ACCUMULATION OF HYDROGEN RELEASED INTO A VENTED ENCLOSURE - EXPERIMENTAL RESULTS

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ABSTRACT

This paper reports experimental results from a series of experiments in which gaseous hydrogen was released into a 31 m3 enclosure and the hydrogen concentrations at a number of points within the enclosure were monitored to assess whether hydrogen accumulation occurred and whether a homogeneous or stratified mixture was formed. The enclosure was located in the open air and therefore subject to realistic, and therefore variable, wind conditions. The hydrogen release rate and the passive vent arrangements were varied. The experiments were carried out as part of the EU Hyindoor Project.

1.0 INTRODUCTION

Hydrogen energy applications often require that systems be used indoors or in enclosures (e.g. fork lift trucks in a warehouse, fuel cells located in a room, or hydrogen stored and distributed from a gas cabinet). The release of hydrogen in such facilities can potentially lead to its accumulation, the formation of a flammable hydrogen-air mixture and subsequent ignition. Existing knowledge gaps in the behaviour of indoor hydrogen releases are to be addressed as part of the three year HyIndoor project.

This paper reports the initial results from an experimental programme to investigate the accumulation and dispersion behaviour of hydrogen released within an enclosure fitted with passive ventilation.

The objective of the experiments at HSL is to provide concentration data that can be used by HSL and other Hyindoor partners to test the validity of predictive mathematical models and simple engineering tools. In particular, the experiments are to investigate; the influence of the wind on the dispersion regimes (mixing versus displacement regime), where the wind would have a negative impact and how this could be mitigated, and how the dispersion/accumulation behaviour of choked flow hydrogen releases differs from that arising from sub-sonic releases of equivalent mass flow-rate.

2.0 EXPERIMENTAL ARRANGEMENT

2.1 Enclosure and hydrogen release system

The experimental set-up consists of a 31 m^3 enclosure with cross sectional area of 2.5 m by 2.5 m and a length of 5 m. Five similar vents (0,83 m width and 0,27 m height) are located on the sides of the enclosure and a circular vent of same area is located on the roof; these can be closed or opened as required. The enclosure can withstand an internal over-pressure of at least 0.2 bar and is fitted with explosion relief panels in the roof in case of accidental ignition of the hydrogen air mixtures.

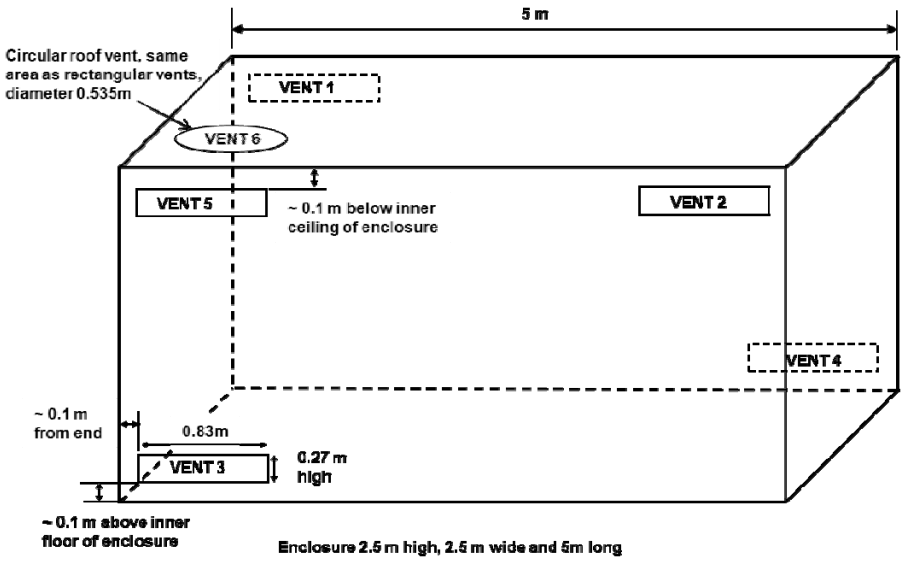

Figure 1. Sketch of the HSL 31 m^3 test facility

Up to the time of writing this paper, the hydrogen releases have been at low pressure via mass flow controllers and a pipe outlet with a 10mm internal diameter. The release pipe is located centrally within the enclosure, directing upwards with the release point 0.5 m above the floor level. The hydrogen releases are operated remotely from a control cabin some distance from the enclosure.

