

HyDelta 2

WP6A – Safety of hydrogen in the distribution grid and built environment

D6A.1 – Outflow experiment results: concentration build-up at leakages between 50 - 1000 dm³/h

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Summary

Hydrogen has different properties from natural gas. Its physical and chemical characteristics are known in detail, but there is still insufficient knowledge about the safety risk when applied in gas pipelines in the built environment. However, this knowledge is needed to know whether different safety measures need to be taken than for natural gas.

This required knowledge mainly relates to probabilities and consequences of the unwanted release of hydrogen. Mitigating measures are then aimed at reducing the probability of a hazardous situation arising and/or reducing its consequences.

In HyDelta 1.0 (the predecessor of this project), concentration measurements were therefore made to gain insight on the diffusion of hydrogen versus methane at small leak sizes of hydrogen and methane in the gas meter cabinet (up to 20 and up to 15 dm³/h, respectively). In the present study, which falls under HyDelta 2.0, the measurements were scaled up to higher gas outflows, namely 50, 100, 300 and 1000 dm³/h. The measurements were carried out in a container composed of a room (26 m³) and a hall (10 m³) containing a gas meter cabinet. See Figure 1:

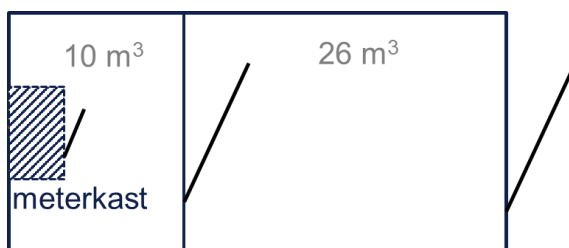


Figure 1: Top view of container with division into hall (10 m³) and room (26 m³)

The distribution of gases was measured with gas sensors attached according to a matrix with three height positions, three width positions and six length positions. See Figure 2.

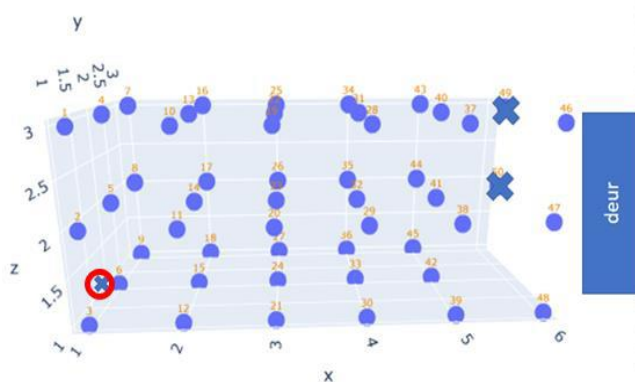


Figure 2: Side view of container showing positions of gas sensors. Red circled the gas discharge point. Gas sensor 50 is used as additional protection (with limit value of 60% of LEL).

Experiments were conducted with the following variables:

Gas outflow:	50, 100, 300 and 1000 dm ³ /h ³
Gas types:	hydrogen/natural gas
Ventilation grilles from gas meter cabinet (ventilation to hall):	open/closed (sealed)
Ventilation grille from the hall to the outside (left, top):	open/closed
Door between hall and room:	open/closed
Air intake over floor:	18 and 36 dm ³ /h
Air extraction via external air grille:	18 and 36 dm ³ /h

The gas outlet was stopped as soon as one of the sensors registered more than 50% LEL. This safety measure was taken to prevent unwanted ignition of the gas.

Extrapolation was used to estimate whether 100% would also be achieved if the gas outflow had not been stopped.

On this basis, the results of the experiments were classified according to final concentration into one of three categories: less than 50% LEL; between 50% and 100% LEL and greater than 100% LEL. As long as the concentration throughout the container is below 100% LEL, the situation is safe in any case because the gas-air mixture cannot ignite.

The measurement results for both hydrogen and natural gas lead to the following findings a. and b.:

a. Inside the gas meter cabinet

At a gas outlet in the gas meter cabinet of:

- 50 dm³/h or more, the concentration rises to more than 100% LEL if no ventilation grilles are fitted, but to less than 100% LEL if grilles are fitted in accordance with the standard.
- 100 dm³/h or more, the final concentration does exceed 100% LEL.

b. Outside the gas meter cabinet

At a gas outlet in the gas meter cabinet of:

- 50 or 100 dm³/h, the concentration outside the gas meter cabinet remains below 100% LEL;
- 300 dm³/h, the concentration rises above 100% LEL in part of the experiments (hydrogen: 3 out of 8; natural gas in 1 out of 8); and
- 1000 dm³/h, the final concentration exceeds 100% LEL in all cases.

