The authors of this report are employed by BRE. The work reported herein was carried out under a Contract placed on 30th November 2005 by the DCLG. Any views expressed are not necessarily those of the DCLG.

ODPM Final Research Report :

BD2539

A study of the effectiveness of 100mm up-stand between integral garages and associated dwellings

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CI 71-5-30

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Fire Safety

BD 2539

A study of the effectiveness of 100mm up-stand between integral garages and associated dwellings

Final Research Report

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Executive Summary

The current version of Approved Document B (AD B) that supports the fire safety aspects of the Building Regulations includes a provision for the inclusion of a 100mm up-stand between integral garages and dwellings. This provision is intended to reduce the risk of petroleum vapour from entering the dwelling.

Experience has suggested that this provision may have caused some access difficulties for disabled people seeking to enter the dwelling from the integral garage.

A similar provision in the Scottish Technical Standards has been deleted from the current requirements in Scotland.

In support of the review of Part B of the Building Regulations DCLG Buildings Division commissioned this study to determine the effectiveness of the garage upstand in preventing the ingress of petroleum vapour into the dwelling and the risks to the occupants that might arise should this provision be removed (or replaced with an alternative proposal e.g. sloping floor) from the soon to be revised AD B.

The study involved a technical review of relevant fire statistics, research/experimental data, modelling and forensic research data from domestic fires involving accelerants within storage areas attached to domestic properties such as garages.

Of the 19 reported fire incidents between 2004 and 2006 involving domestic garage fires, none were attributed to a fuel leak.

The experimental data suggests that the 100mm up-stand does provide protection against liquid fuel spills running under doorways between the dwelling and garage and although it was demonstrated that spills of fuel would splash on to surfaces above the garage upstand, this is unlikely to create a flammable hazard in the adjoining room.

As part of the literature review, data was sought on the evaporation rate associated with petroleum. Since none could be identified, an experimental determination was undertaken at ambient laboratory conditions (nominally 15^{o} C), to provide an indicative figure for the CFD model calculations.

Using these ambient temperatures of around 15^{o} C, a CFD simulation indicates that the garage upstand will prevent flammable vapours associated with a fuel spill of less than 5 litres from entering an adjoining room.

However, in practice a number of factors will influence the evaporation rate, including the spill area, the local air and liquid temperature, air flow rate over the liquid and any thermal radiation from surroundings. The upstand will be less effective under increased ambient temperatures since this will increase evaporation rates therefor making it more likely that flammable fuel vapours from a spill could enter an adjoining room.

The study has shown that the garage upstand does also prevent liquid (potentially flaming) fuel from entering an adjoining room.

The upstand will prevent the flammable vapours associated with small spills entering an adjoining room under limited ambient conditions but is unlikely to prevent flammable vapours associated with larger spills and higher ambient temperatures.

In the absence of an upstand, liquid fuel could enter an adjoining room unless the floor is designed to fall away from the entrance to the adjoining room. The garage floor covering should be designed so as not to ‘retain’ the fuel.

Contents

1 Introduction and Objectives

This study was commissioned by DCLG Buildings Division to undertake the following project titled “A study of the effectiveness of a 100mm up-stand between integral garages and associated dwellings”. DCLG Contract reference CI 71/5/30, BD2539.

The aim of this project is to produce a short research report to review the provision of garage up-stands in the revised AD B.

The following tasks were identified to meet the objectives of this project:

- Task 1 – Technical review of relevant fire statistics, research/experimental data, modelling and forensic research data from domestic fires involving accelerants within storage areas attached to domestic properties such as garages.
- Task 2 – Experimental programme to support Task 3.
- Task 3 – Simple CFD model to review dispersal flow characteristics.

2 Programme of work

2.1 Task 1

2.1.1 Review of recorded fire incidents

Utilising data collected as part of other ODPM projects 19 incidents were identified from press articles as potentially involving domestic garage fires during the period April 2004 to January 2006. In none of the cases where the source of the fire was identified, was a fuel leak implicated as the cause of the fire.

Some examples of domestic garage fires include:

2.1.1.1 Garage, South-East London, 9th May 2004

One person was missing, feared dead, and other suffered second-degree burns after an explosion at a private garage that occurred at 2057 BST on the 9th May 2004. The cause of the fire was believed to be an exploding gas cylinder. Fire fighters evacuated about twenty neighbouring homes as the garage contained a further four cylinders. The A2 was closed between the Black Prince and Danson Interchanges as a precaution. This led to gridlock on the surrounding roads. There were also westbound tailbacks from the M25.

2.1.1.2 Domestic garage, West Sussex, 15th April 2005

A domestic garage was badly damaged after it was struck by a bolt of lighting during a thunderstorm. The incident occurred at about 1700 BST on the 15th April 2005. Fire crews arrived to find the garage well alight. Fire fighters managed to stop the fire spreading to the adjoining house and to neighbouring properties.

2.1.1.3 Domestic garage, Jersey, 26th May 2005

A detached domestic garage was destroyed in a fire on the evening of the 26th May 2005. Fire crews were called to the scene at about 2240 BST; the fire services were alerted to the fire by the owner of the property. Fire fighters took approximately three hours to bring the fire under control. The cause of the fire was believed to be an electrical fault.

2.1.1.4 Domestic garage, Hampshire, 29th June 2005

A resident was treated for facial, chest and hand burns after a fire broke out in a domestic garage on the evening of the 29th June 2005. The victim was rescued by fire fighters and was transferred to a specialist burns unit. Two fire crews attended the incident.

2.1.2 Further analysis UK Fire Statistics for domestic garage fires

A review of the most recent UK Fire Statistics related to domestic garages is summarised in Table **1**. The data identified 6 potential incidents involving petrol or diesel and 1 related injury. No deaths were identified during this period.

Table 1. UK Fire Statistics on Domestic Garages

Fuel	Abnormal circumstances	Number of fires	Average spread	Injuries	Deaths
Unknown/	No	20	Beyond room of origin	3	0
Unknown/	Yes - accelerant	6	Room of origin	0	0
Unknown/	Yes - other specified	5	Building of origin	0	0
No fuel applicable eg naked flame	No	114	Room of origin	11	0
No fuel applicable eg naked flame	Yes - accelerant	8	Beyond item of origin	1	0
Mains gas	No	5	Beyond floor of origin	0	0
Mains gas	Yes - other specified	2	Beyond buiding of origin	4	0
LPG	No	3	Beyond room of origin	0	0
Petrol	No	2	Beyond room of origin	1	0
Diesel	No	4	Item of origin	0	0

2.2 Task 2 - Experimental Programme

In order to establish the key parameters involved in the potential dispersion of fuel and vapour as the result of a fuel leak within a domestic garage a number of experimental trials were undertaken. The data from this work was then used, where appropriate, to provide limited validation for the CFD model.

2.2.1 Assessment of potential fuel splash heights associated with failures from a 50 litre fuel tank.

2.2.1.1 Objective

The aim of this study was to establish how effective a 100mm up-stand would be in preventing liquid from a from a leaking tank entering attached accommodation.

2.2.1.2 Experimental set up

A 50 litre plastic tank, 300mm in depth was used for this study. Two varying hole diameters, 5mm and 30 mm, were cut into the base of the tank to investigate different leak rates.

Three parameters were examined:

a) the tank's proximity to the 100mm high up-stand (0.5m, 0.75m and 1m);

b) its height above the floor 0.3m or 0.6m; and

c) the diameter of the hole (5mm and 30mm).

In each case the leak location was 0.8m from the side wall of the mock up garage wall and the distance to the side wall was varied between 0.5, 0.75 and 1m, see Figures 1 to 4.

The above dimensions are based on a range of car sizes and the potential proximity of the petrol tank to the garage walls. It assumes the car is parked very close to the walls of a garage and that the under side of the car does not interfere with any subsequent splashing of fuel.

2.2.1.3 Experimental procedure

Table 2 summarises the various experimental configurations studied and the resultant findings. In each case, the ambient temperature was 15 deg C, and the tank was filled with 50 litres of water as a substitute for petrol. One of the holes was then opened allowing the subsequent jet of water to hit the floor. The walls of the test rig were made of plaster board which showed any splashing by the dampening on the surface of the walls. After each test a record was made of the heights at which the water made contact with either of the walls.

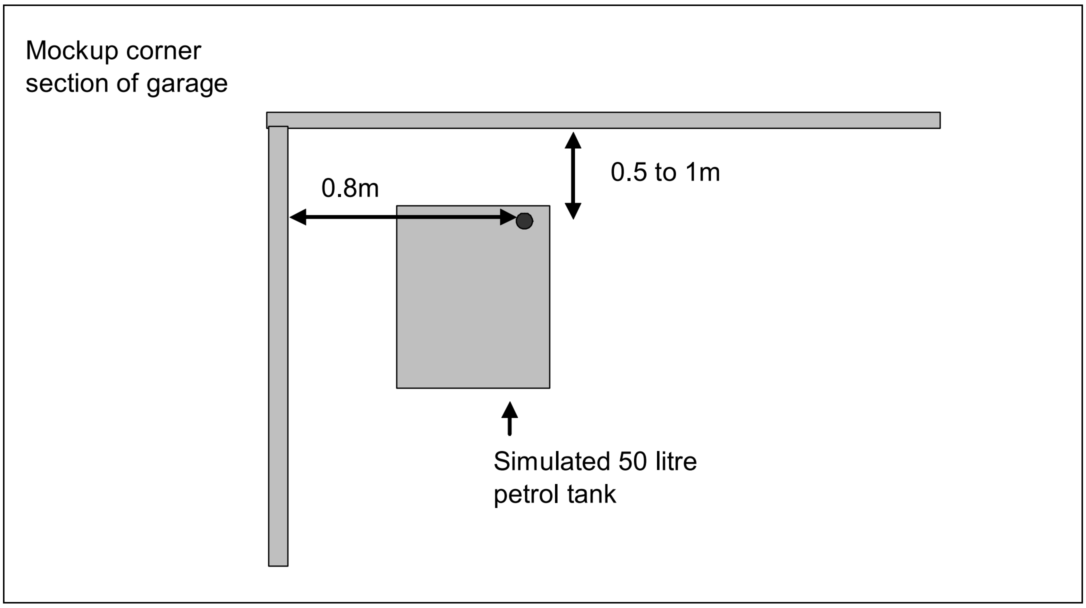

Figure 1 Plan view of splash test rig

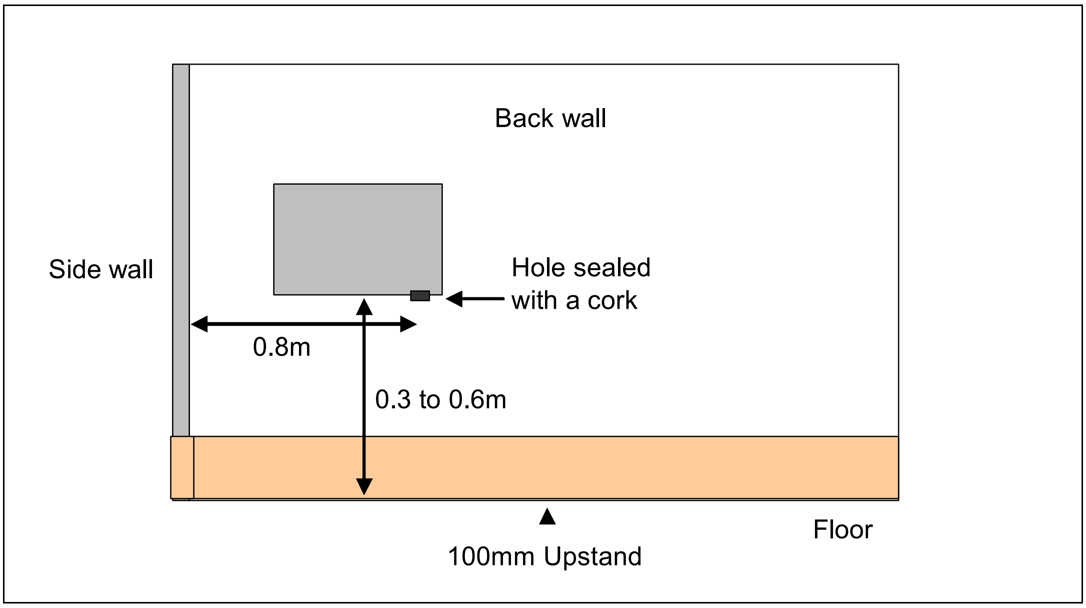

Figure 2 Elevation of splash test rig

Figure 3 Photograph of splash test rig

Figure 4 Splash test in progress

2.2.1.4 Results

Table 2. Summary of experimental configurations and findings

Test No.	Hole size (mm)	Wall distance (m)	Side wall distance (m)	Height of tank (m)	Ht. of water staining above upstand on front wall (mm)	Ht. of water staining above upstand on side wall (mm)	Comments
1	30	1	0.8	0.6	100	300	
2	30	0.5	0.8	0.6	100	100 to 150	
3	30	0.75	0.8	0.6	200	100	
4	5	0.75	0.8	0.6	50 - 100	none	(tank 1/2 full)
Repeat 4	5	0.75	0.8	0.6	150	none	Repeat of T4
6	5	1	0.8	0.6	none	none	
7	30	1	0.8	0.3	none	none	
8	5	1	0.8	0.3	none	none	

2.2.1.5 Conclusions

This study has shown that it is possible to achieve liquid splashes above the 100m up-stand line with both the 5mm and 30mm diameter leaks when the tank is placed in close proximity to the front and side walls.