A schematic of the release system is shown in Figure 2 and a photograph of the release point is shown in Figure 3.

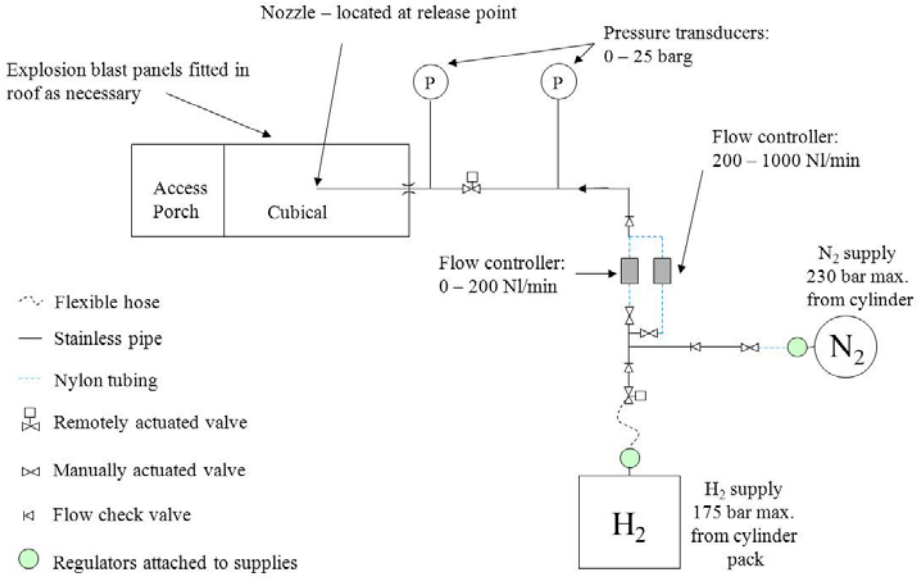

Figure 2. Schematic of the Hydrogen supply system

Figure 3. Photo of the hydrogen release point within the enclosure

2.2 Instrumentation

The enclosure was fitted with the following instrumentation.

- 27 electrochemical cell oxygen sensors were mounted on suspending wires within the enclosure, in “layers” at three different heights from the floor (1 m, 1.75 m and 2.25 m), as shown in Figure 4. Additional oxygen sensors were placed within the open vents as required. The hydrogen concentration was then calculated from the oxygen depletion that was detected by each sensor.

- 14 thermocouples (Type K) were mounted within the enclosure as shown in Figure 5. Thermocouples were also peened into the centre of each of the 6 walls of the enclosure (i.e. the four walls, the ceiling and the floor) and an additional thermocouple was placed within each open vent as required.

- Pressure transmitters were installed on the hydrogen supply pipeline.

- Bidirectional probes connected to differential pressure transmitters (+/- 19.6 Pa) were installed for some of the later runs in an attempt to detect flow through the open vents.

In addition, the weather conditions close to the enclosure were monitored (i.e. wind speed, wind direction, temperature and humidity).