The results lead to the following conclusions:

1. The build-up of concentrations (hydrogen and natural gas) remains below 100% LEL in the gas meter cabinet and other rooms when the gas meter cabinet is fitted with the vents prescribed for natural gas, at a gas outlet of up to 50 dm³/h.

This means that a leak size in the meter cabinet of up to 50 dm³/h can be technically accepted. The ventilation grilles prescribed for natural gas are therefore more than sufficient for hydrogen. It is recommended to install ventilation grilles in meter cabinets for hydrogen gas meter installations in accordance with the current standard NEN 2768 + A1 for natural gas meter cabinets.

2. Hydrogen has stronger stratification than natural gas.

Especially with low ventilation, this can lead to areas of high gas concentration ("dead spots") under the ceiling. Mechanical ventilation can reduce the likelihood of this. Both extraction and air supply can reduce the likelihood of such zones:

- With extraction high in the room, the highest concentration is discharged.
- When air is blown in, the gas is more mixed with air so dead ends are avoided.

3. The usefulness of a gas stopper cannot be demonstrated with this study

Based on this study, no recommendation can be made on whether or not to apply a gas stopper, as the gas stopper only intervenes well above the gas outflow used in the project.

4. Mechanical ventilation is highly effective

The ventilation flow rates determined afterwards, calculated on the basis of a change in concentration, are often higher than the set ventilation flow rates. This means that mechanical ventilation often appears to be even more effective than expected on the basis of the set air supply or air exhaust.

Some possible causes were found for this, however, an unambiguous explanation cannot be given based on the results.

The results lead to the following possibilities for follow-up research:

- Experiments with different (set-up locations for gas meters than examined here)
- Experiments with small spaces other than a gas meter cabinet (e.g. a crawl space, kitchen sink or riser cupboard).
- Experiments or CFD calculations to understand the causes of higher than expected ventilation (see above under 4).

Content

Document summary	2
Summary	3
1 Introduction.....	9
1.1 HyDelta 2.0 versus HyDelta 1.0	9
1.2 Terminology.....	9
LEL, UEL, lower and upper flammability limit	9
2 Practical details of the experiments.....	10
2.1 General	10
2.2 Layout of the container	10
2.3 Simulation of a gas leak.....	12
2.4 Ventilation	13
No ventilation	13
Natural ventilation	13
Mechanical air supply.....	14
Mechanical exhaust ventilation	15
3 Gas outlet with gas meter cabinet, 10 m ³ and 26 m ³ spaces.....	16
3.1 Layout and placement of sensors.....	16
3.2 Variables	16
4 Results in brief.....	19
4.1 Main conclusion	19
4.2 The measurement results summarised in two tables	19
4.3 The limit of 100% LEL.....	20
4.4 Construction of profiles and determination of final concentration.....	20
4.5 Measurement data.....	21
5 Section 1: Measurements in the gas meter cabinet	22
5.1 Closed ventilation grilles in the gas meter cabinet (configuration 1)	22
5.2 Effect ventilation grilles in gas meter cabinet (configuration 3)	25
5.3 Effect open connecting door (configuration 4)	27
6 Section 2: Measurements outside the gas meter cabinet	30
6.1 Closed grilles in the gas meter cabinet (configuration 1).....	30
6.2 Effect open grilles in the gas meter cabinet (configuration 3).....	31
6.3 Effect open connecting door (configuration 4)	33
6.4 Effect of natural ventilation in the container (configuration 7).....	36

