fire design solutions

Waterside, Twickenham

Air Management to Car Park Environmental and Smoke Clearance

February 2016

CFD REPORT CONTENTS

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Issue	Date	Amendment Details	Author	Checked
01	03/02/16	-	DS	AC

1.0 INTRODUCTION

This report is intended to document the air management proposals for the car park on the Waterside Twickenham development using the induction ventilation concept. This will allow acceptable environmental conditions in the car park and assist fire fighters in their operations.

The car park consists of a single level of car parking, with an approximate net floor area of 845m². Access into the car park is provided via an entrance / exit ramp.

The layout below shows the car park.

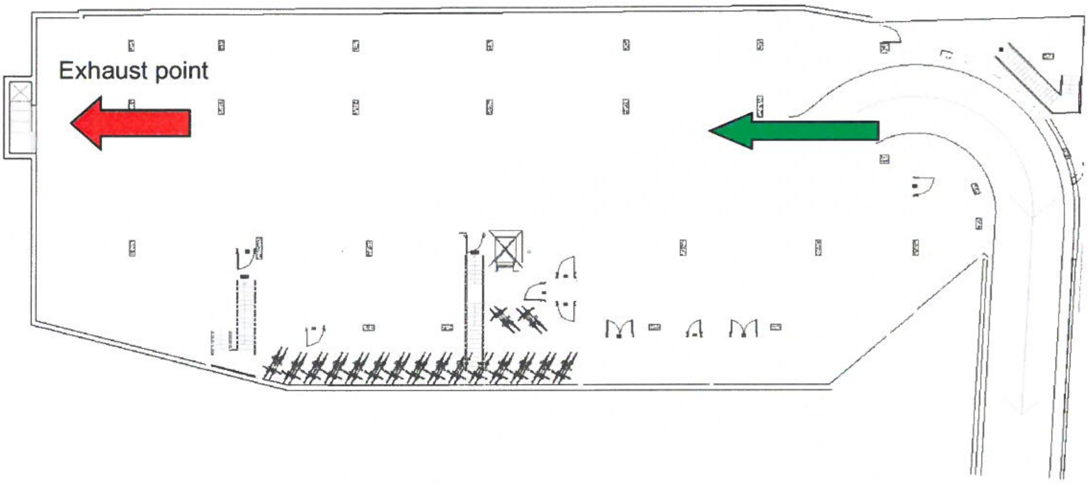

Figure 1 – Car Park layout

This report is intended to document the proposed smoke clearance conditions as required by Approved Document B (ADB) and the environmental conditions as required by Approved Document F (ADF).

1.1 Code Recommendations to the Building Regulations

The following summarises the air management requirements of the codes applicable to this car park.

Approved Document B (ADB)

This code provides recommendations for both natural and mechanical ventilation of smoke in the event of a fire. For natural ventilation the code recommends that 2.5% permanent ventilation should be provided to each level which is equally divided between opposite facing walls. In the case of mechanical, the code recommends a minimum of 10 air changes per hour is provided from each level which should be automatic in operation.

The staircases serving the basement car park will be separated from the staircases serving the upper parts of the building. This separation will be achieved via a physical break such that any heat and smoke affecting the basement stair cannot spread to the upper sections of the stairs concerned.

Approved Document F (ADF)

This code provides recommendations for both natural and mechanical ventilation of carbon monoxide (CO) for environmental conditions. The code is based around a notional value of ensuring the levels of CO do not exceed a level of 30PPM over an 8 hour period. In the case of car ramps the CO level should not exceed 90PPM over a 15 minute period.

To satisfy the above environmental requirement, the code recommends for natural ventilation that 5% permanent ventilation should be provided to each level which is equally divided between the opposite facing walls. In the case of mechanical, the code recommends a minimum of 6 air changes of the volume should be provided from each level.

2.0 CAR PARK ANALYSIS

The various codes in use do not distinguish between the uses of car parks. For example the same environmental and fire requirements are required for commercial car parks as to that of residential use. It is worth considering that a commercial car park such as a shopping centre will have continuous use with shoppers coming and going constantly all day. In the case of residential use, it is likely the occupants will leave in the morning and then return in the evening. Alternatively they may be going out in the evening. The important issue is that the car park is not in constant use like a commercial car park.

Consideration should also be given to the location of this development with its excellent links to central London. In reviewing similar car parks in the area, the usage would appear to be evenings and weekends due to the public transport links, limited parking and congestion charges within central London.

As the car park is land locked the code recommended natural approach is not achievable. The mechanical approach will therefore be adopted on this car park. In summary this will be 6 air changes per hour for environmental conditions, so as to limit the CO levels below 30PPM over an 8 hour period. In the event of a fire this will be at least 10 air changes per hour.

Approved Document B states that BS7346 Part 7:2006 (superseded by BS 7346 Part 7:2013) may be used as an alternative to the 10 air changes per hour system mentioned above. To assist with the movement of air through the car park an induction ventilation concept will be utilised generally in accordance with the guidance found in BS7346 Part 7:2013. This will rely on inlet air through the car ramp. Induction fans will be located below the soffit along the length of the car park, which will assist with air movement from the ramp to the extract point of the car park.

The means of escape from the car park have been considered when determining the locations of the induction fans and extract point, along with the correlation between induction fans and stair / lobby doors to prevent products of combustion from being forced into stairs or lobbies. Induction fans have been arranged taking into account all building geometry so as to ensure that all areas of the car park are ventilated effectively without stagnation or recirculation. The extract fans will achieve the necessary air flow rates to satisfy the general and emergency ventilation requirements, but it has also been ensured that velocities on the escape routes will not exceed 5m/s so as not to impede means of escape for occupants. Induction fans have also been located far enough from the main extract point so as not to overcome the specified extract rate and cause air recirculation.

In this case it is proposed that it is not necessary to incorporate a delay in activation of the induction fans as recommended by BS7346 Part 7:2013. This proposal is based upon the fact that the car park is code compliant for means of escape purposes (e.g. no extended travel distances or other deviations are present).

Operating a system at 6 air changes per hour so as to ensure the CO levels do not exceed 30PPM over an 8 hour period is a waste of energy in residential car parks and gives little consideration for modern controls, which will optimise the required conditions. To minimise energy losses an engineered approach will be utilised which will involve using CO detectors which will register levels of CO and operate fans at various speeds as necessary.

2.1 System detailed description

Level	Area (m^2)	Height (m)	Volume (m^3)	Q - Volume flow rate (m^3/s)	
				General vent	Emergency vent
Basement	845	3.0	2535	4.2	7.0

Table 1 – Car park details

Example calculation

Area = 845m^2
Height = 3.0m

Volume = Area x Height
= 845 x 3.0 = 2535m^3

Volume Flow Rate = (Volume x Air Change Rate) / 3600
= (2535 x 6) / 3600
= 4.2m^3/s for 6 air changes per hour

= (2535 x 10) / 3600
= 7.0m^3/s for 10 air changes per hour

When any CO detector detects levels above 30PPM it will bring on all the induction fans so as to dilute the level of CO and the extract fans will operate at 3 air changes per hour. If the detector continues to detect a level above 30PPM the extract fans will step up to 6 air changes per hour and the induction fans will continue to operate. When CO levels are reduced, the system will revert back to the first stage.

In the event of a smoke / heat detector or the fire service override switch being activated, the system will switch into full fire mode. In this situation the induction fans will operate and extract fans will switch to full extract mode. As discussed previously, it is not considered necessary in this particular situation to incorporate a delay prior to activation of the induction fans.

The operation of the induction ventilation system described above is detailed in the table below.

Mode	Detection Criteria	Induction Fan operations	Extract fan operations
Low Pollution Mode	CO <30ppm	None	None
Normal Pollution Mode**	CO =>30ppm*	Induction Fans operate	Extract fans operate to provide 3AC/H
High Pollution mode**	CO =>50ppm*	Induction Fans operate	Extract fans operate to provide 6AC/H
Emergency mode***	Smoke / fire is detected*	Induction Fans operate	Extract fans operate to provide at least 10AC/H

Table 2 – Cause and Effect

Notes
* Detected from any sensor within the car park.
** When activated, the system will operate for 15 minutes. If CO rises above the next threshold during this time period the system will ramp up, and the 15 minute period will start again. If the pollution levels detected are below the required threshold after the allotted 15 minutes, the system will revert back to the required mode of operation.
*** System will operate until reset by the fire brigade.

As the induction ventilation system has been designed to operate during day-to-day ventilation and to clear the smoke in case of a fire the induction fans and main fans will be fire rated to 300°C/1hr. Furthermore, the wiring of the extract fans will be done with FP600 cables, whilst the induction fans will be wired using FP400 cabling.

The fans and all associated control equipment will be wired in protected circuits such that continued operation may be ensured in the event of a fire. The discharge point of the extract fans must be located such that smoke and products of combustion exhausted from the car park do not impinge upon neighbouring structures or properties.

3.0 CFD MODELLING OF CAR PARK

Computational Fluid Dynamic Modelling (CFD) simulations are carried out to evaluate CO control ventilation and the smoke clearance ventilation.