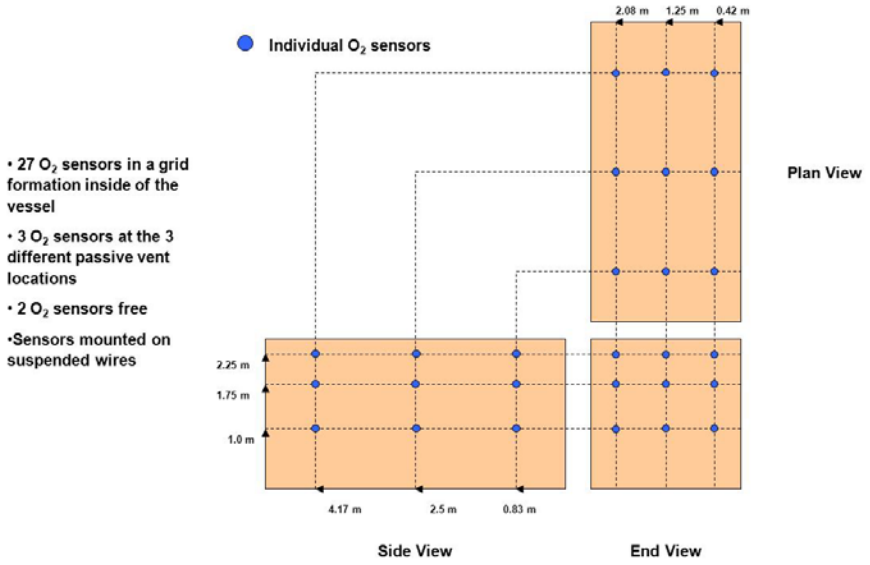

Figure 4. Positions of oxygen detectors within enclosure (for hydrogen concentration measurements)

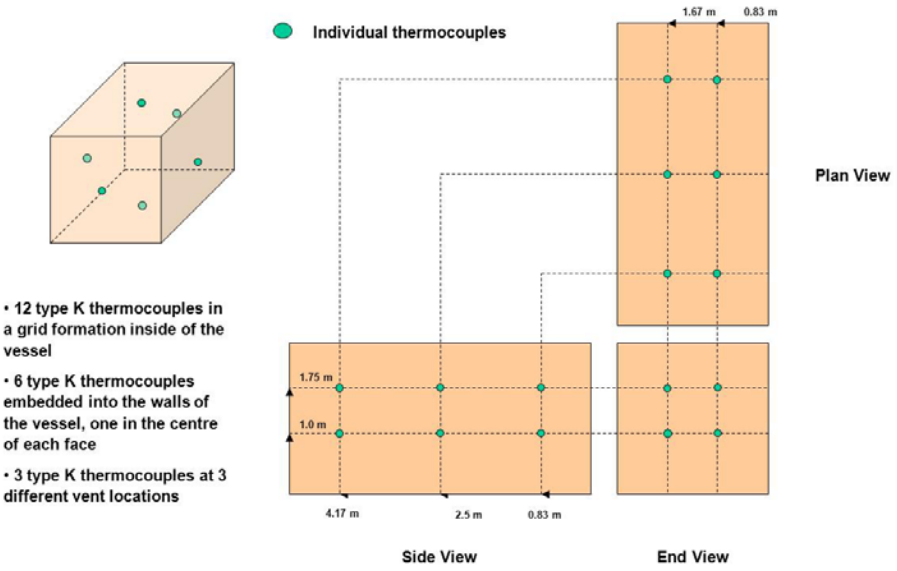

Figure 5. Positions of thermocouples within enclosure

3 PRELIMINARY RESULTS

The following is an initial, somewhat qualitative, discussion of the key results observed so far in the HSL experiments for this project. A summary of the preliminary results from key experiments is given in Table 1. The hydrogen release rate is given in Normal litres per minute (Nl/min) which is the flow normalised to 1 atmosphere and 0°C. The average hydrogen concentration values given in the table are the arithmetic means of the values from the sensors functioning at each of the three levels within the enclosure for a period judged to be at steady-state. Note that for some short duration experiments the steady-state was not yet reached, and for some experiments involving two or more open vents the wind effects meant that only a quasi-steady-state was reached.