2.2.2 An experimental study to provide petrol vapour dispersion data for the CFD model validation.

2.2.2.1 Objective

The objective of this part of the study was to monitor the concentration of petrol vapour at given heights within a room enclosure to simulate a petrol spill of 0.5 litres of petrol.

2.2.2.2 Experimental set up

The ISO 9705 room corner test facility was used as a mock up of a typical small garage for this study.

To reduce the risk of petrol vapour leaking from the test room interior during the experiments, the test room floor and part of the side walls were covered with polythene. Thin sheets of GRP were laid over the polythene to protect the polythene from tearing. The petrol used premium grade unleaded fuel.

The simulated petrol spill was represented by a shallow tray made from aluminium foil measuring 1m x 0.5m x 5mm and was located near the front of the room as in Figures 5 to 7, located on a ceramic board to provide thermal insulation to the fuel from the floor. The tray size was chosen so that half a litre of fuel could be examined occupying a depth of 1mm.

2.2.2.3 Instrumentation

In order to monitor the vapour concentrations in the garage a total of six stainless steel gas sample tubes were located at given heights above the test room floor at the rear of the test room as shown below. Each of these tubes was attached to a calibrated hydrocarbon laser analyser via a six way selector unit. The analyser was specifically calibrated for the petrol used in this study.

0.5mm diameter chromel alumel thermocouples were attached to the ends of each sample tube to monitor the temperature gradient within the test room.

In this study the door opening was covered, as shown in Figures 5 to 7, with a 0.1m opening at the top and bottom. The opening at the bottom of the door was to simulate a gap under a garage door opening typically 0.1m in height. The number of air changes per hour within a domestic garage has been estimated to be between 1 to 2 changes per hour. Given this rate of air change, the average air velocity expected under the garage door would be about 0.1ms^{-1}. The opening at the top of the door represents the leakage path from which the air leaves the garage.

In order to achieve the 1 to 2 air changes per hour, air was ducted into the lower door opening by a small fan which was located on the floor in front of the door. Wooden duct work was used so that the air flow did not disturb the air leaving the upper door opening.

2.2.2.4 Experimental procedure

All the recording equipment was started about 1 minute prior to the test. This provided an ambient record at each of the sampling points.

The fan was also switched on so as to establish a steady air flow though the test room. A check on the air flow was also made using a calibrated hot wire anemometer.

After a minute, half a litre of unleaded petrol was carefully poured into the foil tray ensuring that there was no spillage after which the room opening was closed. Each sample point was monitored at a minute interval. This procedure was carried out over a ninety minute period.

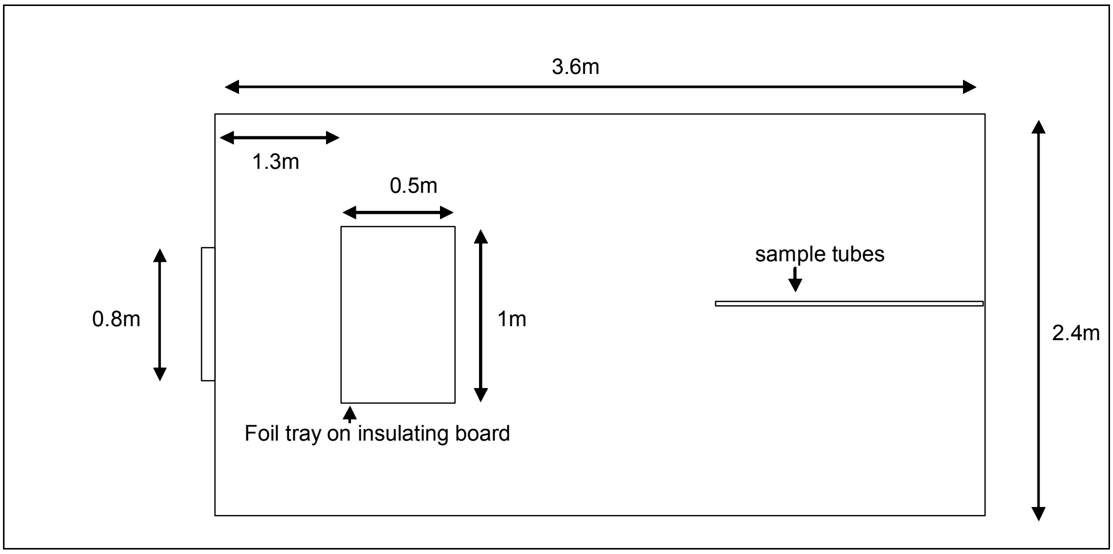

Figure 5 Plan of ISO test room

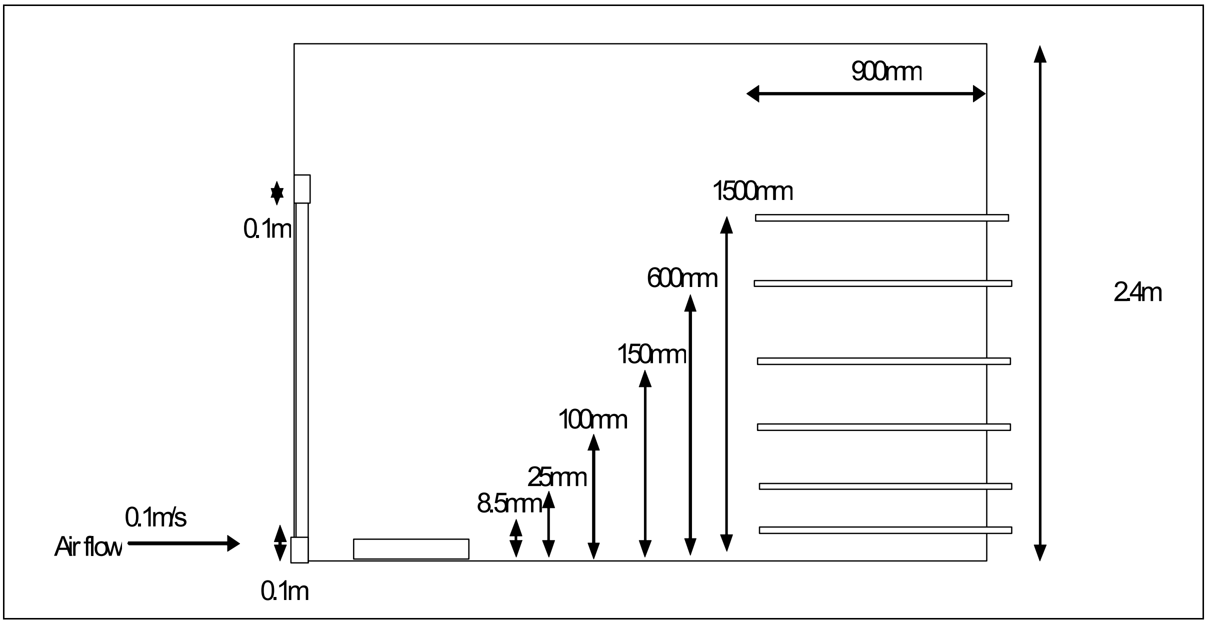

Figure 6 Side elevation of test room

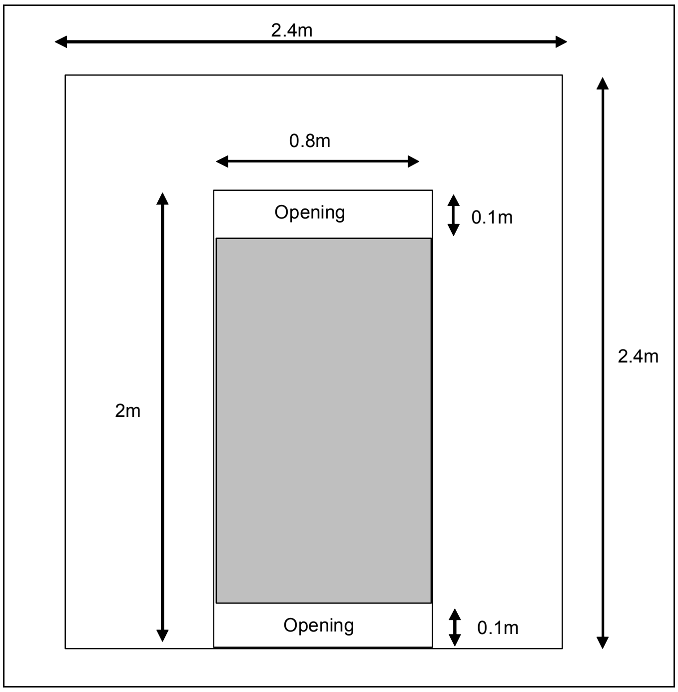

Figure 7 Front elevation of test room

2.2.2.5 Results

Figure 8 is a plot of the data points recorded during the test. Nominal air temperature 10°C.

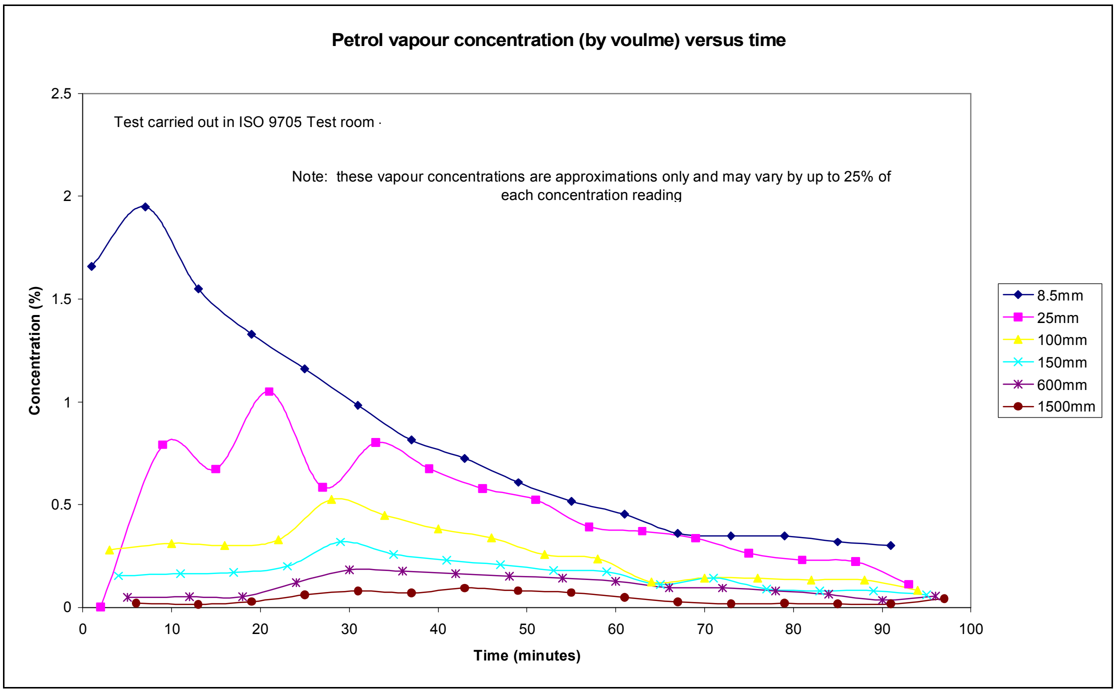

Figure 8 Plot of data points recorded

2.2.3 An Experimental Study to Examine the Effectiveness of a 100mm Up-stand with the test room

2.2.3.1 Objective

The objective of this part of the study was to monitor the concentration of petrol vapour at given heights above a 100mm up-stand within the ISO test room for a simulated petrol spill of 0.25 litres of petrol.

2.2.3.2 Experimental set up

The ISO 9705 room corner test facility as described in 2.2.2.2 was used for this study. In this study the door opening was reduced to half its width to simulate the door being ajar as shown in Figures 9 -11. It was decided to hold the door in this position as it provided a reasonable 'worst case' scnario and ensured that the effect of the upstand could be evaluated in isolation.

2.2.3.3 Instrumentation

In order to monitor the vapour concentrations in the garage a total of six stainless steel gas sample tubes were located at given heights above the test room floor at the rear of the test room as shown below. Three were located close above the foil tray the other three were located close above the 100mm down stand as shown below.

Each of these tubes was attached to a calibrated hydrocarbon laser analyser via a six way selector unit. The analyser was specifically calibrated for the petrol used in this study. 0.5 mm diameter Chromel alumel thermocouples were attached to the ends of each sample tube to monitor the temperature gradient within the test room.

2.2.3.4 Experimental procedure

The experimental configuration is shown in Figures 9 to 11. The procedure is described in section 2.2.2.