The CO control ventilation will be assessed by simulating the proposed strategy in a steady state simulation. The occurrence of non-ventilated areas is analysed.

The smoke clearance ventilation will be assessed by a fire model. In accordance with BS7346 Part 7 it is assumed two cars are involved in the fire. The fire used in the model is an 8MW fast growth rate fire (with t^2 term C=0.0469). The fire grows up to 8MW where it remains at a constant heat release rate until 900 seconds into the simulation, at which point the Fire Service are assumed to have extinguished the fire. The objective of the smoke extract system is to assist with the removal of heat and smoke from the car park following fire fighting activities.

Figure 2 below shows the location of the extract fans and induction fans for both environmental and fire conditions.

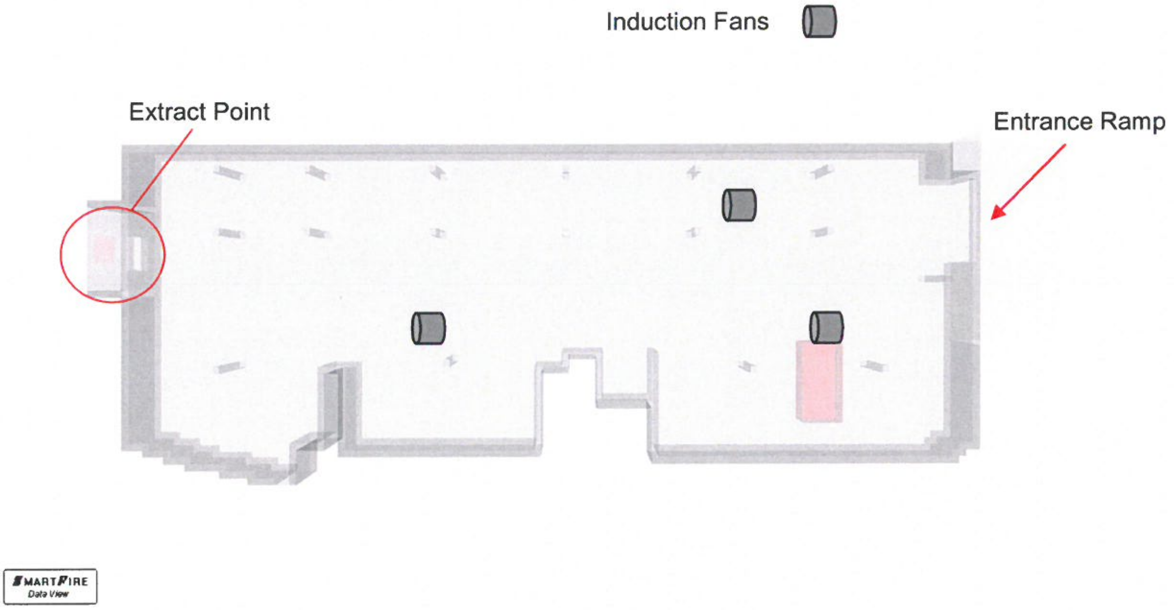

Figure 2 – CFD Model of Car Park

3.1 Global Assumptions

Fan operation in case of CO control

The CO production is continuous with the air management system operating. In order to control the CO concentration, the extract fans will run at 3 air changes per hour if the system registers 30PPM and the induction fans will run. Air is naturally supplied to the parking though the ramp. The extract fans will step up to 6 air changes per hour if the system registers 50PPM and the induction fans continue to run.

In the event of a fire / smoke detector operating the system will switch directly into fire mode.

Fan operation in case of fire

In case of fire the ventilation system is turned onto full extraction mode when the smoke and / or heat are detected. At this stage at least 7.0m^3/s will be exhausted and air will be supplied via the ramp.

Fluid dynamics modelling

The fluid properties in the model are based on the properties of air. Air enters and leaves the calculation domain through openings and extract grilles. Induction fans are positioned directly below the ceiling. The induction fan is modelled in order to give a momentum source to the air inside the fan. This momentum source is calculated based on the properties indicated by the fan manufacturers.

3.2 Attributes

CO sources

The simulation is carried out for a 12.5% full car park during environmental model. A car fire was used during smoke clearance mode.

The cars themselves are not modelled however a source of CO is provided where the exhaust of the car is expected to be located (0.4m from the floor). The locations of the CO sources are evenly spread throughout the car park.

Fire Modelled

The fire used during smoke clearance model was an 8MW fast growth rate fire (with t^2 term C=0.0469). The fire grows up to 8MW where it remains at a constant heat release rate until 900 seconds, where it is considered that the fire service will extinguish the fire.

Induction fans

The induction fans are modelled in respect to the manufacturing drawings and information. Details are included in the model in order to create a realistic airflow in the induction fan. Inside the ventilator a sub domain gives a momentum to the air inside.

Supply and exhaust

The design of the ventilation system includes natural supply and mechanical exhaust.

The opening areas are modelled in respect to the delivered drawings. All natural openings in the model are described as static pressure openings with entrained inflow. The relative static pressure is set at value 0 Pa.

CFD Model

Fire Field (CFD) Modelling has been carried out to show some of the typical worse case scenarios that could be experienced in enclosed Car Parks and the effectiveness of various mechanical ventilation systems in mitigating the effects of both fires and CO exhausts within the structure. The fire field modelling program used is Smartfire. The software has been developed by the University of Greenwich Fire Safety Engineering Group (FSEG) and has been used in a bench mark study carried out for the Home Office (ODPM) Fire Research Division to validate various Fire Field Models.

4.0 ENVIRONMENTAL ANALYSIS

The model uses a number of cars throughout the car park as sources of Carbon Monoxide (CO) gas from their exhausts. These sources represent 12.5% of the car park capacity as active. The 12.5% capacity has been based on statistical observations of similar sized car parks over a peak activity period.

The individual CO emission rate from a single car was established as 0.125 litres/s. This figure was derived based on the minimum pass standard for CO Emissions from the UK MOT Test. To be conservative this figure was based on a higher than average engine size of 2 litres (i.e. 2000 cc) which yielded the typical figure of 0.125 litres/s of CO produced at idle. This emission rate figure was then scaled up based on the frequency of cars that are expected to be active based on the assumed 12.5% capacity.

The CFD modelling produces iso-surfaces of Carbon Monoxide mass fraction (i.e. kg of CO per kg of air). This can easily be interpreted as a ppm mass fraction by multiplying by 10^6. Additionally pressures and velocities are available in the results files.

The modelling assumes that there are 4 cars running throughout the simulation. For modelling purposes the cars are assumed to be stationary. Cars in the car park each produce a plume of slightly warmed (at 27 degrees C) exhaust gasses with an effective emission rate of Carbon Monoxide of 0.125 litres/s.

The system uses a main exhaust fan at $4.2m^3/s$, as shown in Table 1 in Section 2.1, and the induction fans will run. The analysis shows that the system will provide a reasonable CO clearance from the car park. As indicated, the fact that the sources are stationary throughout the simulation is physically unrealistic but helps to give confidence that the typical dispersal of CO exhaust emissions would be adequately handled by the ventilation system.

The inlet air that flows into the car park is entrained by induction fans that induce the air to travel from the right towards the top left -hand side of the car park where the extract point is located. The direction of the airflow in this case ensures that regardless of the location of the CO production, the pollutants will be entrained by the induction fans and induced to away from the source and out of the car park.

CFD outputs below demonstrate that even when the CO output is continuously running the CO rate of 30ppm is not exceeded throughout the car park. Traces of higher quantities are seen but these are from the output sources and are quickly dispersed. The results show that the CO emissions across the main space are below this criterion.