Table 1. Summary of preliminary results of experiments

Test Number	Vents Open (see Figure 1)	Flow Rate (Nl/min)	Average H2 @ 1m (%)	Average H2 @ 1.75m (%)	Average H2 @ 2.25m (%)	Average Wind Speed (m/s)	Average Wind Direction	Release duration (s)
1	V2, V1	150	0.7	0.7	0.6	4.7	20° to vent	734
2	V2, V1	150	1.2	1.3	1.6	3.0	Parallel to vent	478
3	V2, V1	300	1.9	2.1	3.0	3.1	Parallel to vent	409
4	V2, V1	150	0.7	0.7	0.6	2.4	34° to vent	1763
5	V2, V1	300	1.7	1.9	2.4	2.5	34° to vent	1219
6	V2, V1	600	2.4	2.7	3.1	2.5	22° to vent	1181
7	V1	150	1.9	2.2	2.8	2.3	25° to vent	1823
8	V1	150	4.3	4.8	7.1	5.1	Opposite side to vent	1863
9	V1	250	7.3	8.8	11.8	2.8	Opposite side to vent	1776
10	V1, V2, V4	800	2.7	3.1	4.4	2.9	17° to one upper vent, opposite side to lower vent	560
12	V1, V2, V4	1200	2.7	2.9	3.6	4.1	19° to one upper vent, opposite side to lower vent	835
13	V4 & V5	800	2.5	3.5	4.6	3.8	22° to upper vent	1138
14	V4 & V5	1000	2.4	4.6	6.2	3.3	27° to upper vent	951
15	V4 & V5	1200	2.5	5.6	7.6	3.1	19° to upper vent	1020
16	V1	150	6.0	7.0	9.5	3.5	Opposite side to vent	2960
17	V3, V6 (chimney)	800	0.7	9.3	9.5	1.3	Opposite side to bottom vent	660
18	V4, V6 (chimney)	800	0.6	2.5	5.7	2.3	Almost parallel to bottom vent	600
19	V6 (chimney)	150	7.5	8.4	9.9	2.7	On to same end as roof vent	2350
20	V6 (chimney)	130	5.6	6.4	8.2	2.0	On opposite side to roof vent	2656

3.1 Experiments with Single Open Vents

In one experiment (Test 16), hydrogen was released at 150 Nl/min for 50 minutes into the enclosure, which had one open vent at high level in one of the side-walls (Vent 1) on the opposite side to that into which the wind was impinging. It appears that a concentration gradient was established within the enclosure down to a level of 1m, the level of the lowest measurement. However, it is also evident that there is a delay until the hydrogen "layer" descends to the 1 m level compared to the higher levels. The concentration traces that exhibit "spiking" behaviour are from those sensors closest to the open vent and therefore more susceptible to wind activity. These features are shown in Figure 6.