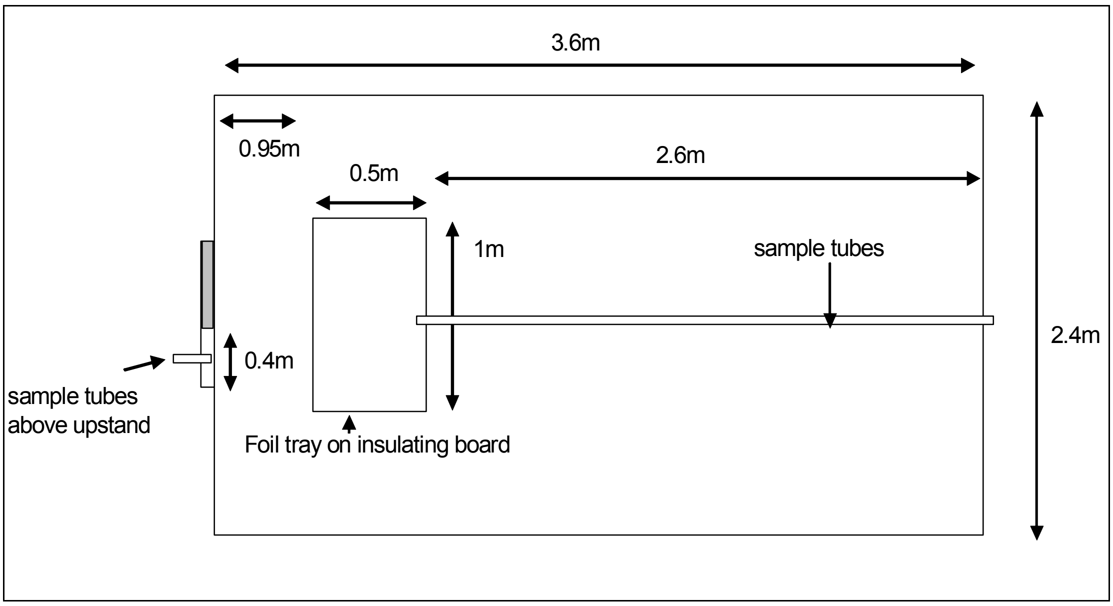

Figure 9 Plan of test room

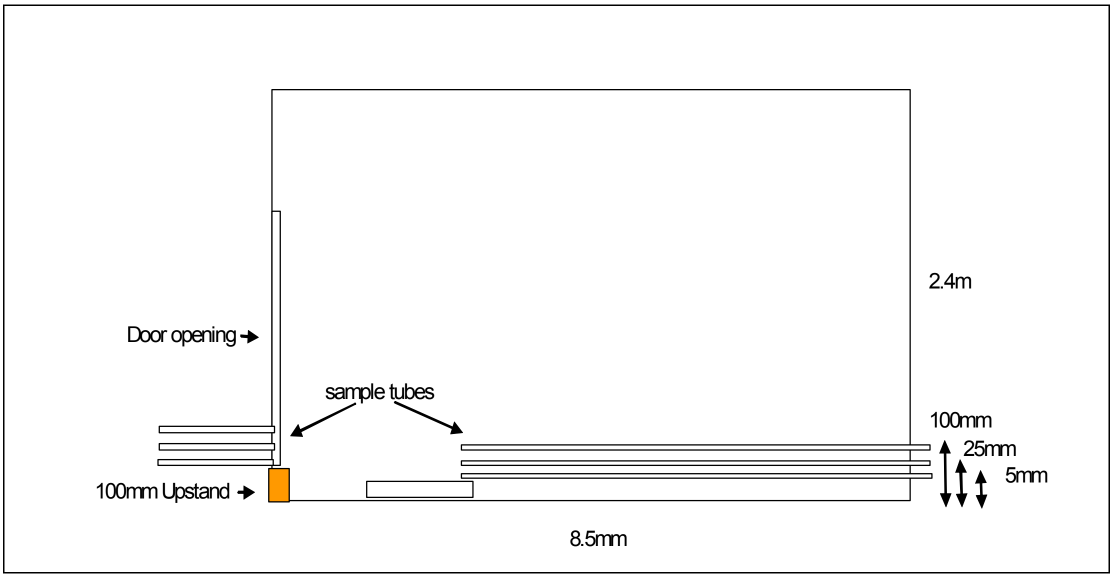

Figure 10 Side elevation of test room

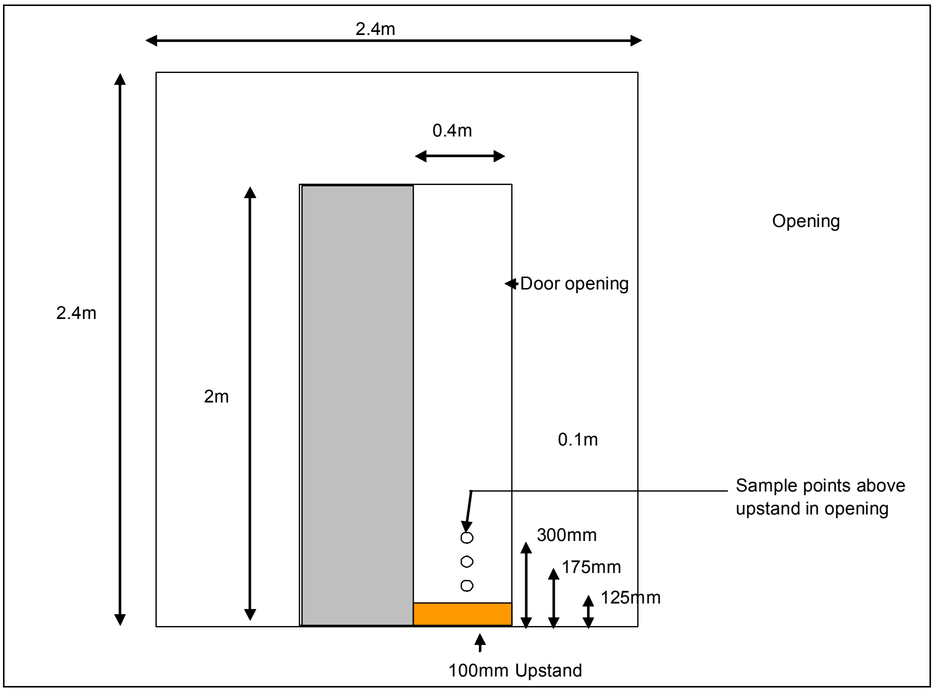

Figure 11 Front elevation of test room

2.2.3.5 Results

Figures 12 and 13 are plots of the data points recorded during the test. Nominal air temperature 10°C.

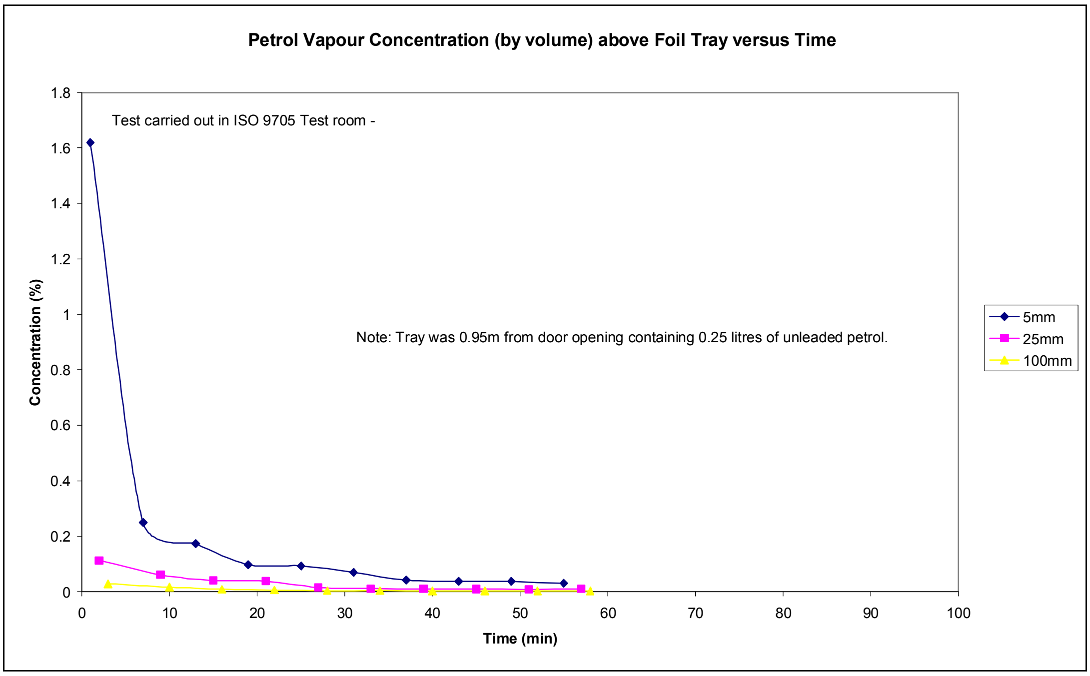

Figure 12 Recorded petrol vapour concentrations above test tray

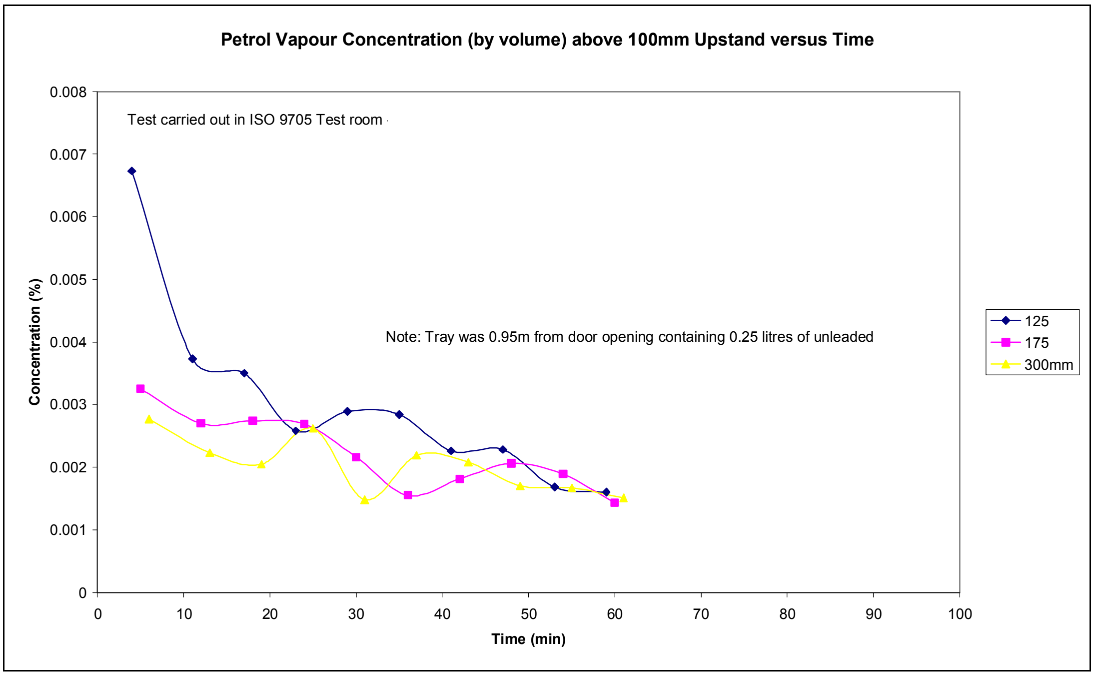

Figure 13 Petrol vapour concentrations above 100mm up-stand

2.2.4 A Study to Estimate the Evaporation rate of Unleaded Petrol

2.2.4.1 Objectives

The evaporation rate of petrol is dependent on a number of parameters, in particular the area that the fuel covers, as well as the temperature and the velocity of air in contact with its surface. In this study, the main emphasis was on the effect of cross sectional area of the fuel.

2.2.4.2 Experimental set up

To estimate the evaporation characteristics of unleaded petrol for this study seven tray designs were used to assess the impact of geometry on the evaporation rate. This study was carried out in a fume cupboard at ambient laboratory temperature with each tray located on a weighing scale. A 1.5mm deep layer of liquid was established in each tray and weight loss at 30 second intervals was recorded.

This procedure was repeated for each of the fuel trays, after which the mass loss per second, per unit area was determined. This estimated rate of evaporation was plotted against the equivalent tray diameter. The results are shown in the Table 3.

2.2.4.3 Effect of air flow

The above tests were carried out under near still air conditions. An additional test was undertaken to look at the potential effect of air speed on the estimated evaporation rate. A 0.32m x 0.32m x 5mm metal tray was subjected to an air flow of about 0.45 ms^{-1} This air flow was achieved by fully opening the fume cupboard shutter. A metal mesh sheet was supported in front of the tray to assist in maintaining a uniform air flow over the tray.

Table 3. Summary of evaporation rate data.

Tray type	Tray material	Tray size	Tray depth	Base area	Perimeter area	Equivalent diameter	Total surface area in cotact with fuel	Mass loss rate	Mass loss per unit area
		(m)	(mm)	m^2	m^2	(m)	m^2	(g/s)	(g/sm^2)
Square	Plastic	0.03x0.03	6	0.0009	0.00018	0.033844549	0.00108	0.000833	0.77130
Square	Plastic	0.06x0.06	20	0.0036	0.00036	0.067689098	0.00396	0.002067	0.52197
Square	Metal	0.148x0.149	29	0.02205	0.00089	0.167521971	0.02294	0.01143	0.49826
Circular	Glass	0.137	28	0.01474	0.000646	0.136967087	0.015386	0.004467	0.29033
Circular	Glass	0.11	15	0.00951	0.000519	0.110016478	0.010029	0.007278	0.72570
Circular	Glass	0.11	15	0.00951	0.000519	0.110016478	0.010029	0.00728	0.72589
Square	Metal	0.203x0.198	29	0.04019	0.0012	0.226165565	0.04139	0.00981	0.23701
Square	Metal	0.32 x 0.32	5	0.1024	0.00192	0.361008524	0.10432	0.01257	0.12049
Square*	Metal	0.32 x 0.32	5	0.1024	0.00192	0.361008524	0.10432	0.016	0.15337

* Airflow at 0.45 ms^{-1}

2.2.4.4 Results

Table 3 is a summary of evaporation test results. Figure 14 is a plot of the still air evaporation data. Nominal air temperature 15°C.

Test 9, the final reported test in Table 3 shows that the evaporation rate increased by about 27% with the increased air flow. Given that typical air flows under a garage door are of the order of 0.1ms^{-1} (equates to 1 to 2 air changes per hour) one could assume that some increase in evaporation might be expected.