4.1 Environmental Analysis Results

4.1.1 CO Outputs

Figure 3 – 300 Seconds

Figure 4 – 600 seconds

Figure 5 – 900 Seconds

Figure 6 – 1200 Seconds

Figure 7 – 1500 Seconds

Figure 8 – 1800 Seconds

4.1.2 Velocity Output

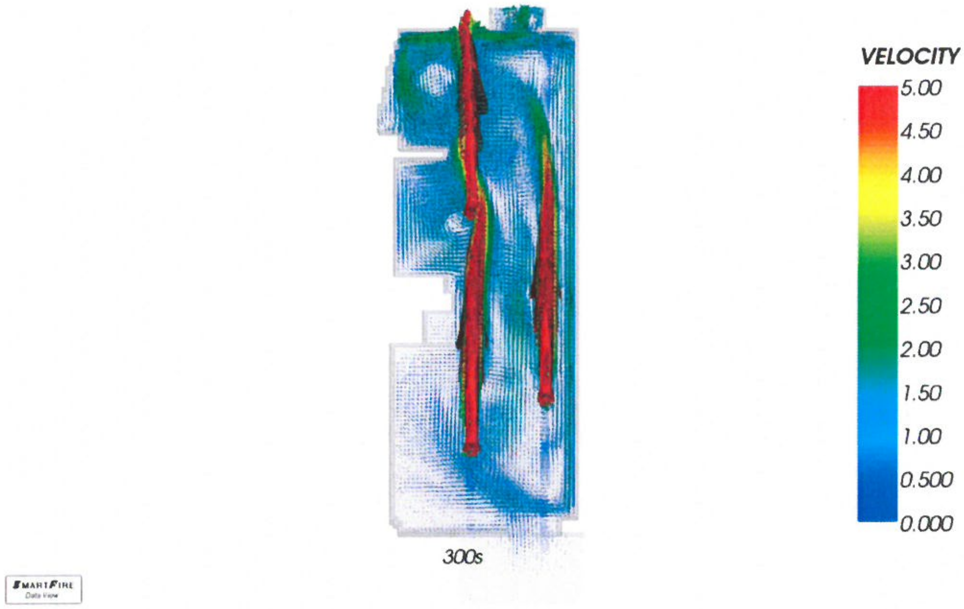

Figure 9 – 300 Seconds

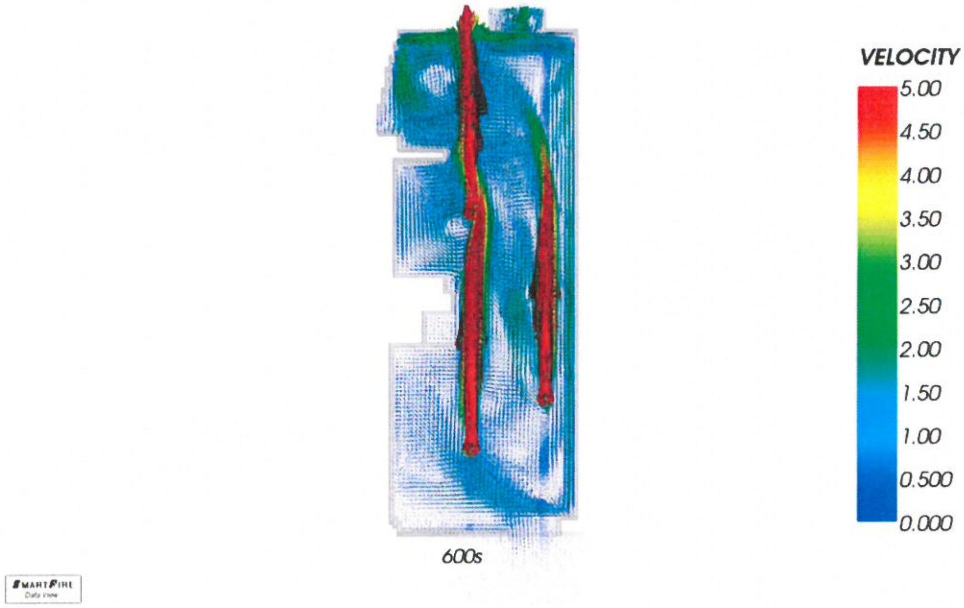

Figure 10 – 600 Seconds

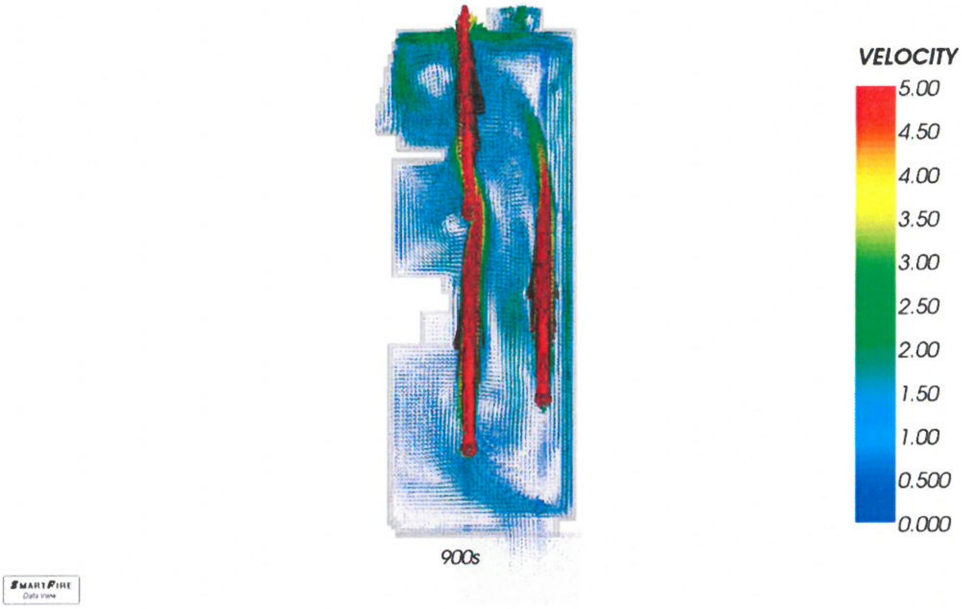

Figure 11 – 900 Seconds

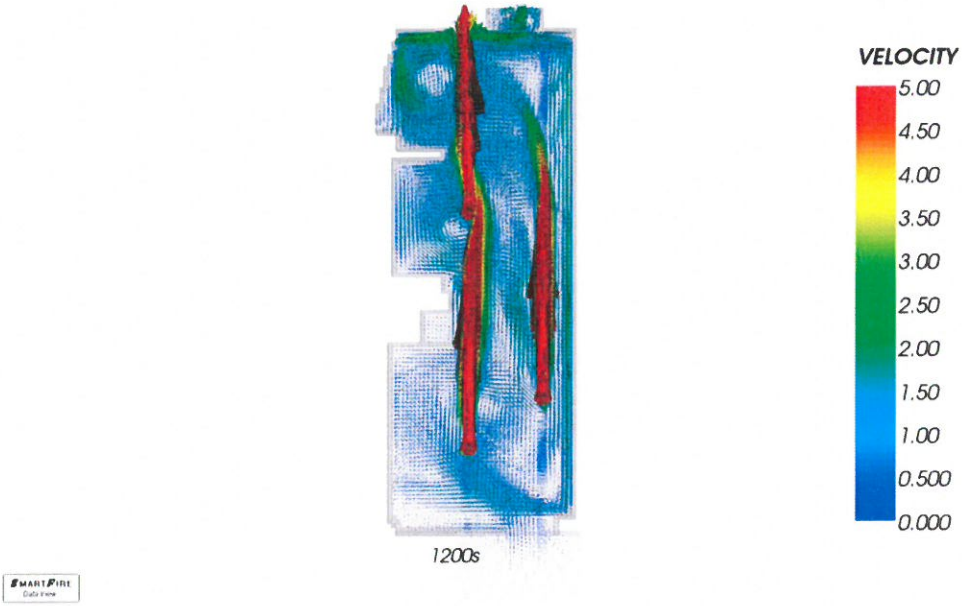

Figure 12 – 1200 Seconds

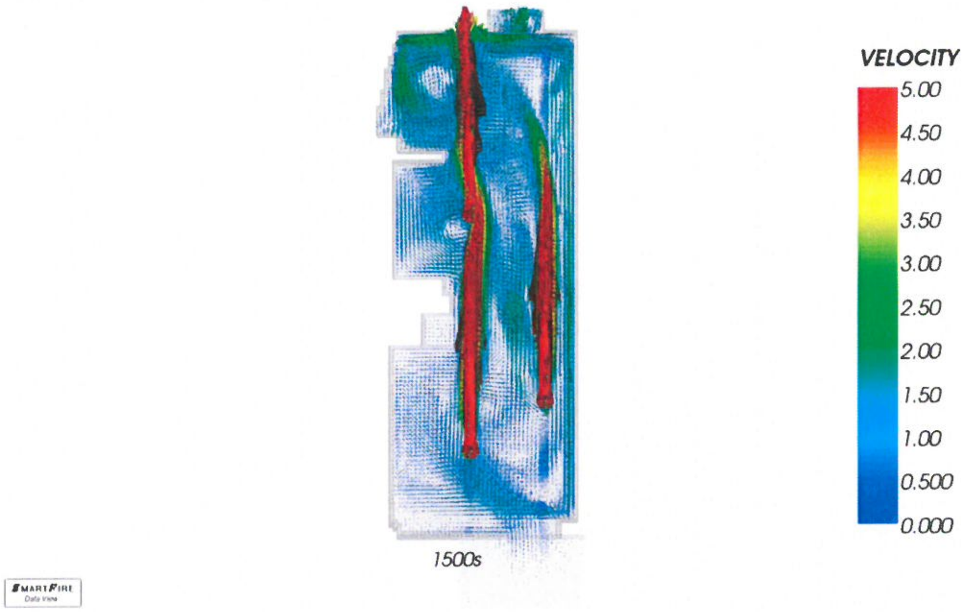

Figure 13 – 1500 Seconds

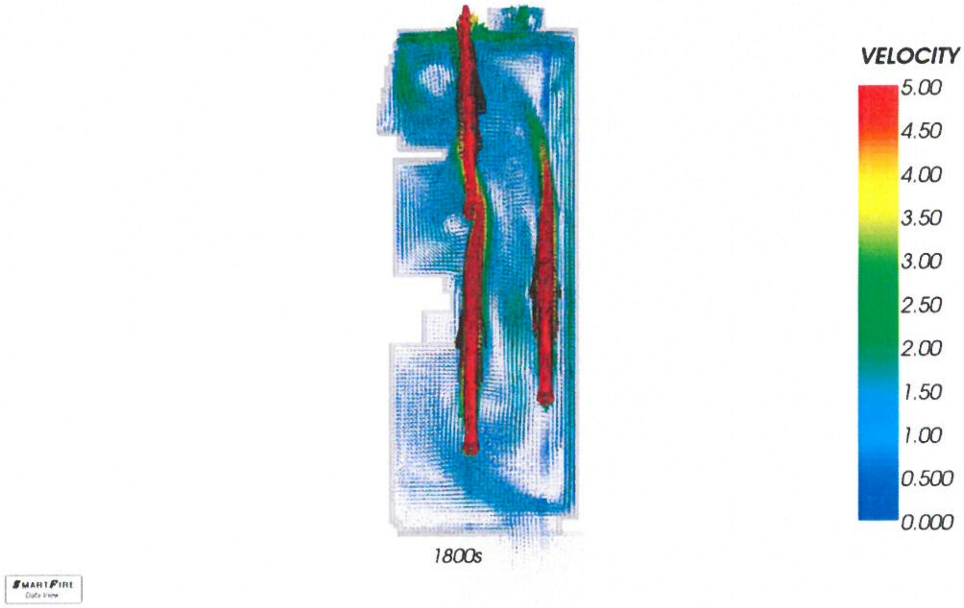

Figure 14 – 1800 Seconds

5.0 SMOKE CLEARANCE ANALYSIS

As described previously no sprinkler system will be provided within the car park and therefore a two car fire has been considered in accordance with BS7346 Part 7. The fire used in the model was an 8MW fast growth rate fire (with t^2 term C=0.0469). The fire grows up to 8MW where it remains at a constant heat release rate until 900 seconds, where it is considered that the fire service will extinguish the fire.

The system uses a main exhaust fan at 7.0m^3/s as shown in Table 1 in Section 2.1 and the induction fans will run. The analysis shows that the system will provide a reasonable smoke clearance from the car park.

The inlet air that flows into the car park is entrained by the induction fans that induce the air to travel around the car park to where the extract point is located. The direction of the airflow in this case ensures that regardless of the location of the car fire, the smoke produced will be entrained by the induction fans and cleared from the car park.