6.5	Effect of forced supply ventilation in the container (configuration 7/0.5 and 7/1.0)	37
6.6	Effect of forced exhaust ventilation in the container (configuration 8/0.5 and 8/1.0)	38
7	Determination of ventilation rate based on measured concentration profiles.....	40
7.1	General	40
7.2	Effect of natural ventilation on ventilation rate.....	42
7.3	Effect of forced air supply on ventilation rate	43
7.4	Effect of forced return air on ventilation rate.....	44
8	Discussion of the results of the experiments	45
8.1	General	45
8.2	Ventilation of gas meter cabinet according to regulations is essential	45
8.3	Leakage size limit for hydrogen need not be different from natural gas.....	47
8.4	Mechanical supply of air is very effective to keep gas concentration low.	47
8.5	Mechanical air extraction is also effective.	47
8.6	Layering in hydrogen	47
9	Conclusions from the experiments	49
9.1	Ventilation of gas meter cabinet is necessary.....	49
9.2	Leakage size limit for hydrogen no different from natural gas	49
9.3	At leak size of 50 to 100 dm ³ /h no ignitable concentration outside gas meter cabinet.....	49
9.4	Leaks outside the gas meter cabinet.....	49
9.5	Differences in ventilation rates	49
9.6	Gas stopper as mitigating measure?	49
10	Recommendations for further experimental research	50
10.1	Other types of gas meter cabinetes	50
10.2	Rooms other than a gas meter cabinet.....	50
10.3	Further investigation into unexplained effects.....	50
Annexes		51
I	Practical examples of leaks	52
II	Determination of average ventilation rate	55
II.1	General	55
II.2	Ventilation	55
III	Measurements in the gas meter cabinet , schematically arranged	59
III.1	Hydrogen configuration 1, 3 and 4 *).....	59
III.2	Natural gas configuration 1, 3 and 4	60
IV	Measurements outside the gas meter cabinet , schematically arranged	61
IV.1	Hydrogen configuration 1, 3 and 4.....	61
IV.2	Hydrogen configuration 7, 7/0.5 and 7/1.0.....	62

IV.3	Hydrogen configuration 8/0.5 and 8/1.0	63
IV.4	Natural gas configuration 1, 3 and 4	64
IV.5	Natural gas configuration 7, 7/0.5 and 7/1.0	65
IV.6	Natural gas configuration 8/0.5 and 8/1.0	66
V	All measurement graphs	67
VI	Ventilation rate and final average concentration (calculated)	83
VII	Gas meter cabinet used for the setup	84
	References	85

1 Introduction

Hydrogen has different properties from natural gas. As far as the 'hard' physical/chemical characteristics are concerned, these are known in detail. What is lacking, however, is specific knowledge about what difference in safety risk this poses to professionals and residents in the practice of gas distribution and transport. This knowledge is needed to adapt the use of hydrogen when required from a safety perspective. Extensive knowledge of *natural gas* does exist and this knowledge can serve as a basis in comparing with hydrogen.

In order to estimate the risks when using hydrogen in the distribution and transport network compared to natural gas, it is important to know the differences in probability and consequence. In particular, the probability refers to the possibility of a hazardous situation occurring; the consequences can be expressed in terms of damage caused in the event of a fire or explosion. Mitigation measures then aim to reduce the probability of a hazardous situation occurring.

1.1 HyDelta 2.0 versus HyDelta 1.0

To this end, the HyDelta programme 2021-2022 (HyDelta 1.0) defined the work package 'Hydrogen and Safety' with the following main objective: *Identify risks concerning the behaviour of hydrogen in case of leaks in houses and in the distribution network and define management measures based on the risks.*

This included experiments on the diffusion of hydrogen and natural gas in a container under different forms of ventilation. The gas outflow in these experiments was limited to 20 dm³/h. The present study, which falls under HyDelta 2.0, Work Package 6a/Task1 has the same main objective as HyDelta 1.0. The experiments are an extension of the experiments of HyDelta 1.0; with higher gas outflows than in 1.0. The same test setup was used (with gas outflows of 50, 100, 300 and 1,000 dm³/h) to measure the dispersion and concentration build-up in the container under different ventilation conditions. The measurements were carried out with both natural gas and hydrogen.

1.2 Terminology

LEL, UEL, lower and upper flammability limit

In this report, the abbreviations LEL and UEL are used for the lower and upper flammability limits of a gas, respectively. These abbreviations are in line with the Dutch and European standards in use. These standards do not distinguish between LEL/UEL and LFL (lower flammability limit)/UFL, so this report does not make that distinction either.

LEL refers to the lower flammability limit. Below the lower flammability limit, insufficient fuel is present to sustain a combustion reaction. LEL and LFL mean the same lower flammability limit here. For hydrogen the LEL/LFL is 4 vol% hydrogen in air, for natural gas it is 5.8 vol%.