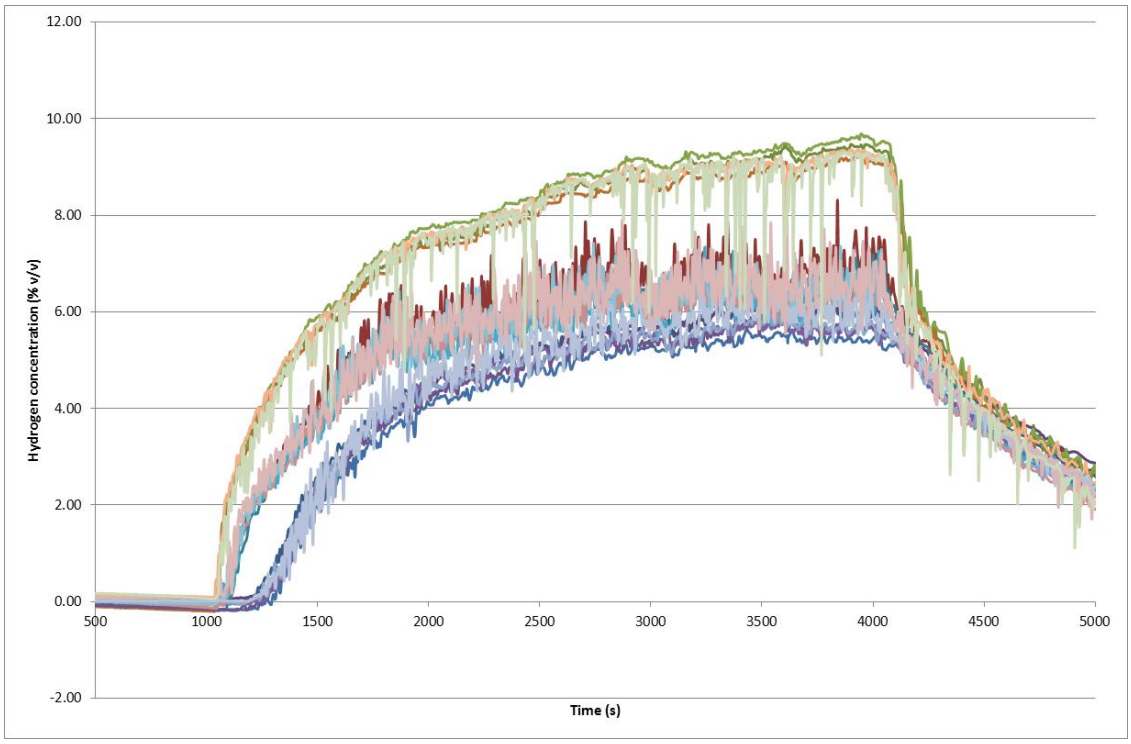

Figure 6. Hydrogen concentrations within the enclosure, 150 Nl/min single upper vent, minimal influence of wind

It is worthy of note that the maximum concentration appears to be reaching between 9 and 10% v/v hydrogen. This compares reasonably well with a uniform concentration of about 9% v/v predicted by the Linden model, which accounts for buoyancy-driven flow but neglects the influence of wind [1].

A similar experiment was carried out at the same hydrogen flow rate of 150 Nl/min and the same vent arrangement but on this occasion a variable wind with an average velocity of 2.5 m/s was incident at 25º to the open vent (Test 7). This resulted in a considerably lower hydrogen concentration within the enclosure at the quasi-steady-state which was well-established within the 30 minute duration of the test. This is demonstrated in Figure 7 where the actual volume averaged concentration is about 2 to 3 % v/v. For a release rate of 150 Nl/min a uniform concentration of about 2.5% correlates to a ventilation rate of approximately 10 air changes per hour (ACH) [2]. This compares with the value of 2.8 ACH predicted by the Linden model.