The CFD modelling uses a variable time step size with time steps sizes of between 0.01s and 5.0s depending on the prevailing conditions. Small time step sizes are used to accurately model those periods where there are critical changes in flow rate or geometry (e.g. just after a change in fan rate). This is necessary to ensure that the model is able to correctly calculate the increased flow and is suitably stable over periods of maximal change. A pre-configured regime is used to bring the time step back up to the prescribed time step size, after any such critical event.

The following describes the smoke (in kgm^{-3}) and velocity (in m/s) profiles throughout the model. The model has been allowed to stabilise by running for extended periods of time.

Most of the outputs seen in the model slices are easy to read. In most cases an iso-surface data visualization capture is also included. This shows the value of the output results, such as the temperature or pressure at a particular simulated time. When viewing the smoke visibility, the iso-surface shows a critical mass fraction (kg of smoke per kg of air) concentration of smoke. This iso-surface value can be interpreted as an approximate visibility in metres. The way in which this is converted is as follows:

S (light emitting visibility) = 8 / K

Where,

$K \approx 7.6 \times 10^3 m_s$

K is the light extinction co-efficient (m^{-1}) and m_s is the mass concentration of smoke (kgm^{-3}). For practical purposes a smoke mass fraction iso-surface at 1.05e^{-4} is used to show the extent of the region that has a visibility distance of 10m or less (lower value iso-surfaces are also displayed – representing progressively higher visibility distances – to definitively show the clear air region).