UEL refers to the upper flammability limit. Above the upper flammability limit, insufficient oxygen is present to maintain a combustion reaction. UEL and UFL refer here to the same upper flammability limit. For hydrogen the UEL/UFL is 75 vol% hydrogen in air, for natural gas it is 15.9 vol%.

Ventilation rate

The number of air changes of a room or building per hour.

2 Practical details of the experiments

2.1 General

To study hydrogen leaks in an indoor space, a standard office unit container that can be flexibly arranged into different rooms was used. In this way, future research can easily expand the measurement installation and layout of the container. This container was previously used for HyDelta 1.0, which also makes reuse for HyDelta 2.0 and specifically this research logical. For HyDelta 2.0, the capabilities were further extended, allowing a larger flow rate of outflowing gas and so that the ventilation rate could be set by controlled blowing in and blowing out of air.

The internal dimensions of the container are 600 cm x 250 cm x 250 cm (l x w x h) with a working volume of about 36 m³. The advantage of this office unit container is that all walls are flat and the unit is insulated, making it easy to set up and minimising external influences (temperature, wind, etc.).



Figure 1: Photo of the standard office unit container

2.2 Layout of the container

The container is set up to simulate hydrogen and methane leaks in indoor spaces in order to determine the outflow profile in the space.

On the walls, floor and ceiling, wooden battens are installed; boards can be mounted against the wooden battens to divide the interior space into compartments of 10, 20 or 30 m³ (see also Fig.2). The gas meter cabinet from [1] was used for this purpose. The passage of the ventilation grilles in the gas meter cabinet door meet the standard; see Appendix VII. Prior to the experiments, the container can be heated to 20°C. If necessary, the container can be shielded from direct sunlight.

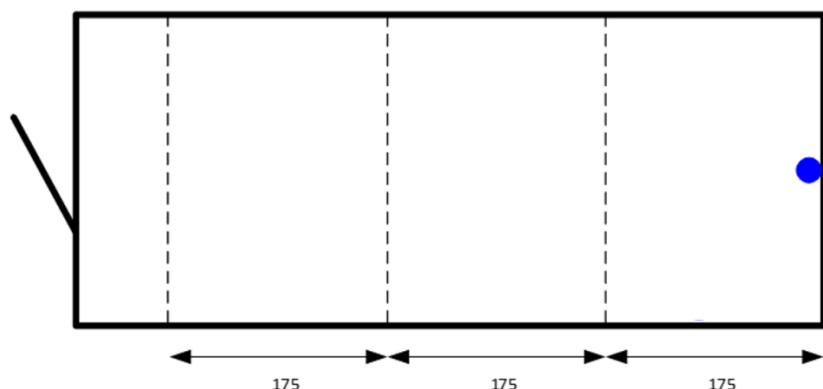


Figure 2 Layout of the container (top view) showing the 10-20-30 m³ spaces to be arranged (right to left) and with the location of the outflow (blue dot)

To monitor the distribution of gas in the container, a matrix of 50 gas sensors with different horizontal and vertical positions was placed where methane or hydrogen concentration can be monitored at different locations.

Table 1: Gas sensor data

Brand	GDS Technologies XDI-F6
Sensor type	Catalytic gas sensor
Measuring range methane	0-5 vol% (0-100% LEL)
Measuring range hydrogen	0-4 vol% (0-100% LEL)

The gas sensors are distributed through the room using a steel wire grid (see e.g. Figure 3). For each experiment, the location of the sensors can be changed.



Figure 3 Matrix of sensors on the inside of the container

2.3 Simulation of a gas leak

Simulating a gas leak in the container is shown schematically in Figure 4.

During the experiments, methane or hydrogen gas flows are measured with a Bronkhorst EL-FLOW mass flow meter. With this, the gas outflow can be set between 50 - 1000 dm³/h. The gas flows into the container using a gas valve (Figure 5). To ensure safety during the experiments, in case the placed gas sensors register an exceedance of 50% of the lower flammability limit (LEL), the Normally Closed (NC) valve¹ will close so that no more gas flows into the container. As an additional safety measure, a sensor is installed that signals to the NC valve when 60% of the LEL is exceeded. The operator will be alerted in both cases so that the container can be vented. Furthermore, the usual residential pressure of 30 mbar will be used during the experiments.