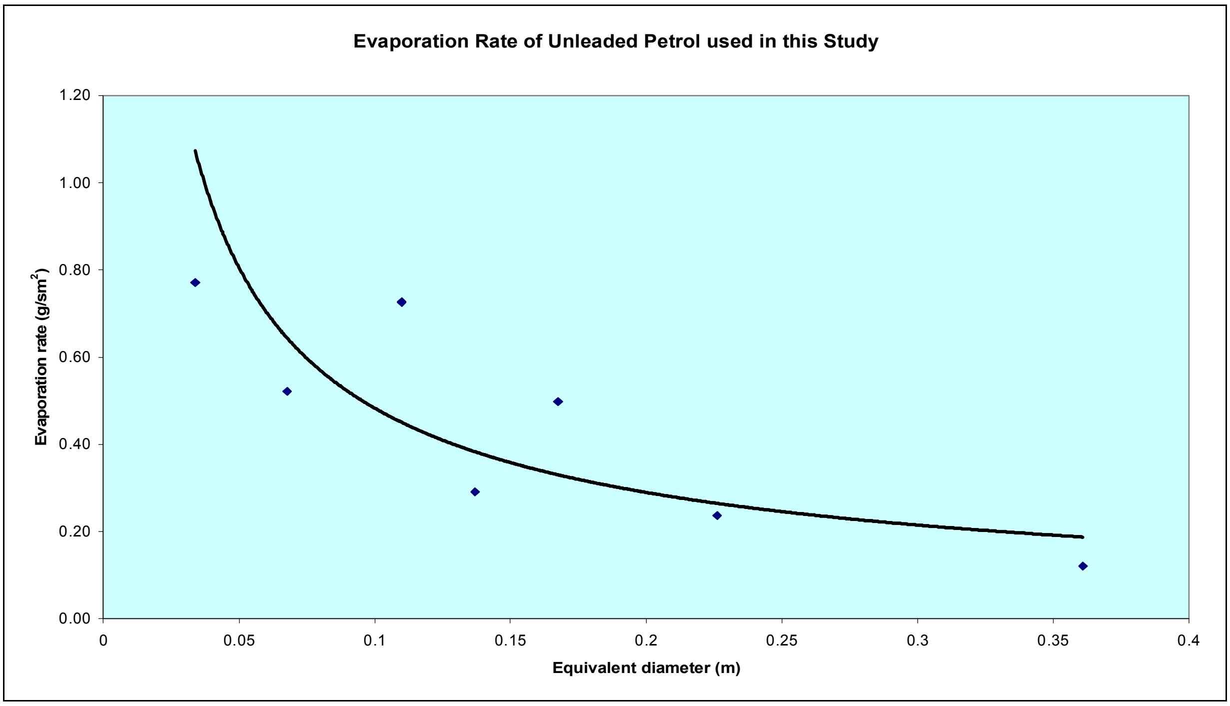

Figure 14 Plot of Evaporation rate versus Equivalent Diameter

The plot suggests that, if extrapolated towards increasing equivalent diameters, the evaporation rate may tend towards a plateau where the evaporation rate may become independent of tray diameter.

2.3 TASK 3 – CFD MODELLING OF DISPERSION OF PETROL VAPOURS

2.3.1 Background information

2.3.1.1 The effect of temperature on the equilibrium between liquid and vapour

If the temperature of a liquid is raised, the molecules are likely to have enough energy to escape from the surface of the liquid, which will tend to increase the saturated vapour pressure.

When the space above the liquid is saturated with vapour particles, equilibrium between liquid and vapour is established on the surface of the liquid in accordance with the Le Chatelier's Principle, where the temperature of a system in a dynamic equilibrium favours the endothermic change:

$$\text{liquid} \rightleftharpoons \text{vapour} \qquad \Delta H \text{ is +ve}$$

This means that an increase in temperature will increase the amount of vapour present, and so increase the saturated vapour pressure.

2.3.1.2 The vapour pressure, flash point and the lower flammability limit (LEL)

Vapours from a liquid fuel will support the flame over the liquid surface of the fuel. The flash point of a material is the lowest temperature at which it produces a flammable mixture. At the flash point, the vapour pressure of the liquid fuel is equivalent to the lower flammability limit (LEL). The vapour pressure is also dependant on the contour of the liquid surface, and is higher for a convex surface than for a concave surface.

Table 4- Vapour pressure data at 1 atmosphere for typical petrol constituents

Compound	Vapour pressure		Saturated vapour pressure	
	kPa	kPa	(% v/v)	(% v/v)
	0°C	25°C	0°C	25°C
benzene	3.19	12.7	3.2	12.6
heptane	1.52	6.09	1.5	6.0
toluene	-	3.79	-	3.8
octane	0.386	1.86	0.4	1.8
2,2 dimethyl hexane	1.1	4.54	1.1	4.5
nonane	-	0.57	-	0.6
decane	-	0.17	-	0.2

Notes: Atmospheric pressure =101 kPa and Vapour to air ratio is by volume

Petrol or Gasoline is generally a mixture of volatile, low-boiling point and mid-range hydrocarbons with boiling points ranging between 40°C and 200°C. Some generic vapour pressure data taken at 1 atmosphere for typical petrol constituents, quoted from the CRC handbook [1], are given in Table 4. Here vapours are assumed to behave like ideal gas.

2.3.1.3 Relationship between liquid and its vapours

The volume of vapour that can be generated by the evaporation of a known amount of a volatile liquid is important in evaluating the fire hazard from volatile liquid spills such petrol or diesel fuels.

If total evaporation is assumed, 1 kilo mole of liquid substance produces 22.4 m^3 of vapours at standard temperature (273K) and pressure (1 atmosphere). For higher temperatures, the vapour volume will increase by a factor (T+273)/273, where T is the temperature in degree centigrade.

The vapour produced for a given volume of a liquid can be calculated from the following relationship:

$$V_{vap} = V_{liq} \times 22.4 \times (T+273)/273 \times d_{liq}/M_{liq}, \qquad (1)$$

Where,

V_{liq} is the volume of the liquid, V_{vap} is the volume of vapour produced, d_{liq} is the liquid density (kg/m^3) and M_{liq} is the molar mass (in kg) of the liquid substance.

The average molecular mass of petrol is sometimes taken to be close to n-octane (C_8H_{18}), about 114. The density of the petrol used in the present study was measured to be approximately 750 (+/- 25) kg/m^3.

Using d_{liq}= 750kg/m^3, and M_{liq} = 114 kg, Equation (1) gives the liquid to vapour expansion ratio of approximately 150 at STP (standard temperature and pressure) or 160 at T=25°C.

This implies that 1 litre of liquid petrol will produce 150 to 160 litre petrol vapours in the temperature range 0 - 25°C when all liquid has been completely evaporated.

However, Table 4 indicates that for this temperature range octane has vapour pressure between 0.386 and 1.86kPa, giving (percentage vapour-air mixture ratio of) saturated vapour pressure between 0.4% and 1.8%. This suggests that the maximum molar concentration that octane vapours can achieve is 1.8% in the temperature range 0 - 25°C. Consequently, only the LEL is possible for the petrol (or octane) in this temperature range.

In view of the above discussion, for simplicity, in this study petrol has been approximated by n-octane (C_8H_{18}). Based on the molar mass ratio (114/28.8) of octane relative to air, its vapour density is approximately 4, indicating that it is 4 times heavier than air. The specific gravity of the liquid octane (liquid density divided by water density) is approximately 0.7, indicating that it will float on water.

2.3.2 Initial Analysis

Having carried out a detailed literature search, it has been concluded that the data available in the published literature is primarily relevant to outdoor situations. Thus, a small-scale experimental study was undertaken to obtain the evaporation rate data for petrol in a typical garage environment, for a temperature range 10 -15°C and ventilation rate of 1-2 air changes per hour.

The experimental study was based on a limited set of measured data and has indicated an estimated specific evaporation rate in the range 0.05 g/m^2/s and 0.1g/m^2/s. Although typically the fuel tank of a parked car in a garage may contain up to 50 litres of petrol, the probability of leakage or spillage from the car itself is considered very low. Hence, spillage of petrol from a spare container of petrol has been taken as a more probable scenario.

The size considered for a typical garage is 5m x 3m in plan and 3m in height, giving a plan area of 15m^2 and volume of 45m^3. If 5 litres of petrol were spilt on to the floor of the garage and allowed to cover the entire plan area, then a 3mm deep layer of liquid would be formed. This would, in principle, give rise to 450mm deep layer of condensed petrol vapour on the floor. This assumes that all the liquid has been evaporated extremely efficiently into vapour. However, in practice a number of factors will influence the evaporation rate as discussed previously, including the spill area, the local air and liquid temperature, air flow rate over the liquid, and any thermal radiation from surroundings.

Table 4 has indicated that the maximum concentration of saturated octane vapour above the liquid surface (in equilibrium) is less than 2% by volume. This has been supported by the measurements of the vapour concentrations, taken 5mm above the liquid petrol tray of 0.5m^2 in area, in the ISO room with a door opening set at 50%.

Furthermore, the measurements undertaken in this study have indicated a very low rate of evaporation for petrol. Therefore, using a petrol density of 750kg/m^3, 5 litres of petrol will have a total mass of 3.75kg (liquid or vapour). Using the lower estimated specific evaporation rate of 0.05g/m^2/s, the total time for the complete evaporation of 5 litres of liquid petrol could be calculated to be approximately 2.0 hours for a spill area of 10m^2, and 1.5hours for a spill area covering the entire garage floor (15m^2).

The data from the experimental programme found that after 4.5 hours some liquid was still remaining from a 0.5 litre spill of petrol in a 0.5m^2 tray. This may be due in part to the fact that petrol is made up from a number of components with varying volatiles, some of the less volatile fractions are unlikely to be evaporated, thus leaving some un-evaporated liquid in the tray.

2.3.3 CFD Study - Scenarios considered

Having undertaken a detailed literature search of the published data on the emission and dispersion of pollutants inside the enclosed spaces, it was concluded that the methodology best suited for the present study is based on computational fluid dynamics (CFD).

The study was undertaken in two stages:

- Stage 1 – Limited validation of the model
- Stage 2 – Application of the CFD model to investigate various scenarios.

2.3.3.1 Stage 1 – Model Validation

Stage 1 was focussed on the limited validation of the CFD model against experimental data. The CFD simulations were performed by using an estimated evaporation rate of 0.05g/m^2/s, based on the experimental determination described in section 2.2.4, as the input source term for the model, where the characteristics of the n-octane were assumed to represent the petrol.

It should be noted that since the temperature mainly affects the evaporation of the liquid, this effect was accounted for through the measured evaporation rate used as input to the CFD model. Consequently, it was not necessary to solve the enthalpy equation in the CFD simulations.

The dispersion of the vapours from the liquid surface to the surroundings was mainly controlled by laminar and turbulent diffusion of vapour molecules into the air and convection currents due to any ventilation inside the enclosure. The turbulence was modelled by using the standard two-equation k-ε model, where k is the turbulent kinetic energy and ε is its dissipation rate. The turbulent Prandtl number of 0.9 and Schmidt number of 1 were used to account for the relative effects of viscosity and the mass and momentum diffusivities.

The experimental validation scenario was based on data from the ISO 9705 room configuration (3.6m x 2.4m in plan and 2.4 in height) with a rectangular tray (1m x 0.5m in plan and 5mm deep) containing up to 0.5 litre of fresh petrol located centrally on the floor. The room has a door with height of 2m and width of 0.8m. The schematic of the ISO 9705 room configuration is shown in Figure 15.

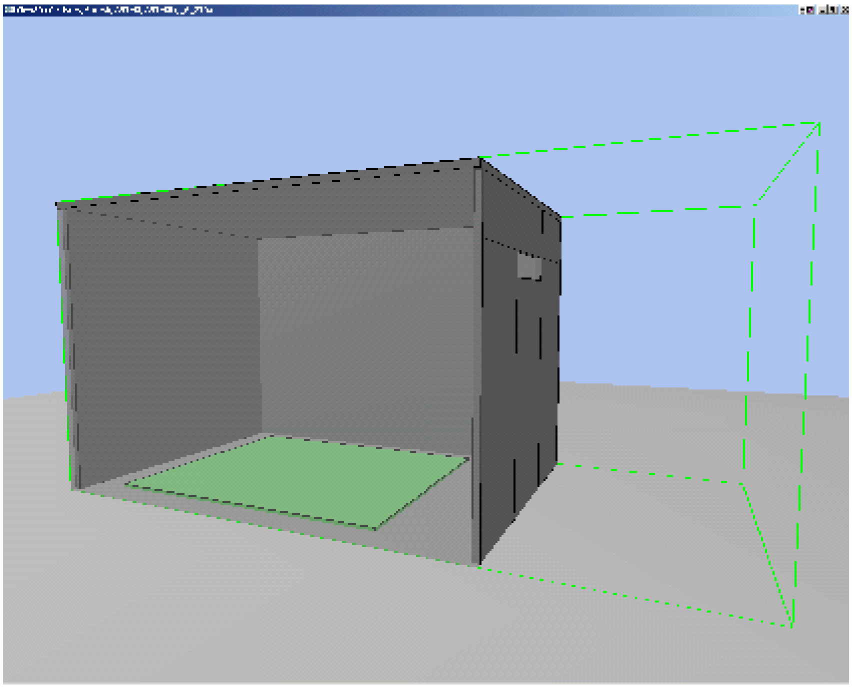

Figure 15 Schematic of the ISO 9705 test room used in Test 1

Two model validation tests were undertaken in this room. Test 1, described in section 2.2.2, with the door closed, but with 0.1m high gaps above and below the door to allow air movement. A supply of fresh air of 0.1m/s was forced into the room through the gap below the doors towards the petrol tray. Measurements of the vapour concentrations and ambient air temperature were made at six vertical locations close to the downwind side of the tray.