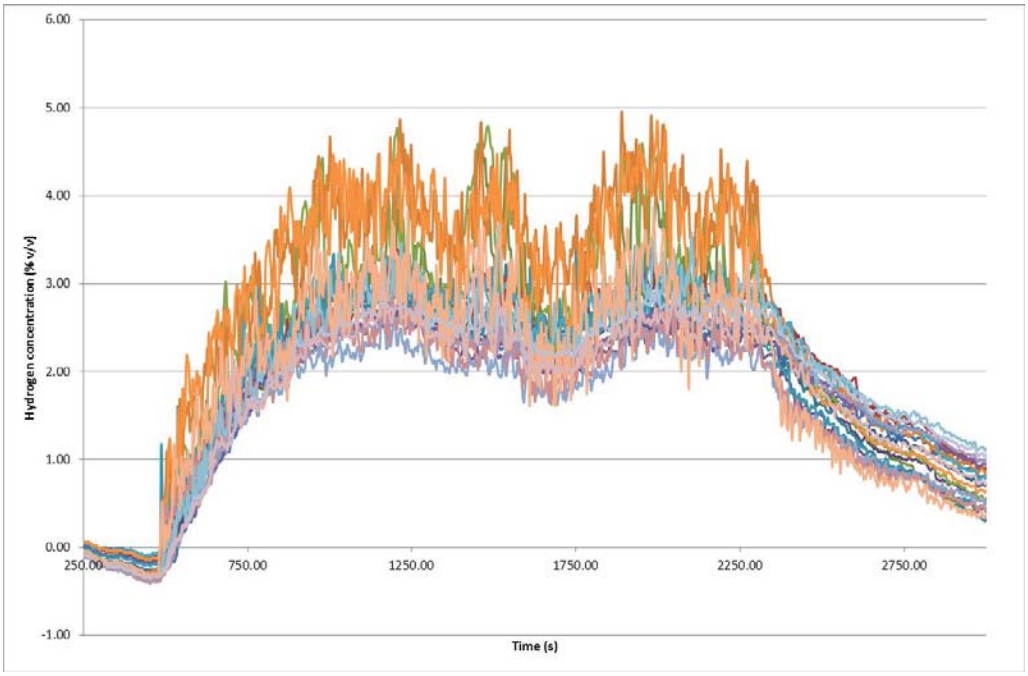

Figure 7. Hydrogen concentrations within the enclosure, 150 Nl/min single upper vent, marked influence of wind blowing into open vent

In another experiment (Test 19), a flow rate of 150 Nl/min of hydrogen was released into the enclosure, which was ventilated only through a vent in the ceiling. The ceiling vent had the same area as the upper side-wall vent discussed above. Initial indications are that the maximum concentration is similar to, or slightly higher than, that for the side-wall vent without incident wind.

3.2 Experiments with more than one open vent

In all experiments where more than one vent is open and both vents are at the upper level, the maximum hydrogen concentration has been lower than that predicted using the Linden model, indicating that wind-driven ventilation dominates. In these cases, predictions from wind-driven ventilation models such as Quadvent [4] appear to be in better agreement with the measurements.

However, where there is one lower vent open on one side and an upper vent open on the other side, with the wind incident on the upper vent, the wind appears to be able to overwhelm the effect of buoyancy as considered previously by Linden et al [3]. An experiment (Test 15) was carried out in which hydrogen was released at 1200 Nl/min into the enclosure with one upper open and one lower vent open. The wind was incident on the upper vent although the wind speed was variable. Figures 8, 9 and 10 show a period of the experiment in which the buoyancy is overwhelmed by opposing wind. Figure 8 shows the hydrogen concentration at the 1 m level, Figure 9 shows the hydrogen concentration at the vents (indicating flow into and out of the enclosure) and Figure 10 shows the wind speed for the same period (both the raw data and a 30 point rolling average). It appears that while the wind speed is sufficiently high, the flow is into the enclosure via the upper vent and out of the enclosure via the lower vent. This appears to result in higher concentrations than when buoyancy is allowed to dominate with the maximum wind speed and maximum concentration coinciding at about 550 seconds, after which the concentration decreases once again.