5.1 Smoke Clearance CFD Results

5.1.1 Smoke Outputs

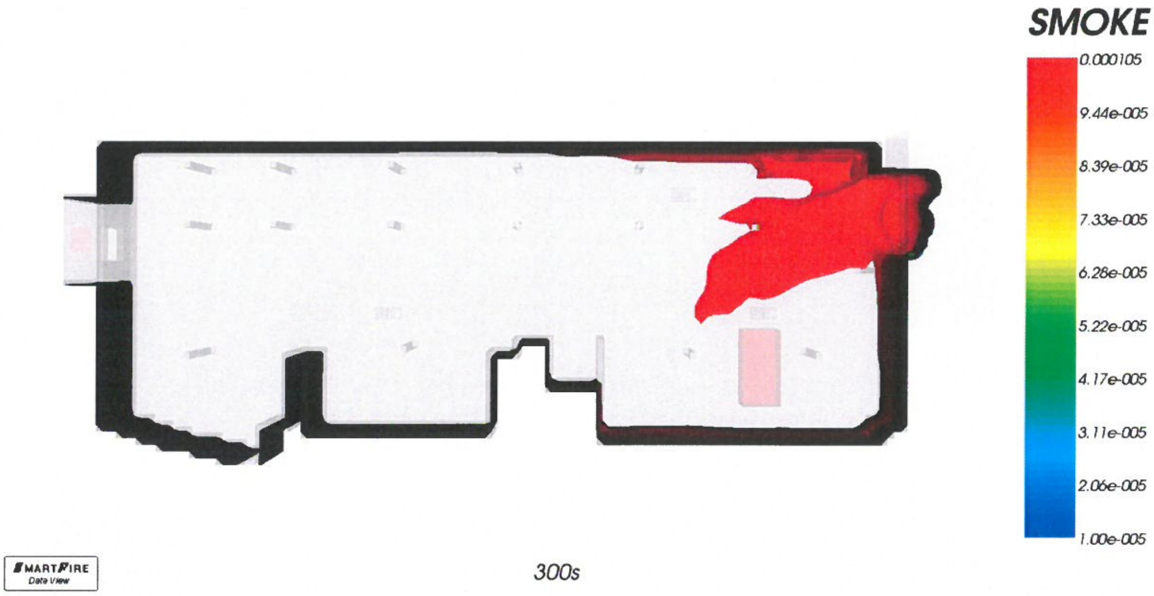

Figure 15 – 300 Seconds

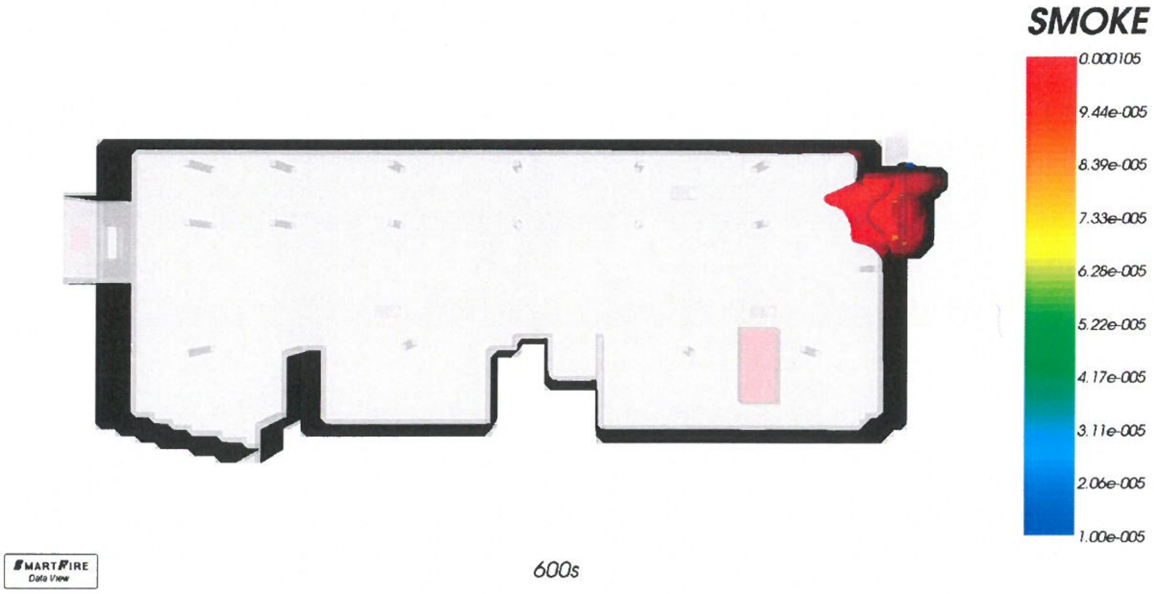

Figure 16 – 600 seconds

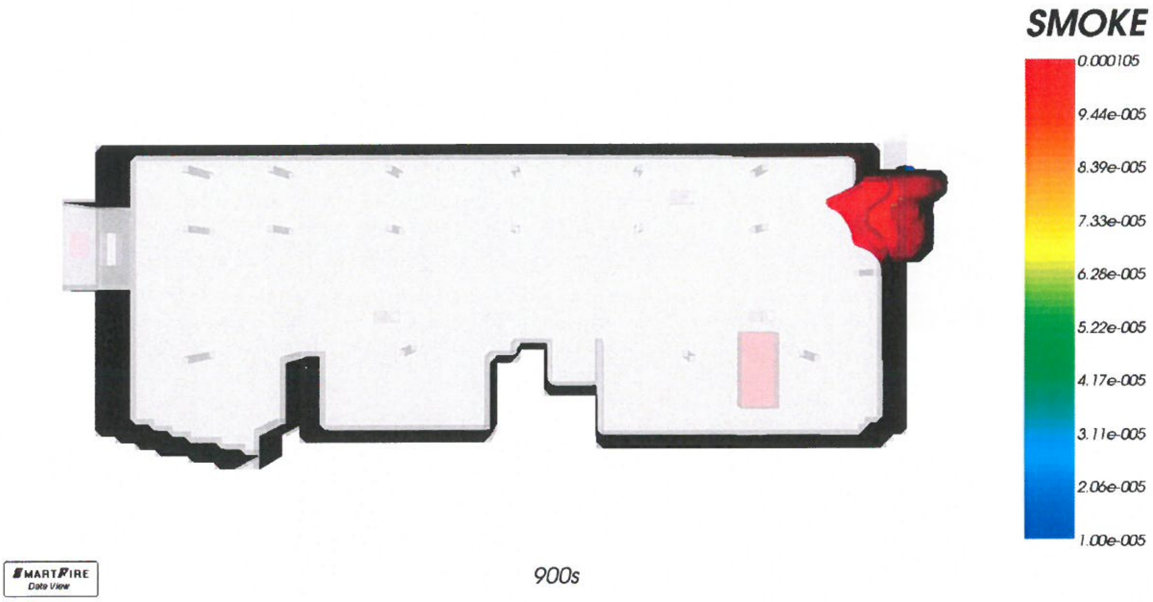

Figure 17 – 900 Seconds

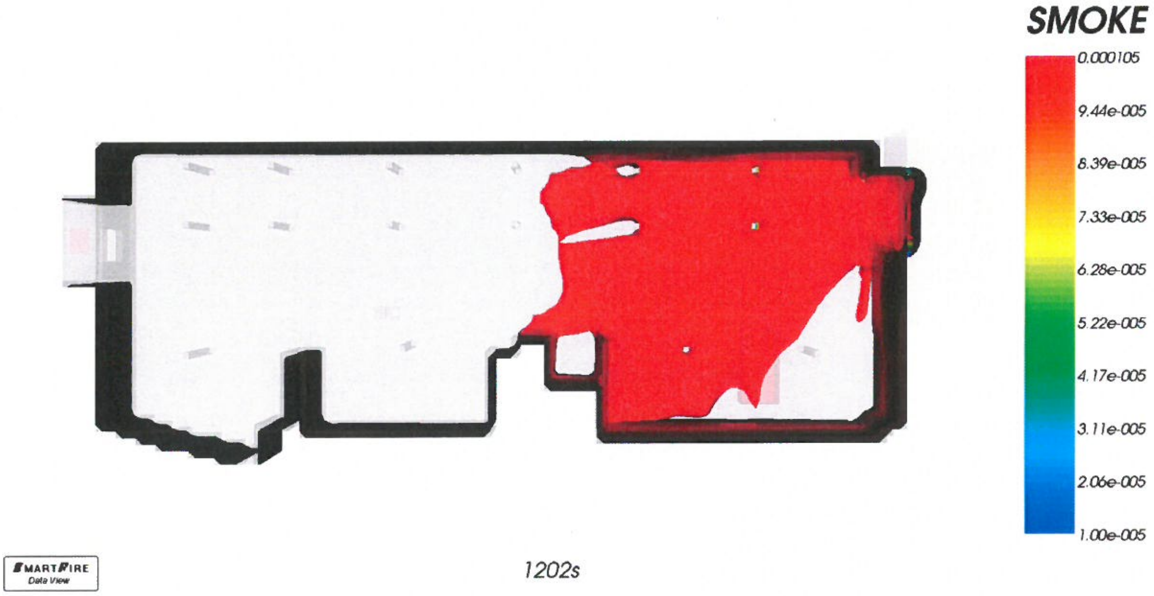

Figure 18 – 1200 Seconds

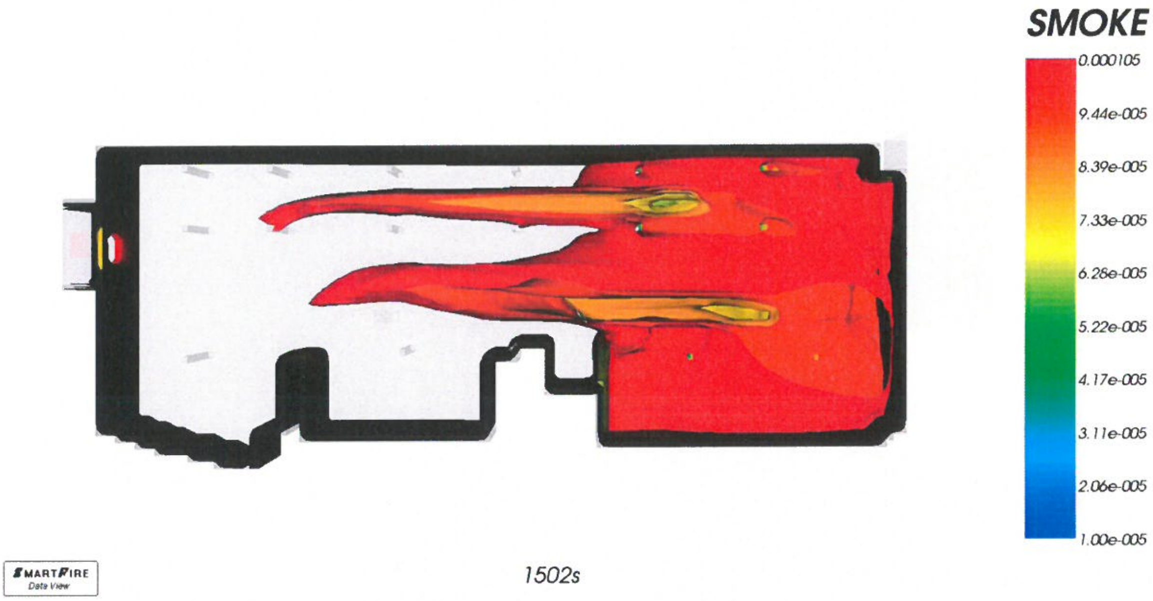

Figure 19 – 1500 Seconds

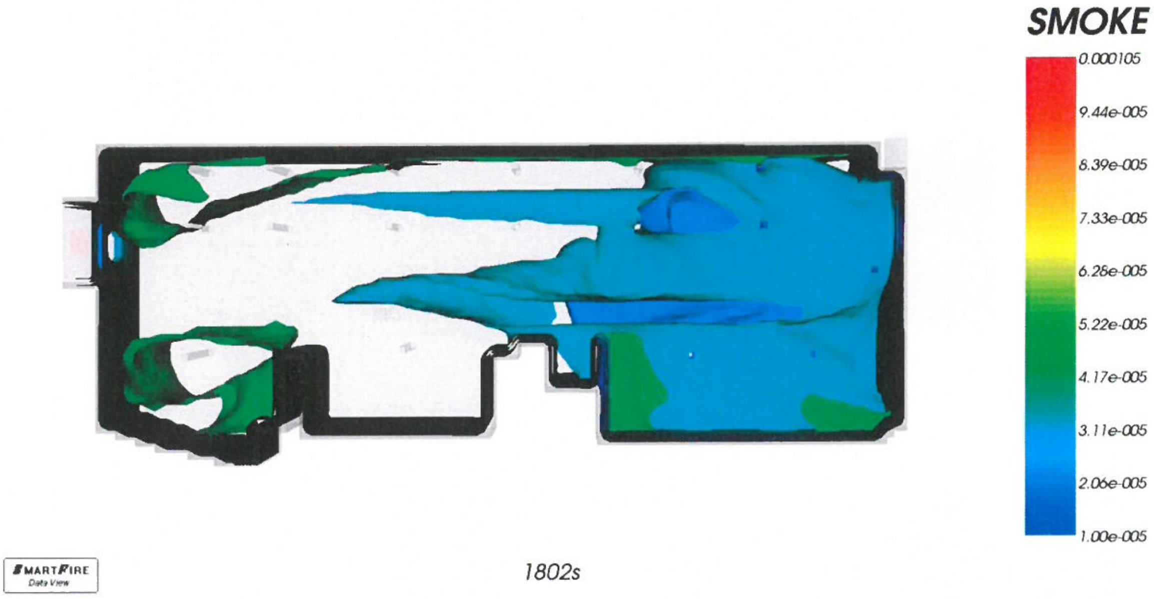

Figure 20 – 1800 Seconds

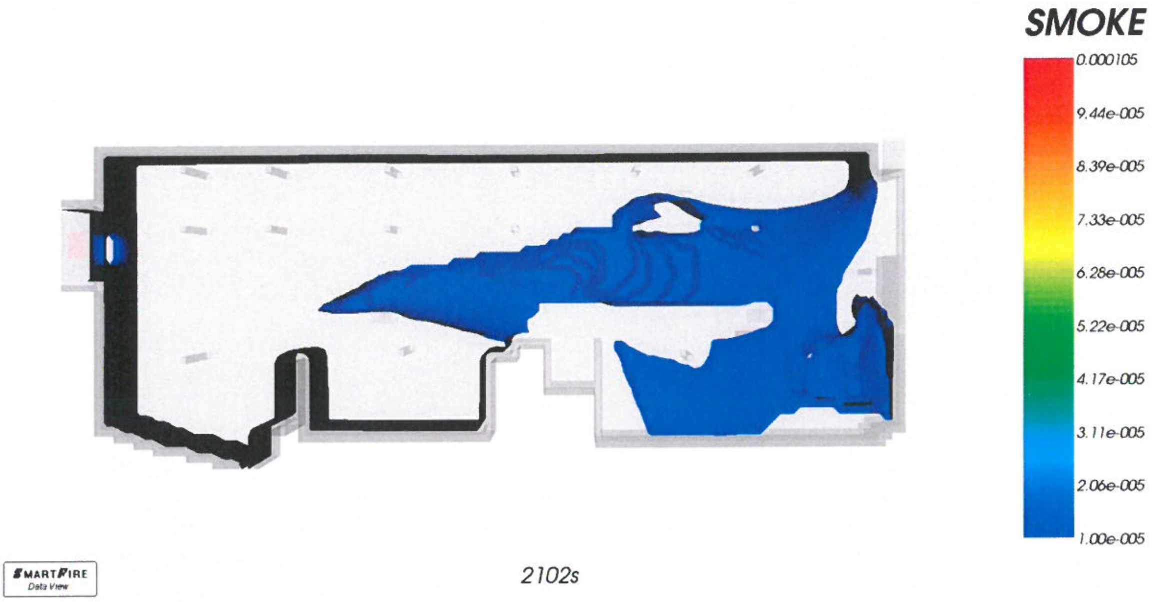

Figure 21 – 2100 Seconds

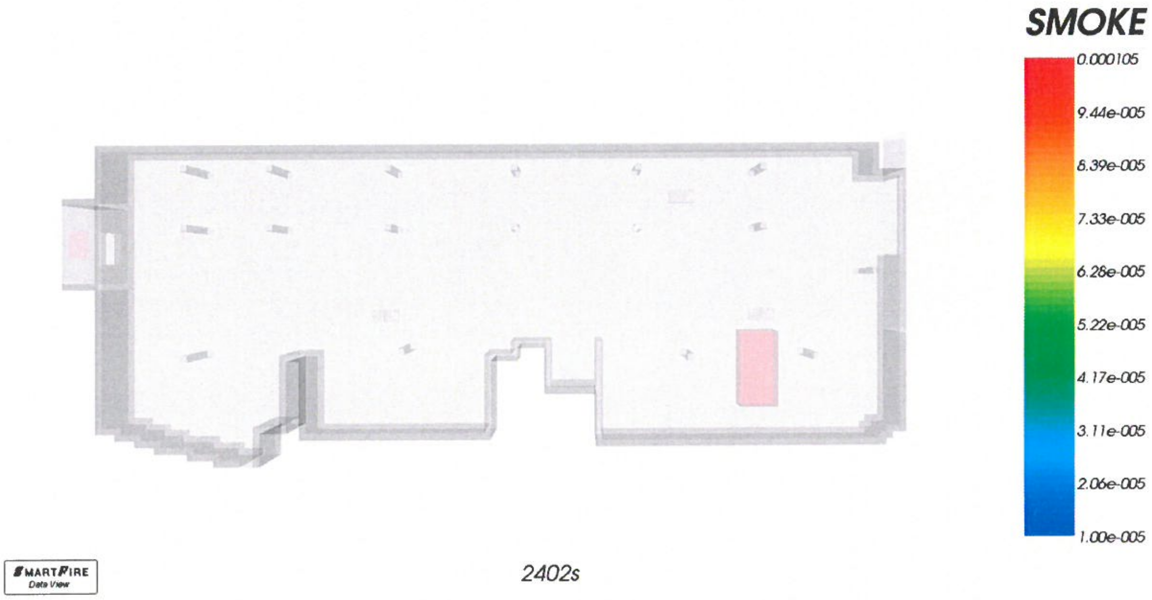

Figure 22 – 2400 Seconds

5.1.2 Velocity Output

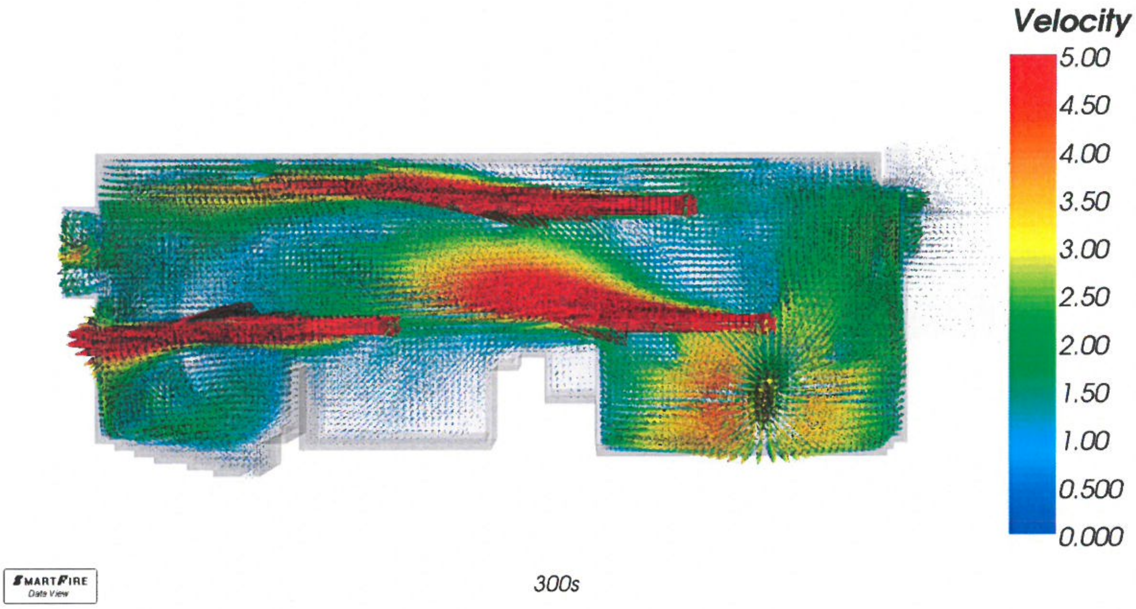

Figure 23 – 300 Seconds

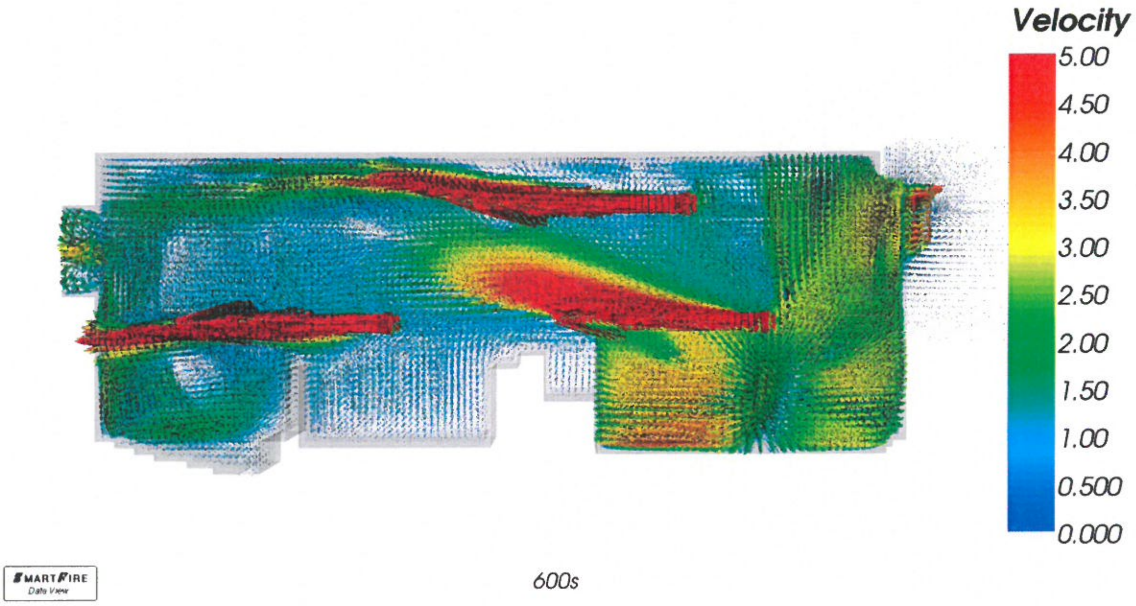

Figure 24 – 600 Seconds

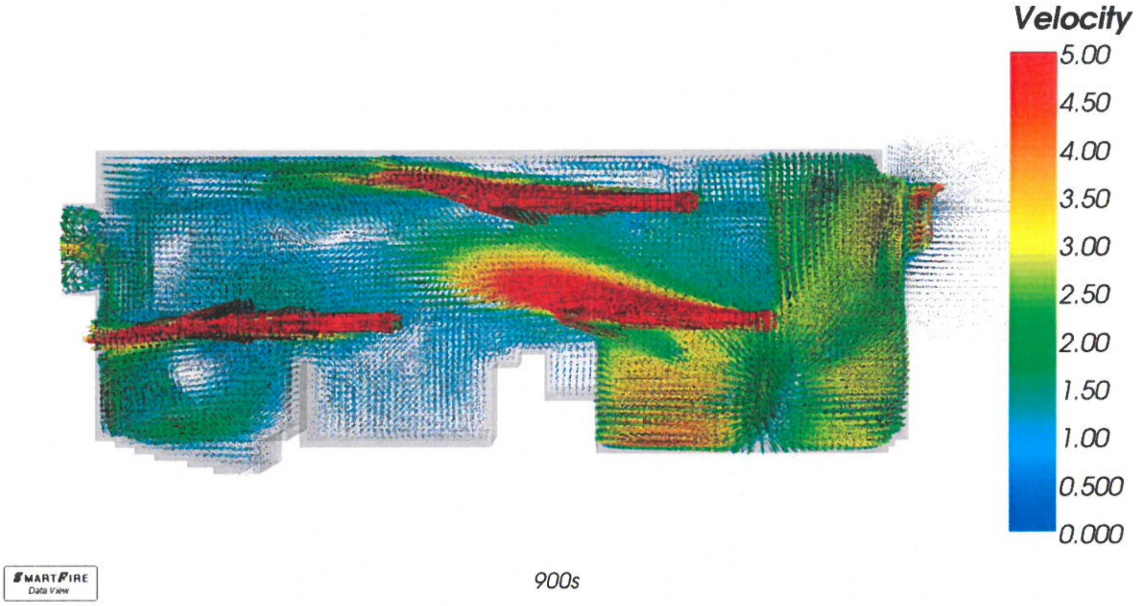

Figure 25 – 900 Seconds

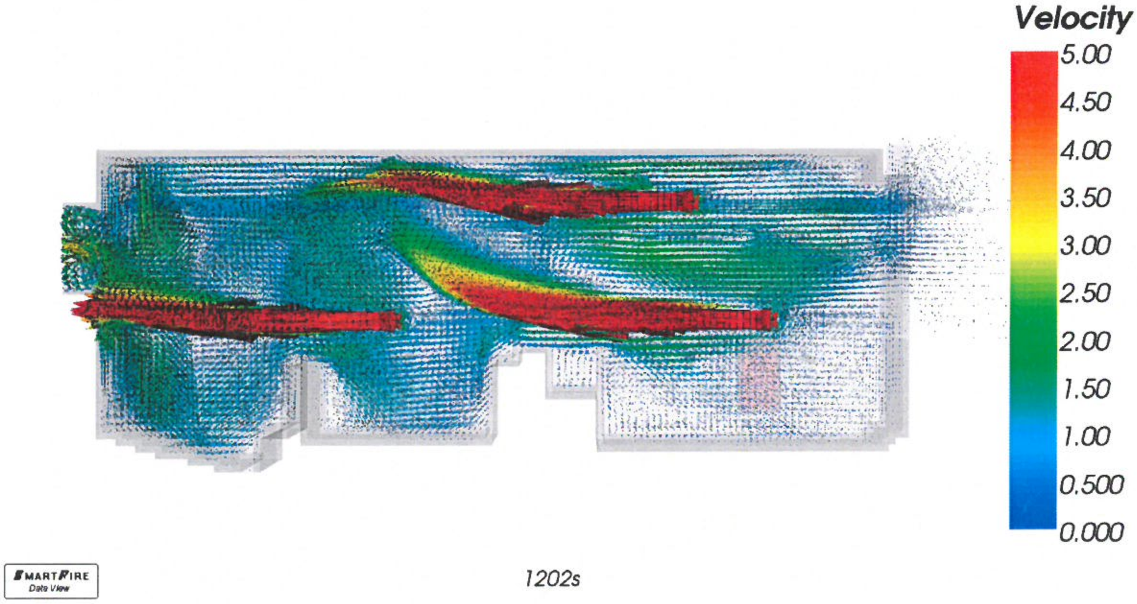

Figure 26 – 1200 Seconds

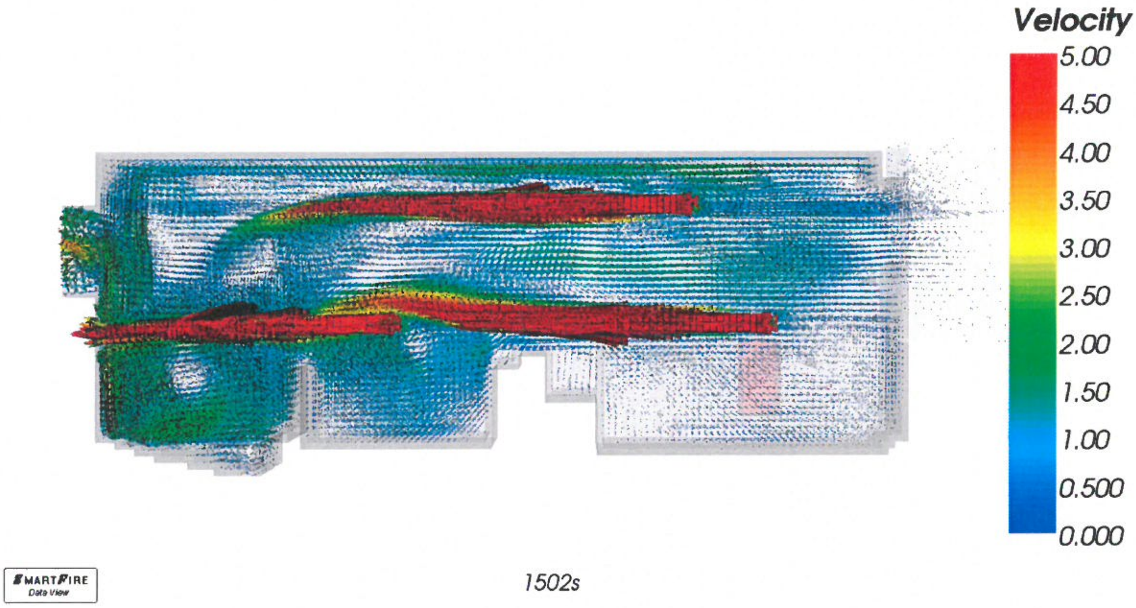

Figure 27 – 1500 Seconds

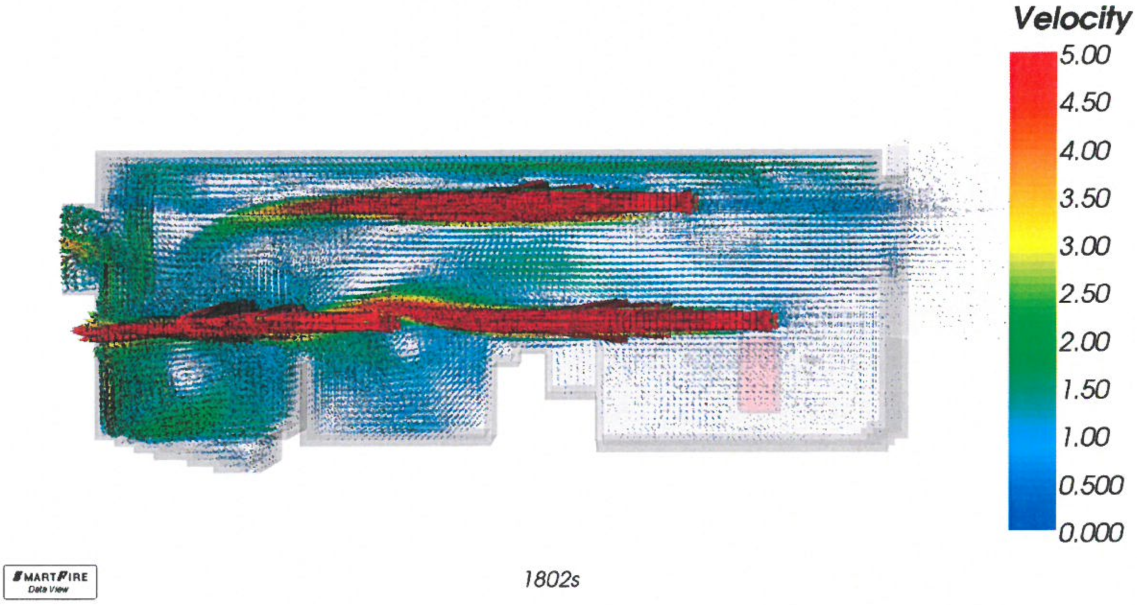

Figure 28 – 1800 Seconds

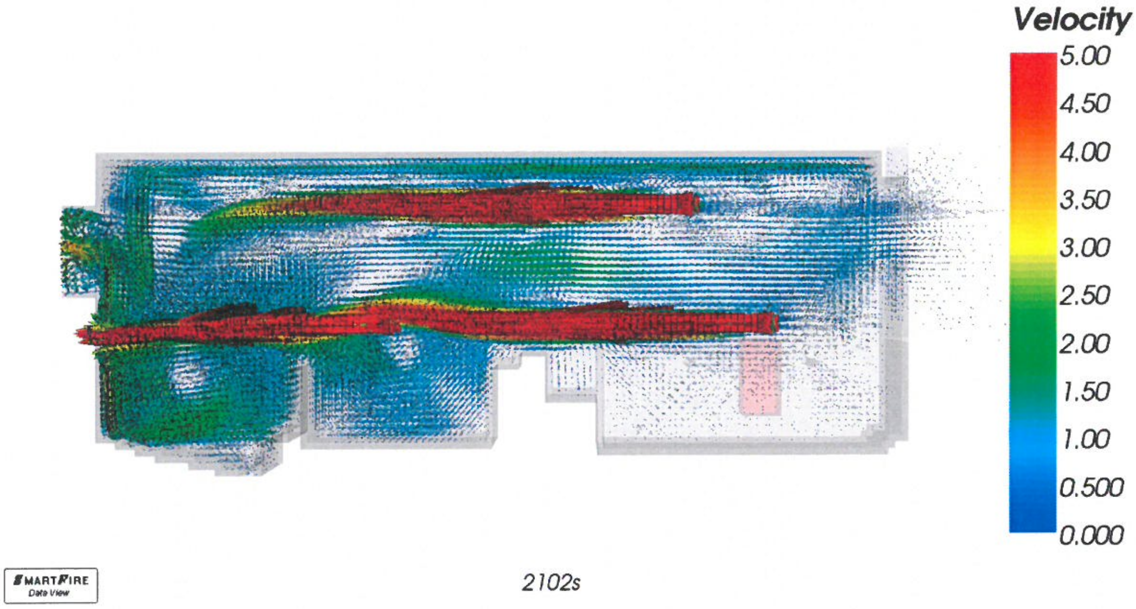

Figure 29 – 2100 Seconds

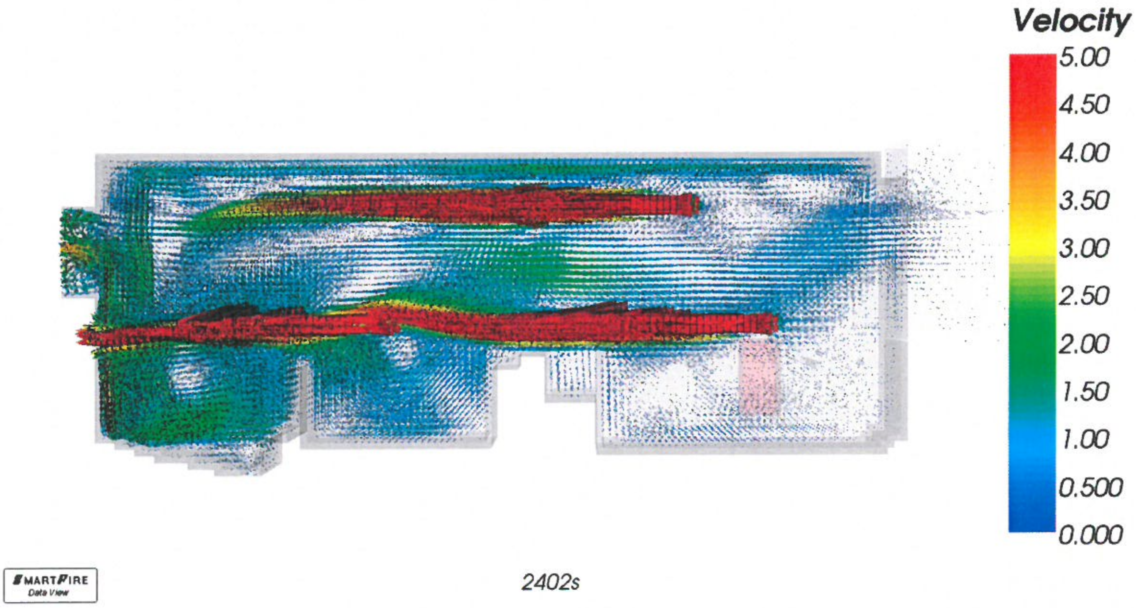

Figure 30 – 2400 Seconds

6.0 CONCLUSIONS

The system creates air movement in the whole parking volume, with enough movement to dilute and exhaust CO concentrations. It is not likely that there will be any CO accumulation within the parking volume. The ventilation system works properly during this operation.

The modelling also demonstrates that the system can provide good smoke clearance provided that ample make-up air is available from across the car park (away from the extraction point), which is achieved in this case.

The wind effects on the system are not critical because the system is a mechanical system designed to overcome pressure drops. In most cases, additional airflow will actually provide better smoke and heat clearance, within the structure.