In Test 2, described in section 2.2.3, a partly open door scenario with natural ventilation was studied. Half the door width was closed, thus providing an opening of 0.4m in width and 2m in height. In this case, in view of the increased potential hazard of the spread of vapour from the open door to the surrounding environment, 0.25 litre of petrol was used with the tray located at about 1m away from the door. The tray used for this test was the same as used in the Test 1, see Figure 16.

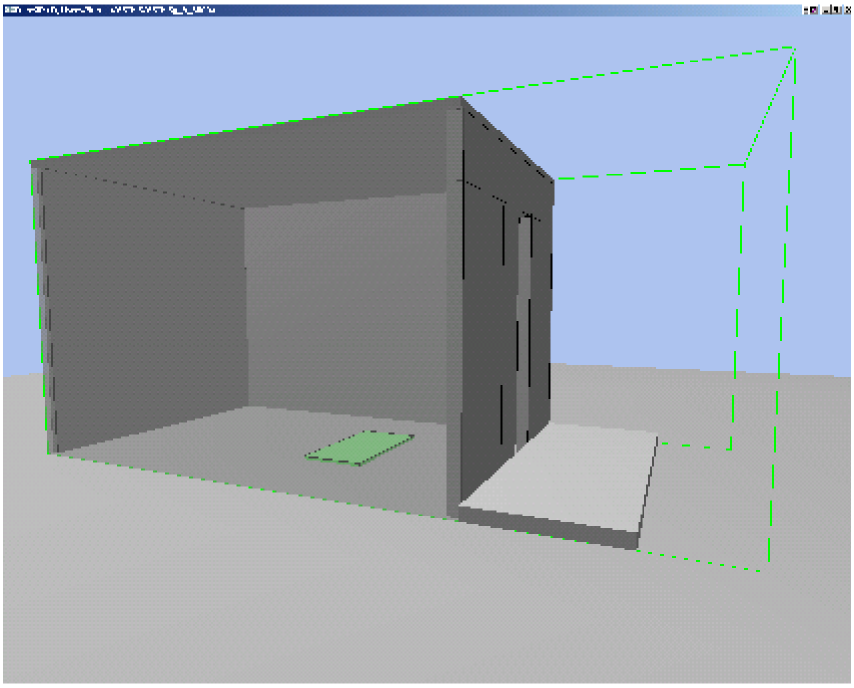

Figure 16 Schematic of the ISO 9705 test room used in Test 2

In the CFD simulation of Test 1, the inflow velocity of 0.1m/s was simulated by specifying the volume flow rate of 0.008m^3/s through the bottom gap at the door. For the Test 2 simulation, the half open door was modelled by blocking half the door across its width over its height of 2m, thus limiting the door opening to 2m x 0.4m in area in its vertical elevation.

The CFD model then provided detailed transient predictions of the mass concentrations inside the room. The two-equation turbulence model was included in the CFD simulations but, the model predicted little turbulence, as expected, confirming that the mixing was mainly controlled by molecular diffusion due to high vapour density of the liquid, which is generally considered to be very slow.

For comparing the predictions with measurements, the predicted mass fractions of octane and air were converted into volume fractions, using the following relationship:

$$V_{oct} = \frac{m_{oct} / M_{oct}}{m_{oct} / M_{oct} + m_{air} / M_{air}}, \qquad (2)$$

where,

m_{oct} and m_{air} are respectively the mass fractions of the octane vapour and air in the vapour-air mixture, and M_{oct} and M_{air} are the molecular masses of octane (114) and air (28.8).

If $m_{oct} << m_{air}$, then equation (2) reduces to:

$$V_{oct} \approx \frac{m_{oct} / M_{oct}}{m_{air} / M_{air}} \approx \frac{m_{oct}}{m_{air}} \frac{M_{air}}{M_{oct}} \approx \frac{m_{oct}}{4}, if\ m_{oct} << m_{air}, m_{air} \approx 1 \qquad (3)$$

Equation (3) is only valid away from the liquid surface where the vapour concentration is much smaller than the air concentration. For low vapour concentrations, the mass to volume fraction ratio is simply related to the vapour density, and therefore the vapour fraction is quarter of the mass fraction.

For Test 1, the evaporation rate specified in the CFD model was increased by a factor of 20 to reduce the simulation time. This led to the proportional increase in the predicted vapour source concentrations above the liquid tray. To compare the predicted vapour concentrations (by volume) with measurements downstream of the source, it was therefore essential to match the measured vapour concentrations with the predicted concentrations in the gas cell adjacent to the liquid surface, and the conversion factor (predicted/measured ratio) was obtained. The predicted concentrations downstream of the source were adjusted by this factor to compare with the measured values at other probe locations.

The predicted contours of vapour mass fractions are shown in Figures 17 and 18 for Test 1, where the ‘red’ colour shows the highest and ‘blue’ the lowest value. The ‘red’ contour was matched with 1.4% volume concentration of the vapour, corresponding to the LEL value for petrol. It can be clearly seen from Figures 17 to 20 that petrol vapours, approximated by n-octane, are heavier than air and so disperse upwards through diffusive mixing. The convective flow represented by velocity vectors, in Figure 18, is only noticeable near the surface of the spilled fuel and in the top opening of the door. The flow in the top opening is mainly the air with little contamination inside the room being pushed out as a result of the forced air-inflow from the opening at the bottom of the door. During the actual test, it was noted that some fuel vapours were found to be leaking from the air inlet port. So, differences in the predicted and measured concentrations of vapour above the floor were expected. The differences may also be due to the much bigger spill area used in the simulation than in the actual test where the tray size of 0.5m^2 was used.

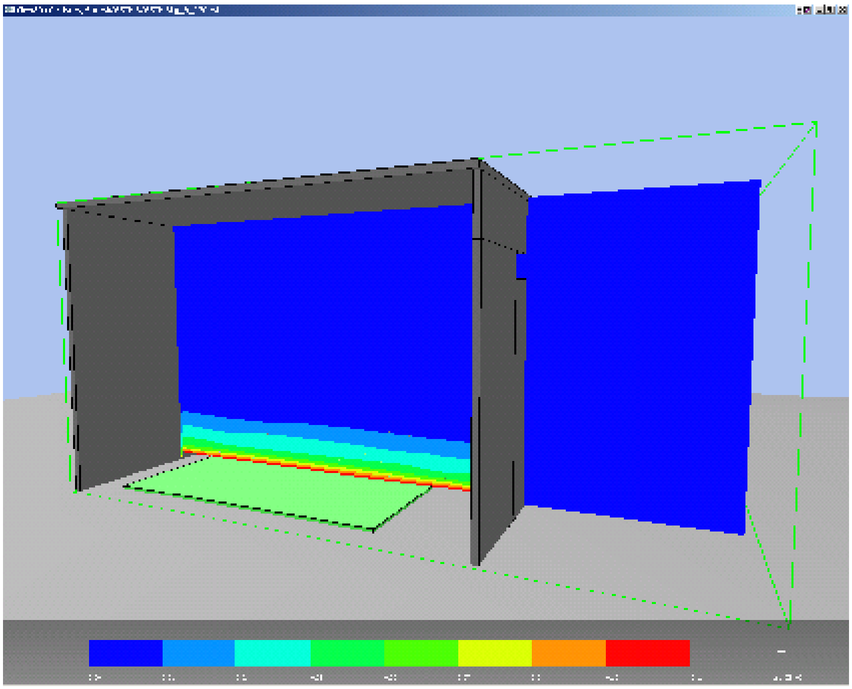

Figure 17 Predicted vapour concentrations contours on the vertical central plane through the door for Test 1 (270s)

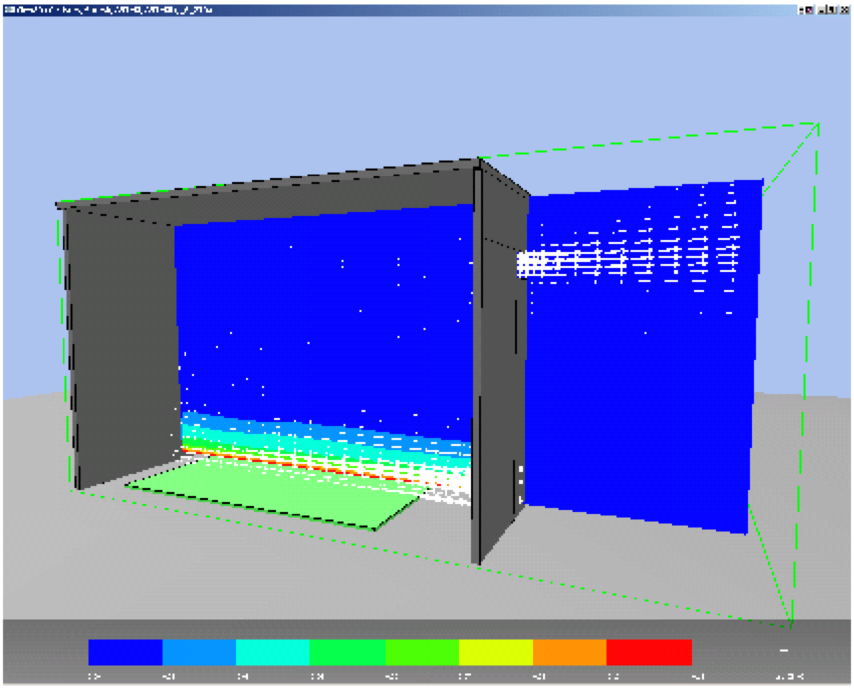

Figure 18 Predicted vapour concentrations contours and velocity vectors on the vertical central plane through the door for Test 1 (270s)

For Test 2, the actual evaporation rate as measured in the small tray-tests was specified in the model, and so, in contrast to Test 1, the predicted concentrations could be compared directly with the measured data. However, some adjustment between the predicted and measured values may still be necessary because of insufficient grid resolution in the model near the source. The predicted concentration contours are shown in Figures 19 and 20 after 1 hour of the evaporation. It can be seen that similar to test 1, the hazard concentrations are limited to close to the floor. Good correspondence was found between the model and the experimental data for Test 2. The contour plots can be used to assess the extent of hazard due to the spread of petrol vapours.

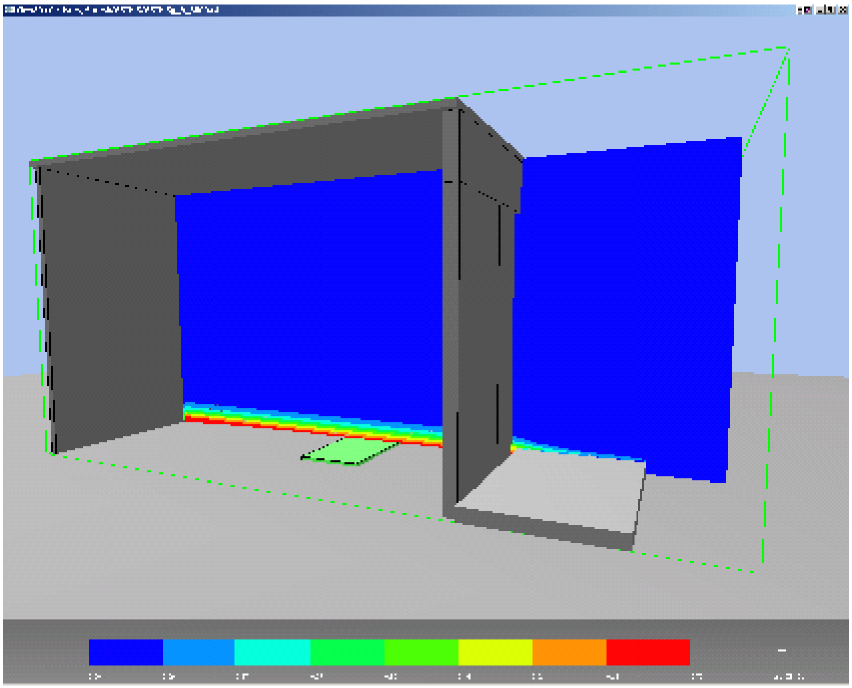

Figure 19 Predicted vapour concentrations contours on the vertical central plane through the door for Test 2 after 1 hour

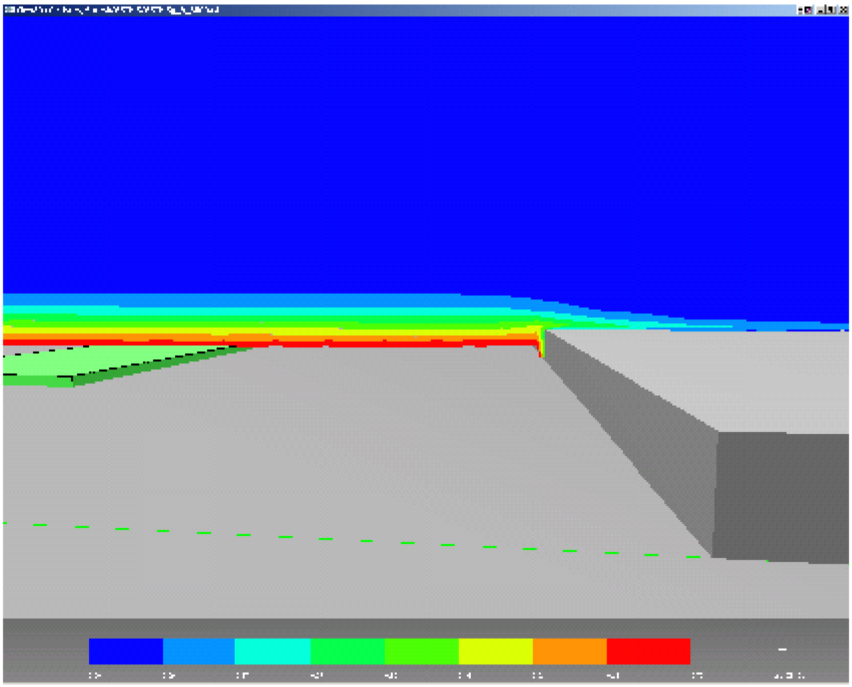

Figure 20 Predicted vapour concentrations contours on the vertical central plane through the door for Test 2 after 1 hour (close-up of Figure 19 near the step)

2.3.4 Stage Two – Scenario Analysis

In Stage 2, the partially validated CFD model was applied to a typical garage, and the effect of 100mm up-stand under different ventilation conditions was examined. Figure 21 shows the geometrical scenario modelled, and figure 22 show it close-up when looking from the rear towards the front of the garage. The scenario represents a garage that is connected to the attached room of a domestic dwelling via an internal door. The garage was 5m x 3m in plan and 3m in height, and the attached room was 2m in width and extending to the full length and height of the garage. The front garage door was considered to be leaky with gaps at the top and bottom of 0.1m in height. The inter-connecting door and the door in the attached room were considered half-open, each with opening size of 0.4m in width and 1.8m in height.