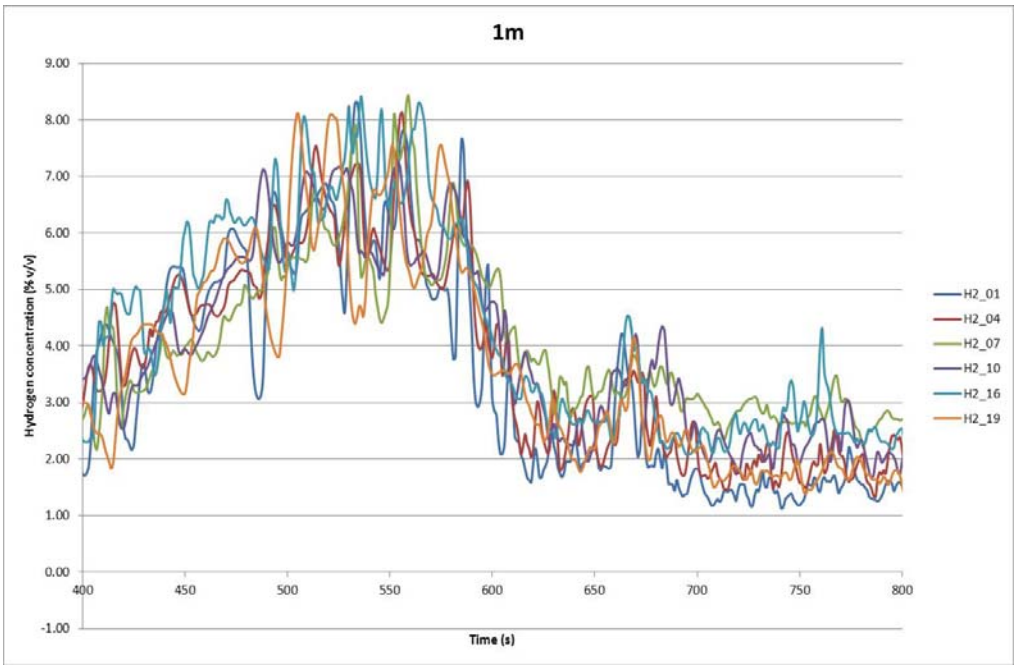

Figure 8. Hydrogen concentration within the enclosure at the 1 m level, 1200 Nl/min, one upper vent, one lower vent, wind blowing into the upper vent

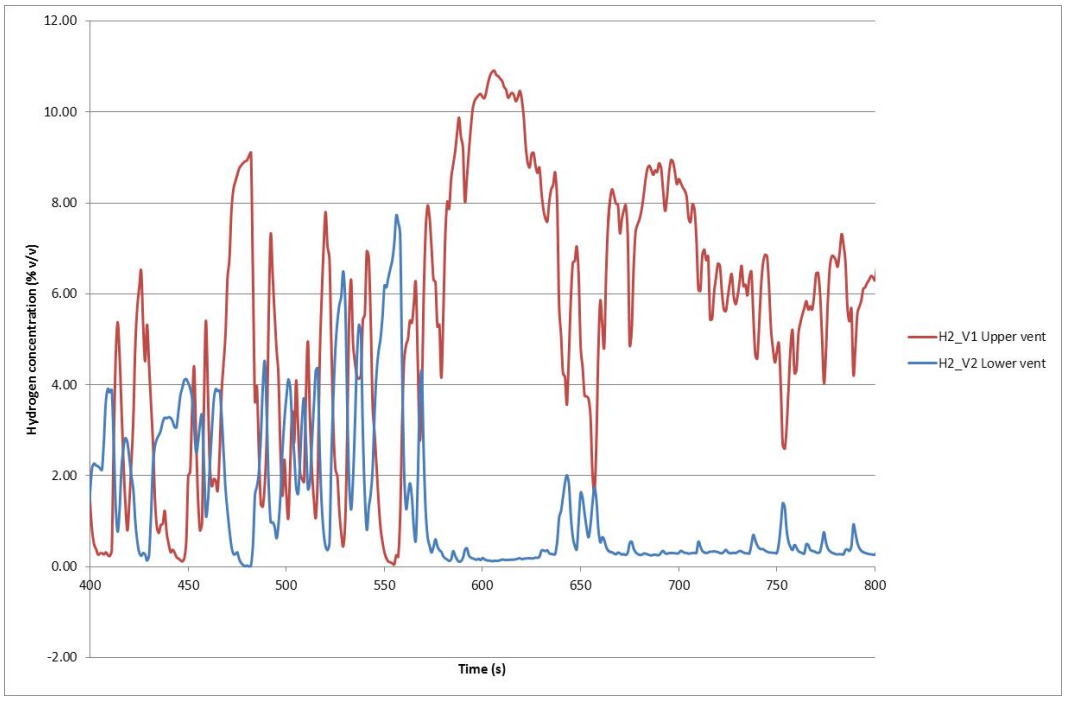

Figure 9. Hydrogen concentration at the upper and lower vents, 1200 Nl/min, one upper vent, one lower vent, wind blowing into the upper vent