¹ The NC valve is a normally closed valve, i.e. it closes automatically in the event of a power failure.

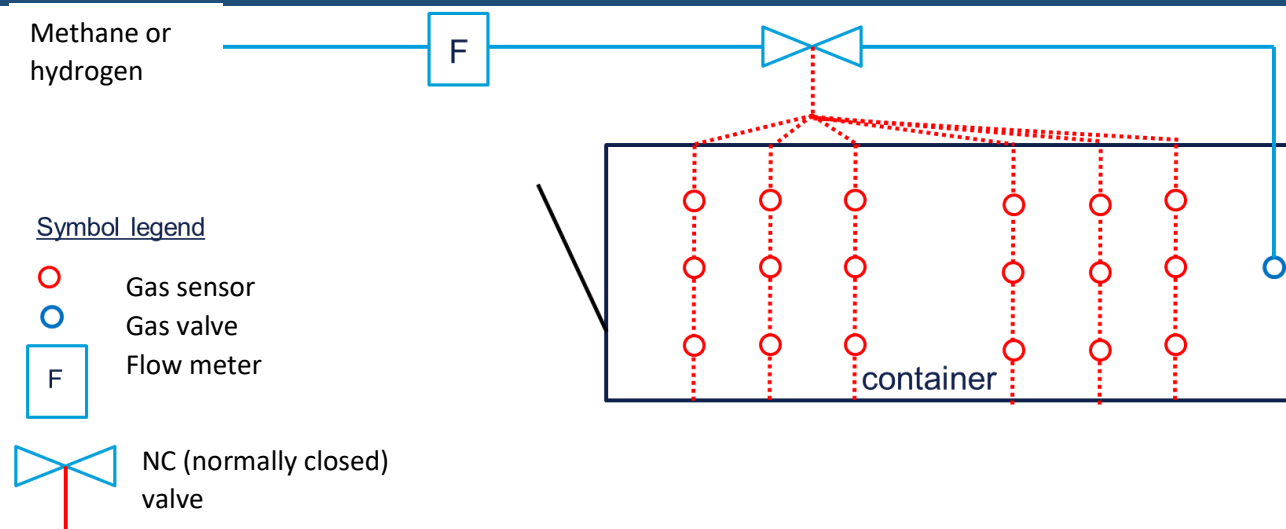


Figure 4 Schematic overview of gas outflow



Figure 5 Gas valve with outlet opening

2.4 Ventilation

in the container should be able to be monitored and measured in order to draw conclusions about the effect of ventilation on hydrogen diffusion in the adjacent areas around the leak in the container.

The measurement setup has several options by which ventilation can be influenced, namely natural ventilation, mechanical supply ventilation and mechanical exhaust ventilation. These are discussed below, with the situation without ventilation explained first.

No ventilation

Several experiments were carried out without ventilation of the container. These measurements are the "worst case" situation and serve as a reference for measurements with ventilation. Although the container has no ventilation facilities in this situation, the container is not completely airtight.

Natural ventilation

As shown in Figure 6, six ventilation openings (50 cm x 2 cm) are provided on both sides of the container; three openings at 200 cm height and three openings at 90 cm height.



Figure 6 Photo of side of container with the 6 ventilation openings

Threaded ends are welded around the openings so that they can easily be closed with flange connections or fitted with a plate with the desired outlet opening.

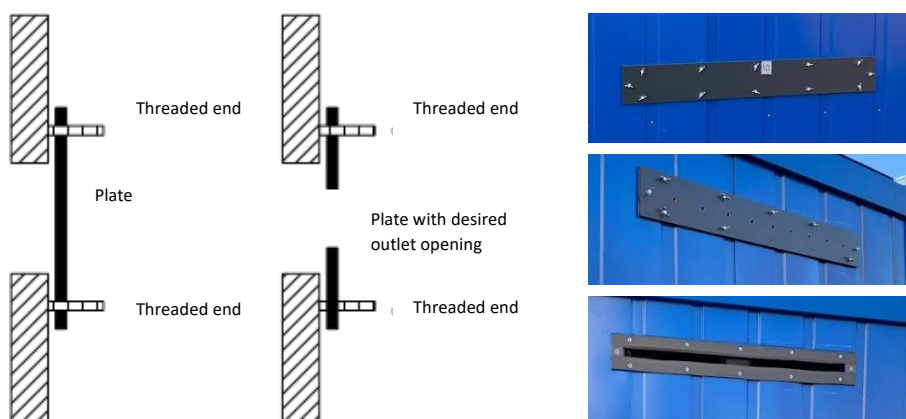


Figure 7 Ventilation openings; right from top to bottom: closed, with 9 holes and open

The ventilation openings are 50 x 2 cm (l x w) at full opening. For some experiments, a plate was made with 9 holes of 1 cm diameter.