A total of 5 litres of petrol, with spillage area of 4m x 2.5m was considered, where the evaporation rate of $0.05g/m^2/s$, measured in small-tray tests, was specified over the spillage area. Simple calculations gave the total petrol mass of 3.75kg and the total time of evaporation of approximately 2 hours, assuming the constant evaporation rate of $0.05g/m^2/s$.

Three scenarios, referred to as Scenarios A, B and C, with varying ventilation conditions at the bottom gap of the garage doors was considered. Scenarios A and B correspond to airflow rates of 0.1 and 0.2 m/s respectively at the bottom of the garage door. In Scenario C, the bottom gap of the garage door was closed to allow natural air-flow in the garage through the inter-connecting door and the front door of attached room, which is open to the outside. In all three scenarios, a 100mm step was considered between the room and the garage.

In the fourth scenario D, the 100mm step between the room and the garage was removed, and air-inflow of 1 air change per hour at the bottom of the garage door was considered. Therefore, the results from

Scenarios A and D can be compared to examine the effect of 100mm step between the garage and the attached room.

In Scenarios A to D, the evaporation rate was artificially increased by a factor of 20 to reduce the computational time for complete evaporation of 5 litre of petrol or the time for the vapour concentration to exceed the 1.4% LEL limit.

In a fifth scenario E, the combined effect of using the fine grid resolution above the evaporating floor surface and the evaporation rate was considered on the predicted vapour concentration levels inside the garage particularly in the close proximity of the interconnecting door.

The predicted results are summarised in Figures 23 to 37. In all the figures, the ‘red’ colour contour was adjusted to correspond to 1.4% vapour concentration by volume, so that the assessment of the explosion hazard due to the petrol spill could be made.

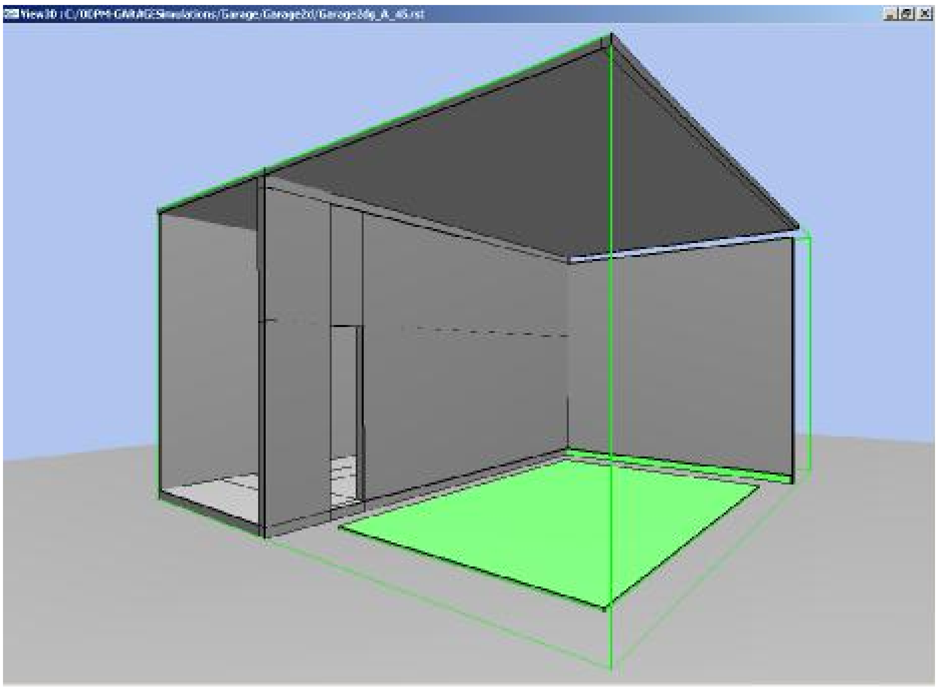

Figure 21 Schematic of garage and the adjacent room used in scenarios A to E.

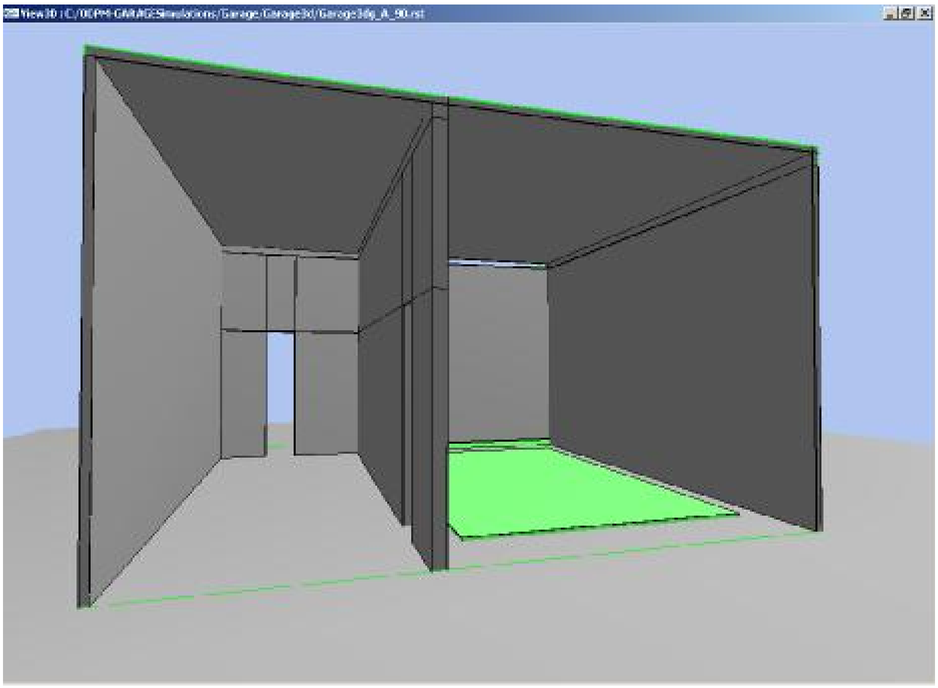

Figure 22 Schematic of garage and the adjacent room used in scenarios A to E – perspective view from the rear looking into the front of garage and the attached room of the property.

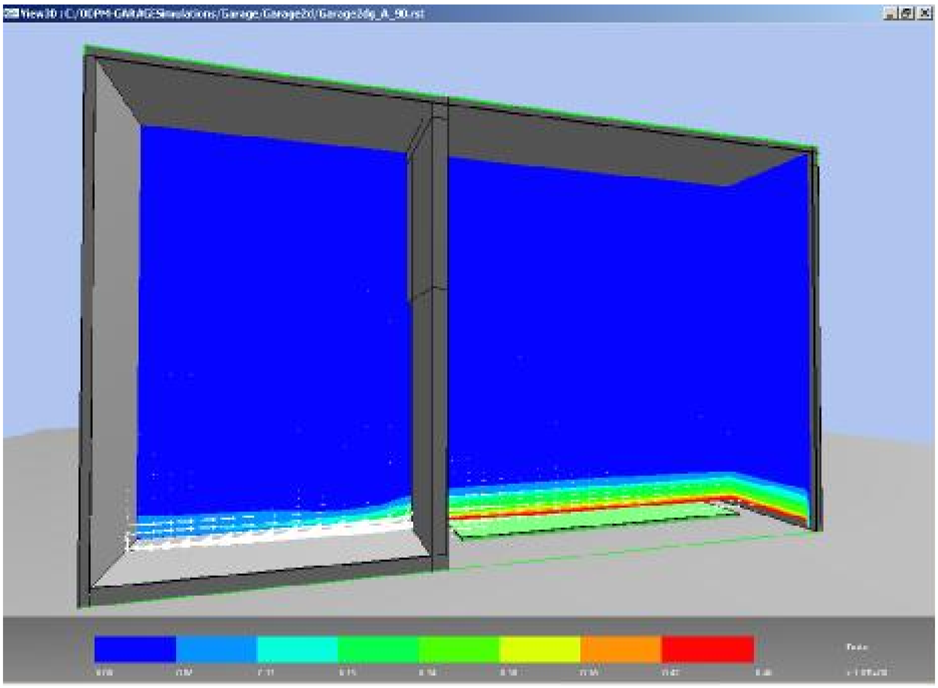

Figure 23 Predicted vapour concentrations contours and velocity vectors on the vertical central plane through the door opening for Scenario A (with 100mm step, inflow velocity of 0.1m/s) after 75s.

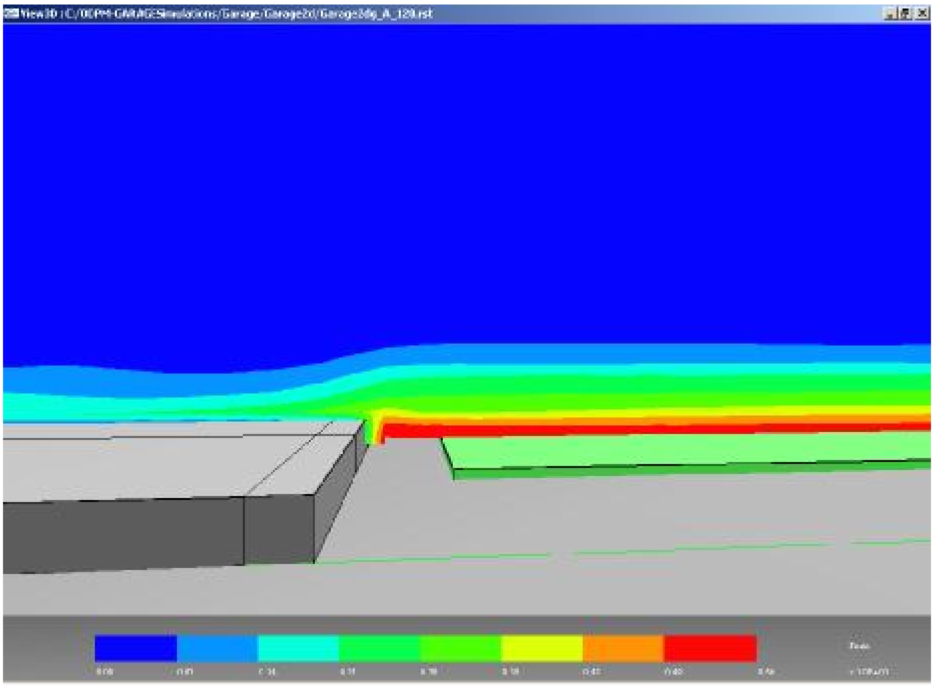

Figure 24 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario A (with 100mm step, inflow velocity of 0.1m/s) after 120s.

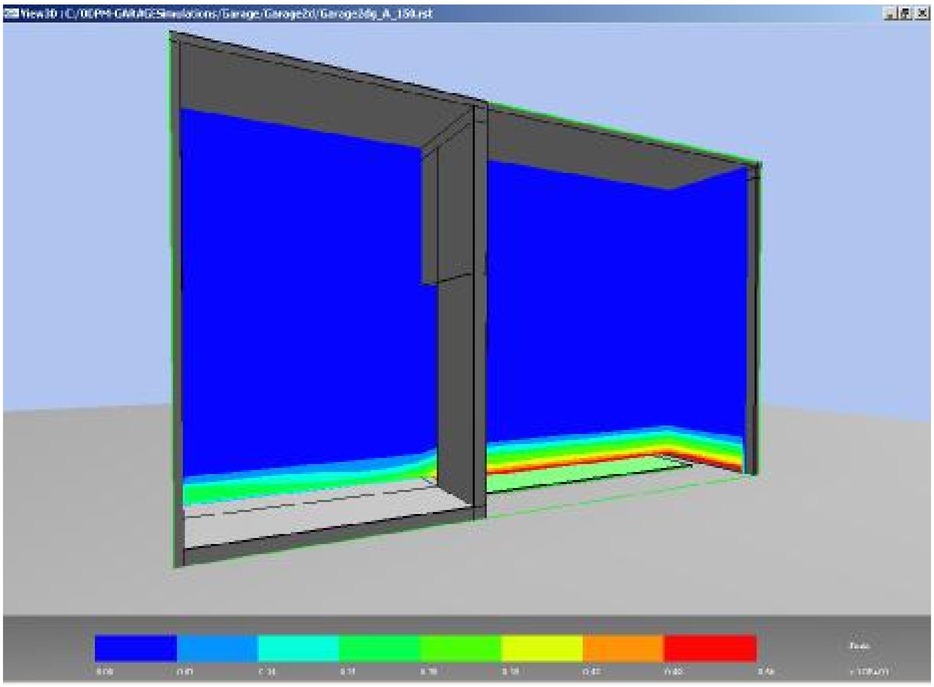

Figure 25 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario A (with 100mm step, inflow velocity of 0.1m/s) after 150s.

