s

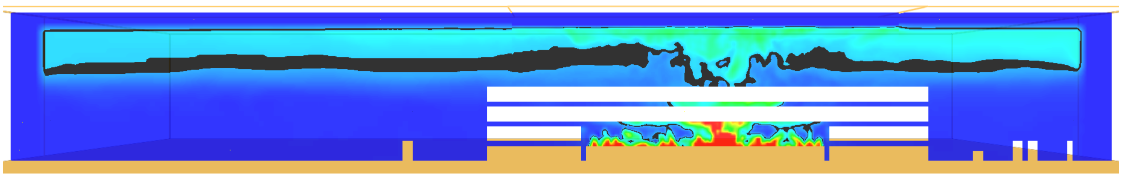


Figure 5 (b). 60ºC Black Contour at 1800 s

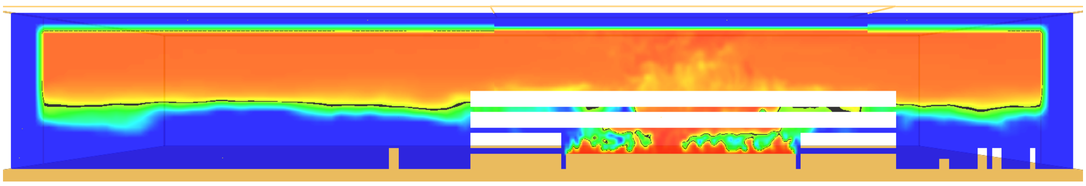


Figure 5 (c). 10 m Visibility Black Contour at 1200 s

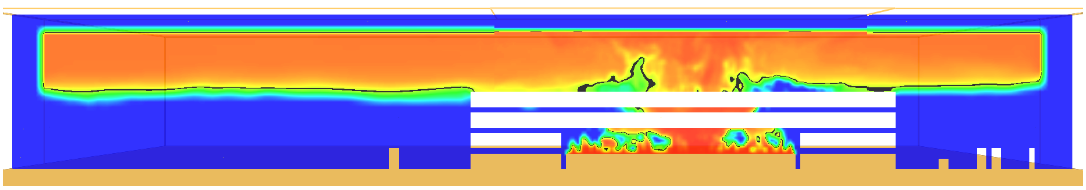


Figure 5 (d). 10 m Visibility Black Contour at 1800 s

The files through the model as illustrated in Figure 6 (a) and (b) below, highlight that the air velocity at the warehouse doors did not exceed 5 m/s.

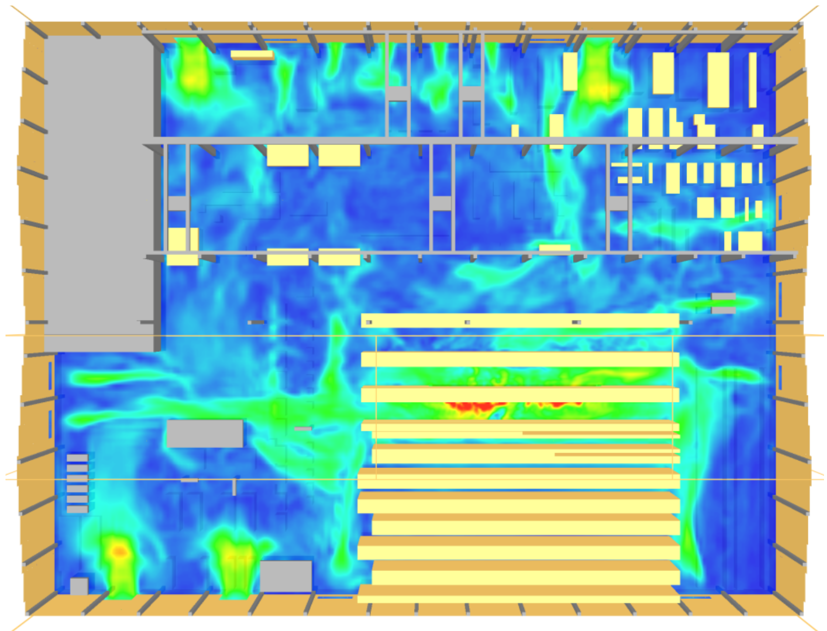


Figure 6 (a). Air velocity at 1200 s

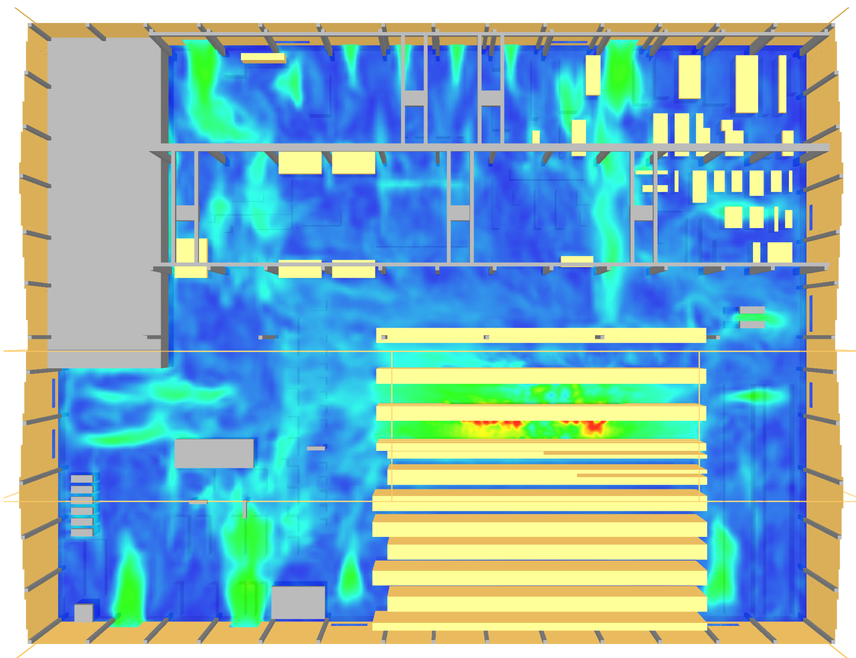
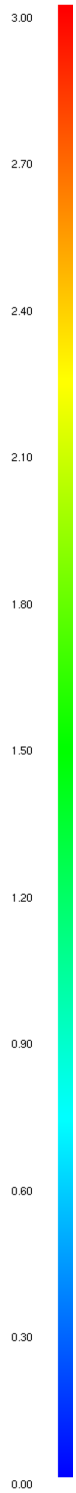


Figure 6 (b). Air velocity at 1800 s



The slice files show the effect of the warehouse doors opening at 1200 seconds to simulate the attending fire crew entrance to the building. The increased layer height is representative of the increase in ventilation inlet area as the warehouse doors are opened by the fire service, inclusive of vehicle loading and delivery bay doors.

CONCLUSION

When the results from the Quantitative Assessment comparing fire loads, and the Deterministic Analysis, substantiating the deviation from the GMA with CFD simulation, were presented to The Greater Manchester Fire & Rescue Service and Stockport Building Control it was agreed that the acceptance criteria set out through the Fire Engineering Brief had been met.

- Fire fighting operations would not be impeded with the omission of sprinklers from the warehouse.
- A significant cost saving had been made for the client with a design which still meet the intention of The Great Manchester Act.
- These both had been achieved through the successful application of the Fire Engineering Brief model.

REFERENCES

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