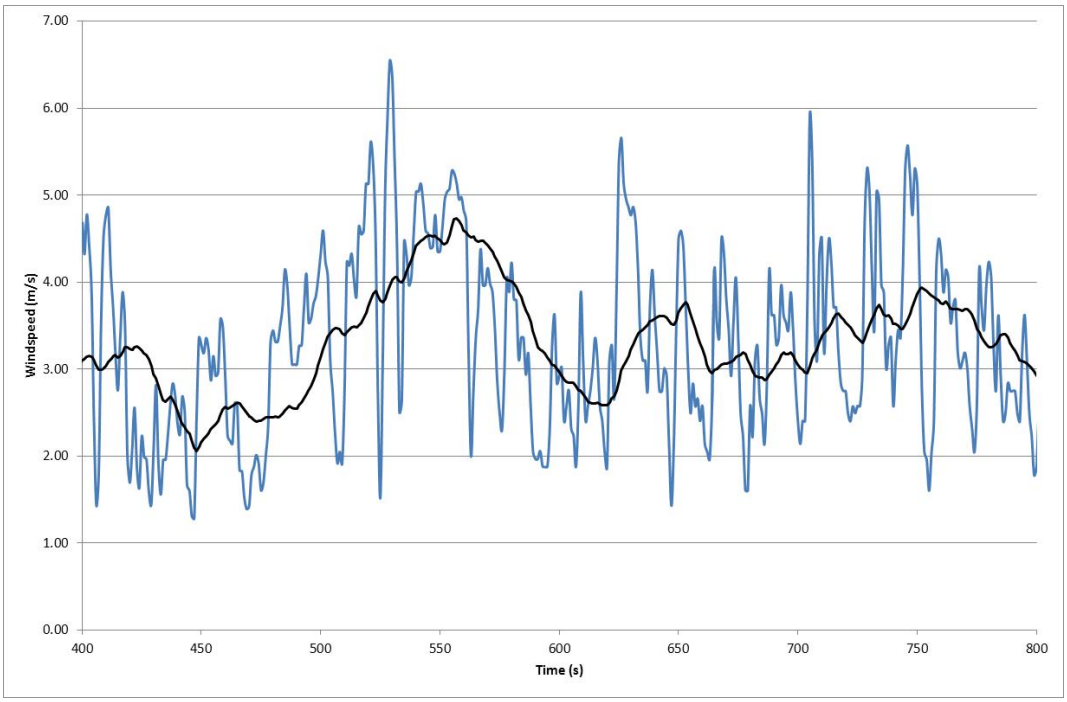

Figure 10. Wind speed during the experiment, 1200 Nl/min, one upper vent, one lower vent, wind blowing into the upper vent

4 CONCLUSIONS

A number of experiments have been carried out in which hydrogen has been released into an enclosure that can be equipped with a number of open vents. A considerable amount of data has been generated that can be used in the future to further understand the accumulation of hydrogen within an enclosure fitted with passive ventilation.

Where there is a single vent and the wind is not incident upon it, the measured maximum hydrogen concentration appears to agree reasonably with that predicted by the buoyancy-based Linden model.

Where wind is incident upon an open vent, this appears to result in a lower concentration than that predicted by the Linden model. However, when wind is incident upon an upper vent the wind may overwhelm buoyancy in a negative sense and change the distribution of hydrogen within the enclosure, with the net flow being out of a lower vent.

5 FURTHER WORK

Hydrogen releases will be performed in choked flow regime to allow comparison of the dispersion / accumulation behaviour with sub-sonic releases at similar flow rates to some of the sub-sonic releases discussed above.

Some hydrogen concentration measurements will be made at heights of less than 1 m above the floor to further assess any layering effects.

Further, more rigorous, analysis of test data will be carried out by HSL and other Hyindoor partners.

6 ACKNOWLEDGEMENTS

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