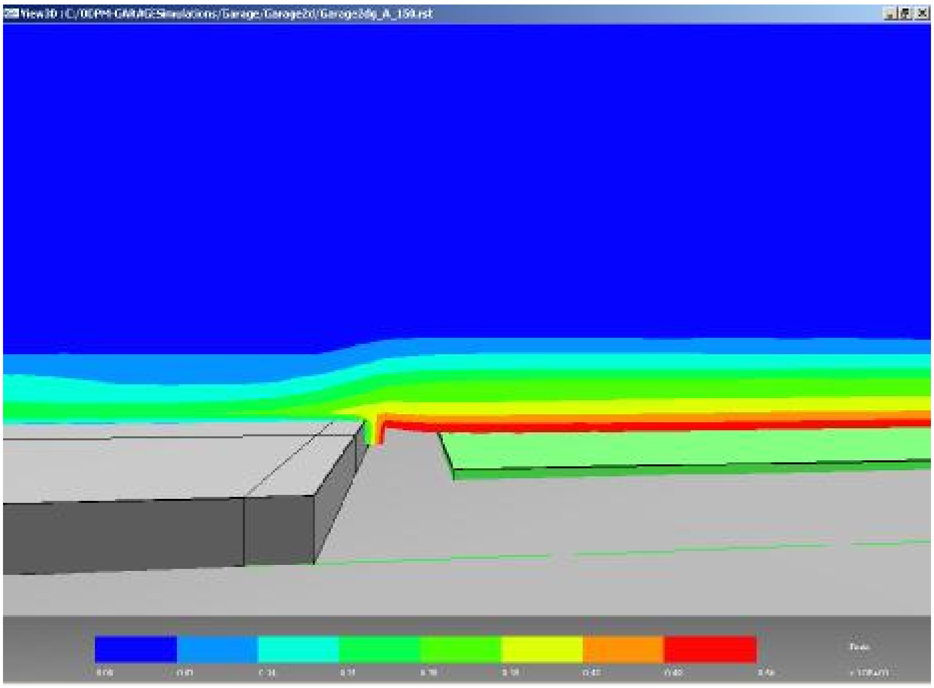

Figure 26 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario A (with 100mm step, inflow velocity of 0.1m/s) after 150s (close-up view near the step).

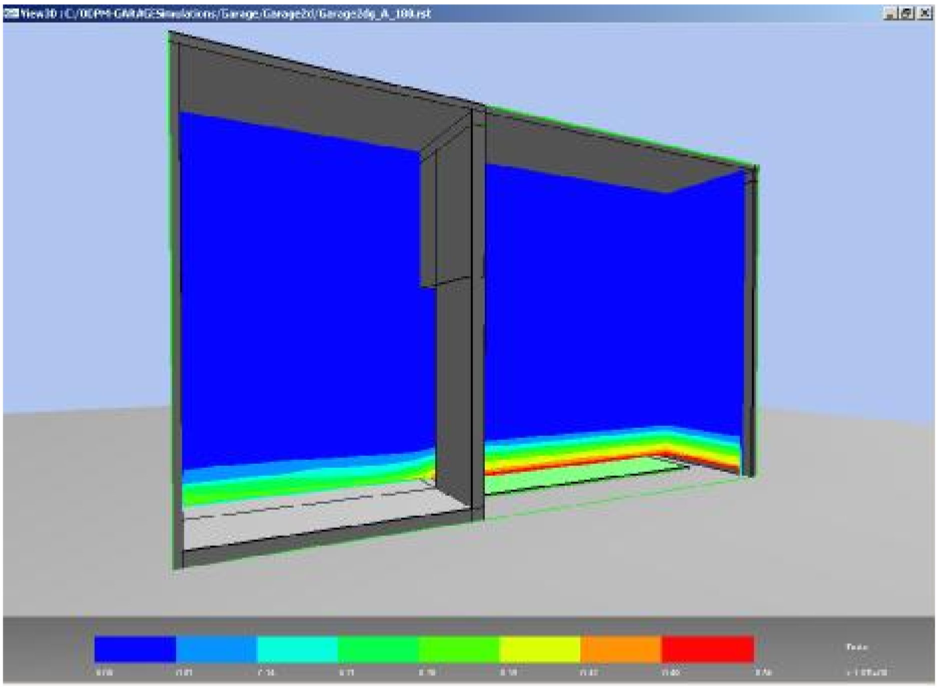

Figure 27 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario A (with 100mm step, inflow velocity of 0.1m/s) after 180s.

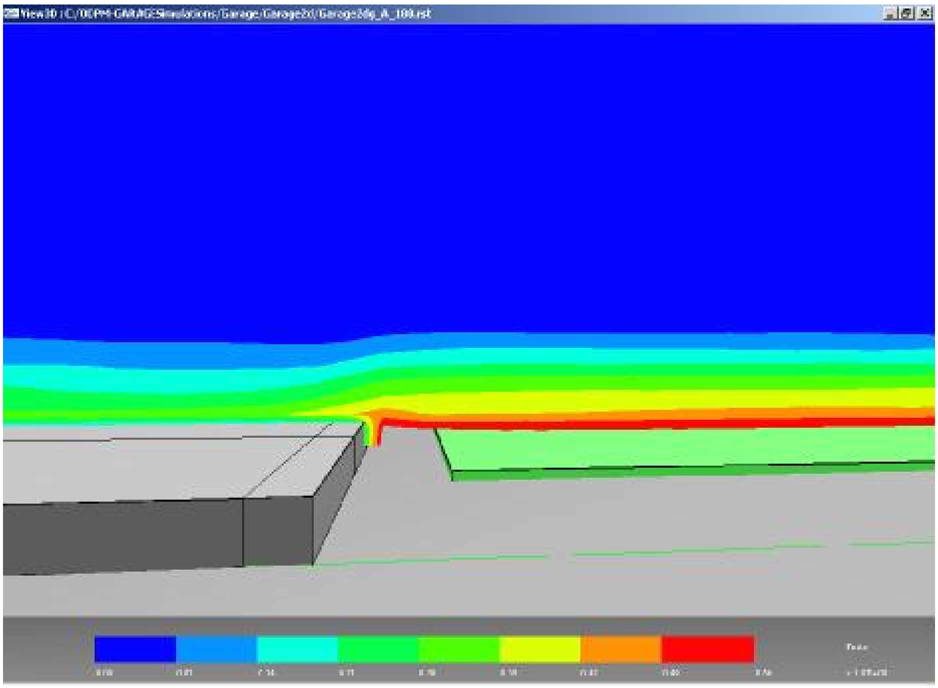

Figure 28 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario A (with 100mm step, inflow velocity of 0.1m/s) after 180s (close-up view near the step).

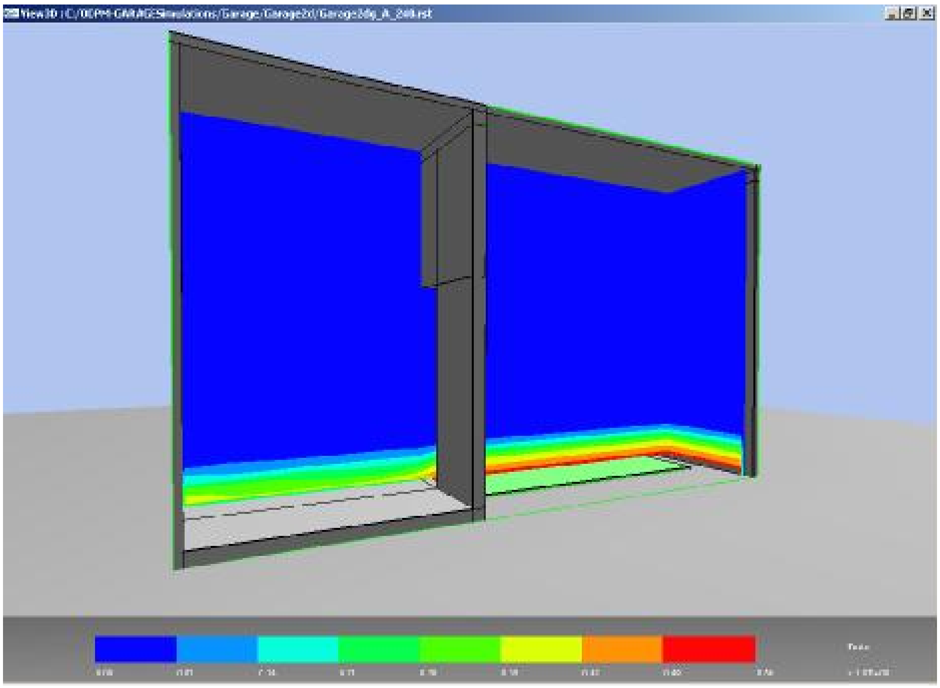

Figure 29 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario A (with 100mm step, inflow velocity of 0.1m/s) after 240s.

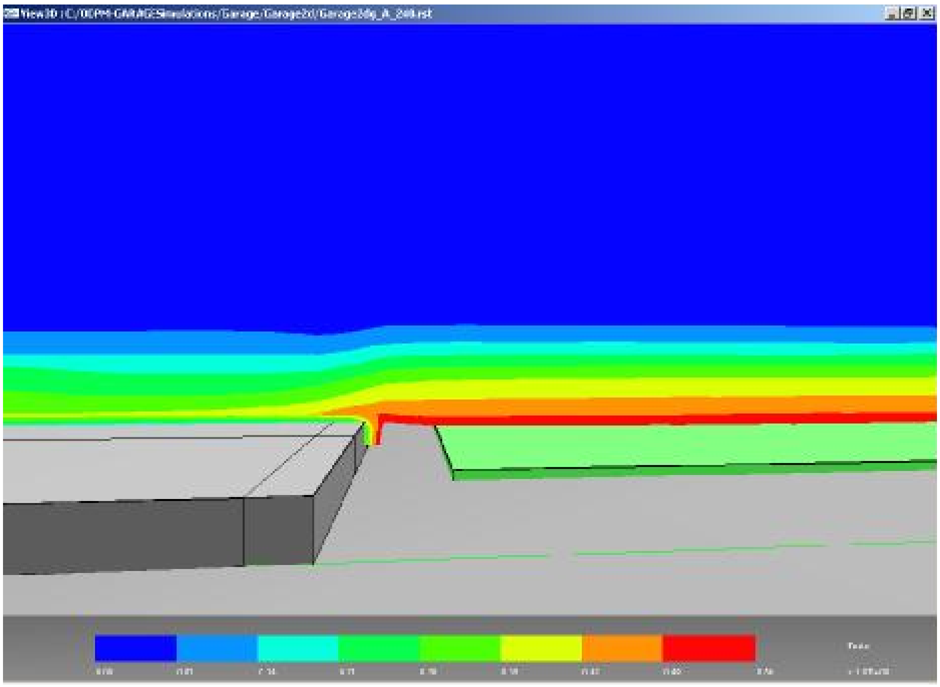

Figure 30 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario A (with 100mm step, inflow velocity of 0.1m/s) after 240s (close-up view near the step).

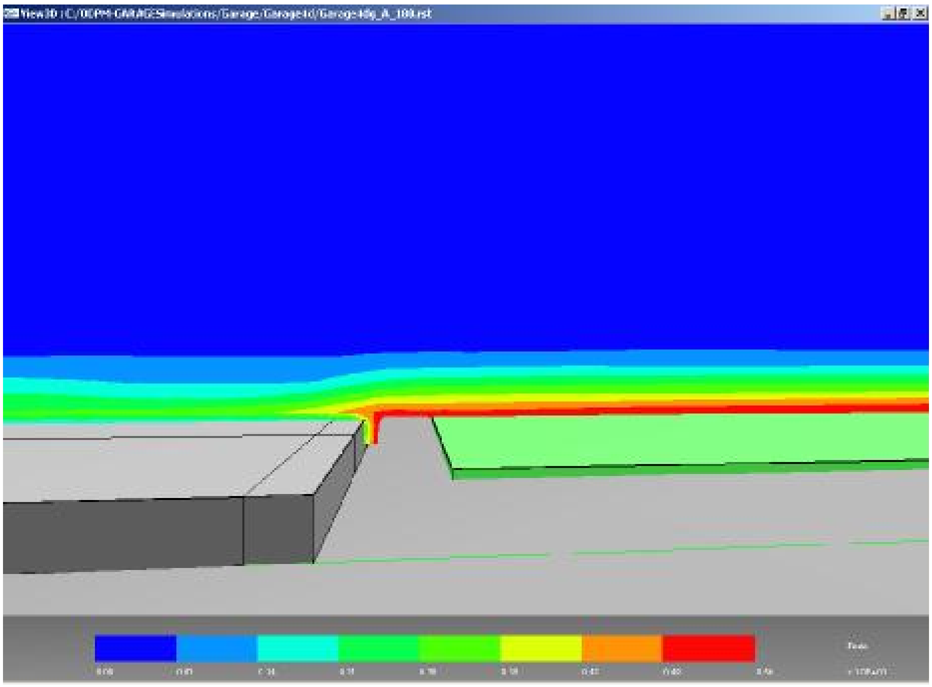

Figure 31 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario B (with 100mm step, inflow velocity of 0.2m/s) after 180s (close-up view near the step) - Garage 4d.