Based on the presented results in this report the conclusion can be drawn that the induction ventilation system during CO control and smoke clearance is sufficient and creates a good situation for both fire fighting and general day to day environmental ventilation.

The requirements of the building regulations for environmental and smoke clearance are satisfied.

APPENDIX A – OVERVIEW BENCHMARK STUDY

The purpose of the proposed standards/benchmarks is to aid the fire safety approvals authority in assessing the appropriateness of using a particular model for a particular fire modelling application. This benchmark has been split into two phases. The first phase is intended to test all the software products using identical or equivalent models. The second phase of testing allows the full range of the software's capability to be demonstrated. In each phase, five non-fire (CFD) and five fire cases are tested.

The first phase of the testing programme has been successfully completed. In studying the outcome of the Phase 1 test cases, it is clear that when identical physics is activated, identical computational meshes used and similar convergence criteria applied, all of the software products (PHOENICS, CFX and SMARTFIRE) tested is capable of generating similar results. This is an important observation and suggests – within the limitations of the tests undertaken – that these three codes have a similar basic capability and are capable of achieving a similar basic standard. While there are minor differences between the results generated by each of the software products; on the whole they produce – for practical engineering considerations – identical results. From a regulatory viewpoint, it is reassuring to have an independent verification of this similarity.

The one area that showed relatively poor agreement between model predictions and theoretical results concerned the six-flux radiation model performance. The six-flux radiation model while capable of representing the average trends within the compartment does not produce an accurate representation of local conditions.

CFX, PHOENICS and SMARTFIRE all provide alternative radiation models which may offer superior performance. This has been demonstrated for the CFX 12-ray Shah-Lockwood model within this document. It should be noted that the six-flux model was used as it was common to both PHOENICS and SMARTFIRE, and CFX could be made to crudely approximate the six-flux model. However, CFX does not possess a six-flux model and so the Shah-Lockwood model was used with a single ray to give the closest approximation possible to the six-flux model. It should be noted that the developers of CFX generally advises that the CFX radiation model should never be used with a single ray. As mentioned previously the intention of phase-1 was to test the codes in as similar a manner as possible to try and give an unbiased reflection of how the codes compared. This task would not have been possible unless the CFX single ray radiation model was used.

A significant – and somewhat reassuring - conclusion to draw from these results is that an engineer using the basic capabilities of any of the three software products tested would be likely to draw the same conclusions from the results generated irrespective of which product was used. From a regulators view, this is an important result as it suggests that the quality of the predictions produced are likely to be independent of the tool used – at least in situations where the basic capabilities of the software are used.