A special form of natural ventilation is when all the vents are closed (the container is not 100% gap-tight, as was found in HyDelta 1.0). So even then, the container is slightly ventilated.

Mechanical air supply

The natural ventilation rate as described above is difficult to set to a specific value because it is influenced by weather conditions. In natural ventilation, air enters low in the room, rises due to heating and flows out through a higher ventilation opening. After the measurements, the ventilation rate can be roughly derived based on the rate of change of gas concentration. However, the ventilation rate cannot be set in advance.

To still measure at ventilation rates of 0.5 per hour and 1 per hour, a forced supply of air through a low slot in the container was used. This low slotted air supply simulates the "natural" supply under the door. The air was blown in with a fan and metered with a mass flow controller. See Figure 8.



Figure 8: Controlled slotted air supply. On the left, the supply fan with mass flow controller that allows setting a ventilation supply (On the right, the penetration through the container wall and the air distribution box).

A ventilation rate $R = 1$ can thus be set (given a container volume of 36 m³) by adjusting the air supply to 36 m³/h and $R = 0.5$ by 18 m³/h.

Mechanical exhaust ventilation

Besides the forced supply of air, a second method of setting the ventilation rate was used, namely mechanical exhaust of air.

Similarly to mechanical air supply, controlled ventilation multiples of 0.5 per hour and 1 per hour were operated by extracting air through ventilation slot No 1. This is located, standing in front of the container entrance, on the left rear (top slot). The same fan and mass flow controller were used, however, with a different exhaust duct. See Figure 9

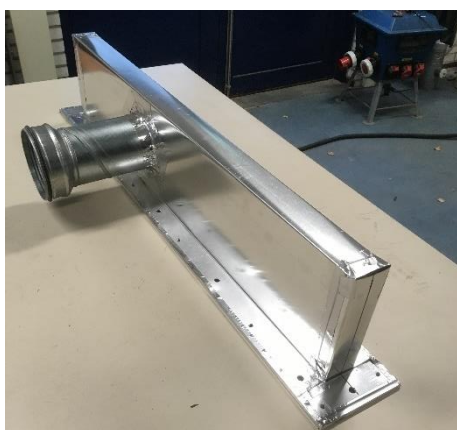


Figure 9: Exhaust duct, used for extraction flows 18 and 36 m³/h.

3 Gas outlet with gas meter cabinet, 10 m³ and 26 m³ spaces

3.1 Layout and placement of sensors

The interior space of the container is divided (like phase 2 in HyDelta 1.0) into two compartments of 10 m³ and 26 m³ (hall and room, respectively) by installing a partition with a door. This simulates a gas meter cabinet placed in the hall where the hall is connected to a larger room. The gas meter cabinet is placed in the smallest room and equipped with three sensors (low, middle and high in the gas meter cabinet). The 10 m³ room also contains 24 sensors, while the remaining sensors are located in the 26 m³ room. Figure 10 shows photos of the indoor spaces and the locations of the sensors.



Figure 10 Pictures of the setup.

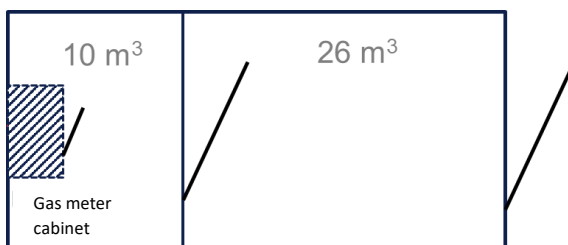


Figure 11 Top view of container with layout for phase 2 experiments

In the experiments, gas outflow takes place in the gas meter cabinet and the effect of different ventilation conditions is examined.