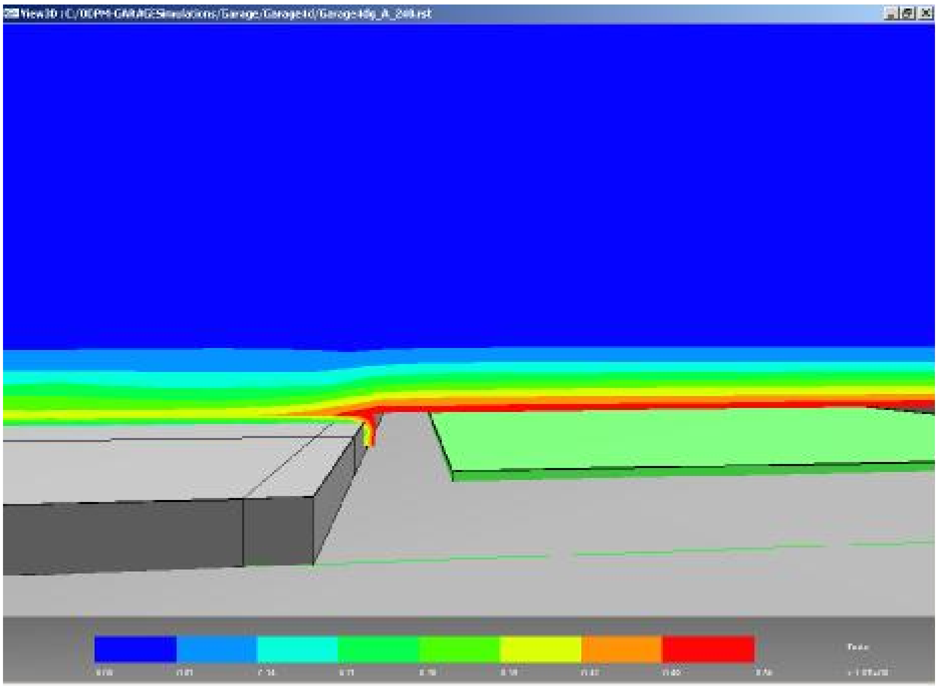

Figure 32 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario B (with 100mm step, inflow velocity of 0.2m/s) after 240s (close-up view near the step).

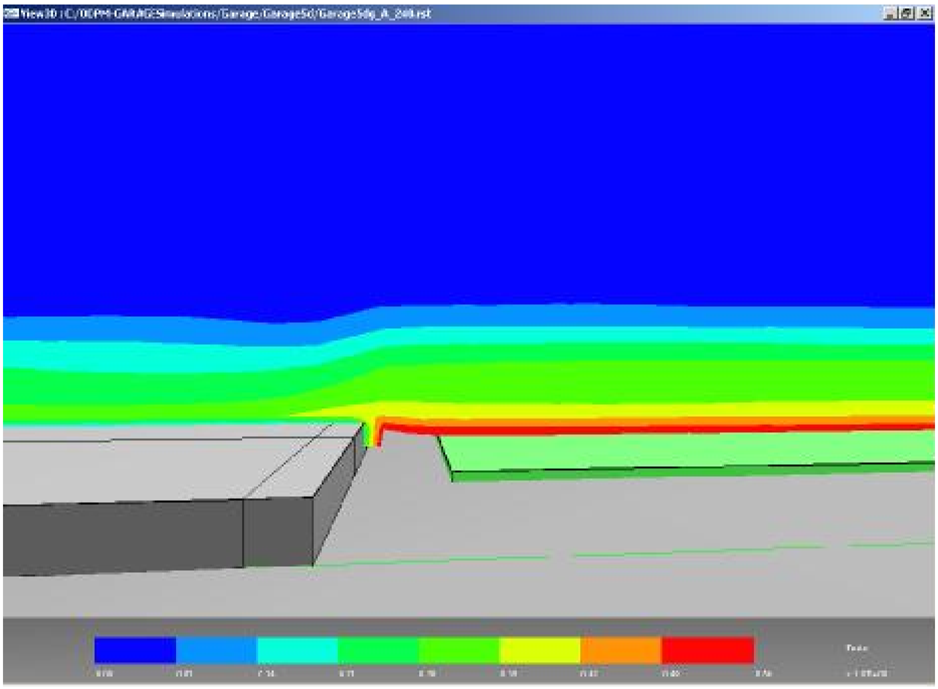

Figure 33 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario C (with 100mm step, no inflow velocity) after 240s (close-up view near the step) - Garage 5d.

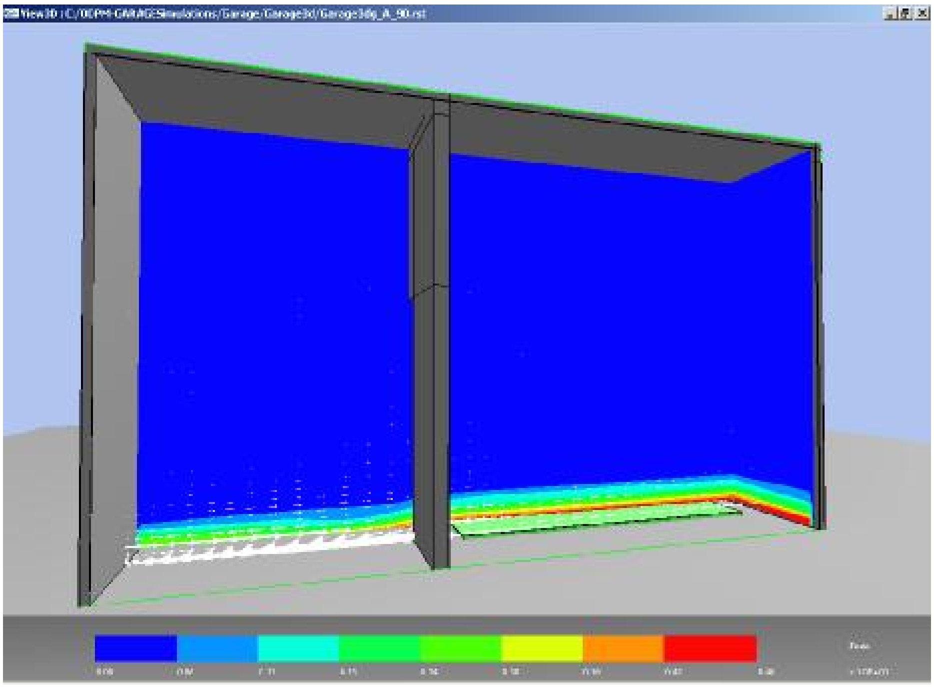

Figure 34 Predicted vapour concentrations contours and velocity vectors on the vertical central plane through the door opening for Scenario D (without 100mm step, inflow velocity of 0.1m/s) after 90s - Garage 3d.

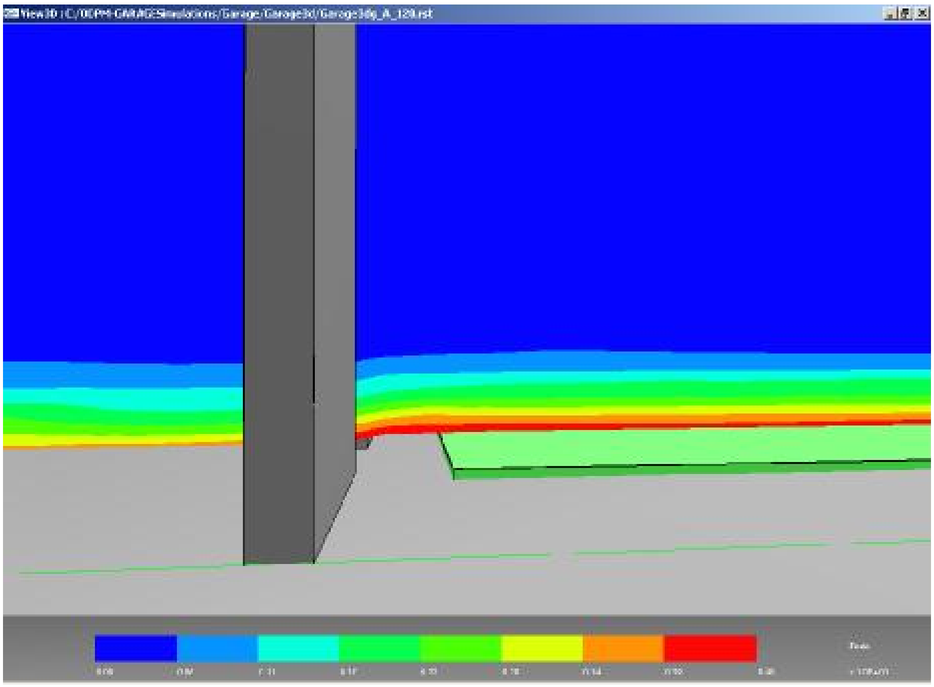

Figure 35 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario D (without 100mm step, inflow velocity of 0.1m/s) after 120s - Garage 3d.

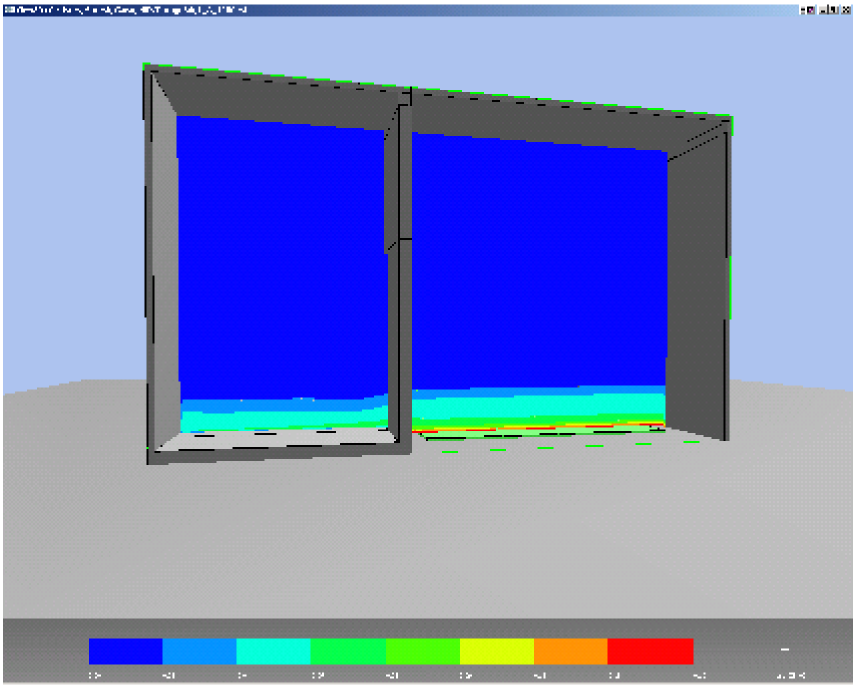

Figure 36 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario E (with 100mm step, inflow velocity of 0.1m/s) after 1200s –GarageE.

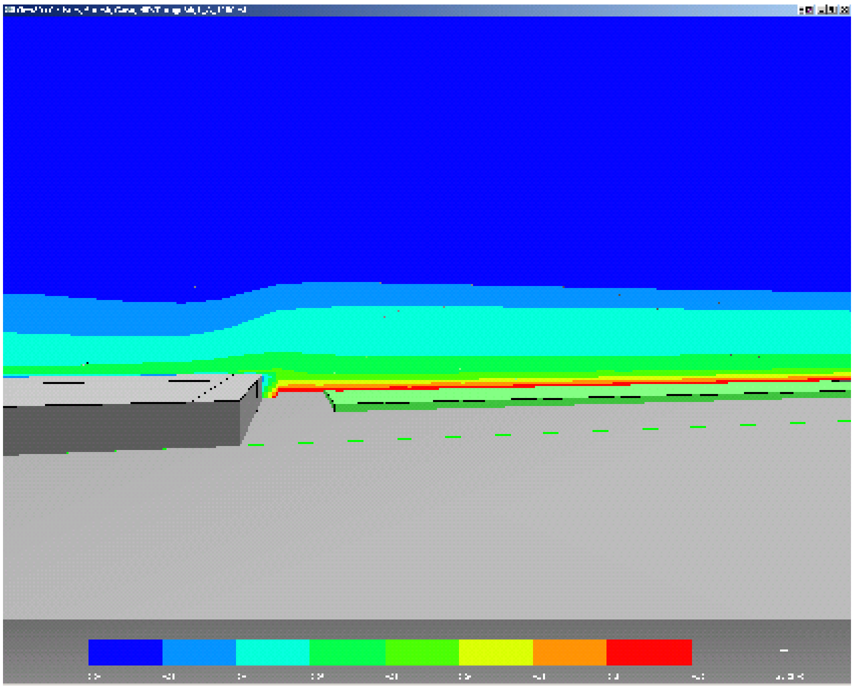

Figure 37 Predicted vapour concentrations contours on the vertical central plane through the door opening for Scenario E (with 100mm step, inflow velocity of 0.1m/s) after 1200s (close-up view near the step) – GarageE.

3 Conclusion

The study has shown that the garage upstand does prevent liquid (potentially flaming) fuel from entering an adjoining room.

The upstand will prevent the flammable vapours associated with small spills, typical of those likely during vehicle maintenance, from entering an adjoining room under limited ambient conditions but is unlikely to prevent flammable vapours associated with larger spills and higher ambient temperatures.

In the absence of an upstand, liquid fuel could enter an adjoining room unless the floor is designed to fall away from the entrance to the adjoining room. The garage floor covering should be designed so as not to 'retain' the fuel.

4 References

1. Weast, R., CRC Handbook of Chemistry and Physics. 66th Edition. CRC Press Inc. Florida. 1986.