A second significant conclusion is that within the limits of the test cases examined and taking into consideration experimental inconsistencies and errors, all three software products are capable of producing reasonable engineering approximations to the experimental data, both for the simple Computational Fluid Dynamics (CFD) cases (i.e. non-fire cases) and full fire cases.

An important element of this work concerned the procedures for undertaking the testing. While all of the test cases using all of the codes were run by a single organisation – in this case the Fire Safety Engineering Group (FSEG) at the University of Greenwich – the code developers also were requested to run an independent selection of the test cases as specified. This was necessary to verify that the results produced in this report are a true and fair representation of the capabilities of the various software products under the specified test conditions. This has proven to be quite useful as it brings the developers into the benchmarking process and it eliminates issues concerning fairness and biased reporting of results.

What remains to be completed at this stage are the Phase 2 results produced by the other testers. In Phase 2, the modellers are free to select which of the test cases to repeat using the full capability of their software to give the best possible representation of the case. These results will then be checked by FSEG for their veracity.

Finally, the concept of the Phase 1 testing protocols has been shown to be a valuable tool in providing a verifiable method of benchmarking and gauging the basic capabilities of CFD based fire models on a level playing field. To further improve the capabilities of the approach, it is recommended that additional test cases in the two categories (basic CFD non-fire and fire) be developed.