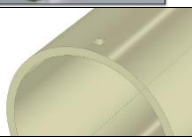
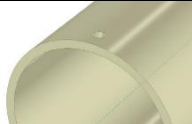
Note: This cabinet is only a model for a gas meter cabinet, not for a “stijgkast” in, for example, an apartment building).²

3.2 Variables

The experiments in HyDelta 1.0 (2021-2022) were limited to gas outflows of up to 20 dm³/h. This follow-up in HyDelta 2.0 has worked with much larger gas outflows, namely 50, 100, 300 and 1000 dm³/h. In Table 2 each leakage rate shows an example of an application where this leakage could occur. The examples are based on a report by Hy4Heat [2]. See Appendix I for more examples and for an explanation for how the data from this report were used.

² Stijgkast (“riser cupboard”): a shaft (duct) where the utilities' pipes are located and from which a meter box can be connected on any desired floor.

Table 2: Examples of leakage rates (more examples can be found in Appendix I)

Hydrogen leakage rate (dm ³ /h) at 20-30 mbar	Leakage rate (order of magnitude) occurs at:	Image
50	Leaking threaded connection (50 to 75 dm ³ /h).	
100	Compression fitting, hand-tightened without a wrench/tool (100 to 150 dm ³ /h).	
300	Drill hole 1 mm in thin-walled copper gas pipe (250 to 375 dm ³ /h).	
1000	Drill hole 2 mm in thin-walled copper gas pipe (1000 to 1500 dm ³ /h)	

The following parameters were varied in the experiments, see Table 3

Table 3: Variables in the experiments.

Parameter	Options
Gas “leakage” rate	50, 100, 300 and 1000 dm ³ /h ³
Gas types	hydrogen/natural gas ³
Ventilation grilles in gas meter cabinet door (ventilation gas meter cabinet to hall)	open/closed (sealed)
Ventilation grille hall to outside (left, top)	open/closed
Door between hall and room	open/closed
Forced air supply over floor (simulation air supply over threshold)	18 and 36 dm ³ /h (resp. ventilation rate 0.5 and 1/h)
Forced air return via external air grille No. 1 (rear left, upper grille)	18 and 36 dm ³ /h (resp. ventilation rate 0.5 and 1/h)

A summary of all experiments conducted is given in Table 4:

³ Unlike HyDelta 1.0 (methane), HyDelta 2.0 works with natural gas because it is the current distribution gas in the Netherlands.

Table 4: Experiments conducted

Configuration code		1	3	4	7	7/0.5	7/1	8/0.5	8/1
Grilles gas meter cabinet		Close	Open	Open	Open	Open	Open	Open	Open
Connecting door hall/room		Close	Close	Open	Open	Open	Open	Open	Open
Ventilation container unit		No	No	No	One slot*	Supply at bottom 18 m/h³	Supply at bottom 36 m/h³	Exhaust at top 18 m/h³	Exhaust at top 36 m/h³
Configuration measured with gas outflow:	Hydrogen (dm³/h)	50	50	50	50	50	50	50	50
		100	100	100	100	100	100	100	100
		300	300	300	300	300	300	300	300
		1000	1000	1000	1000	1000	1000	1000	1000
	Natural gas (dm³/h)	50	50	50	50	50	50	50	50
		100	100	100	100	100	100	100	100
		300	300	300	300	300	300	300	300
		1000	1000	1000	1000		1000	1000	1000
*natural ventilation by applying a plate with 9 holes of around 1 cm; effective ventilation rate varies per experiment and can be approximated afterwards.									

4 Results in brief

4.1 Main conclusion

This chapter provides an overall view of all experiments, focusing on the extent to which the final concentration of the gas may pose a risk and the effect of ventilation on the final concentration. Individual measurement results are discussed in more detail in the following chapters.

The summary answer to this research question is as follows:

In the presence ventilation of the gas meter cabinet (i.e. ventilation as per current regulations), a leakage of 50 dm³/h (comparable to a leaking threaded connection hydrogen at 20 mbar or the same connection to natural gas at 26 mbar) will not reach the flammability limit of both natural gas and hydrogen. For larger leaks, at least from 100 dm³/h, the flammability limit (100% LEL) will be exceeded if the gas meter cabinet is not ventilated. This applies to hydrogen and natural gas.

As long as the flammability limit is not exceeded, there is no risk of fire or explosion.

4.2 The measurement results summarised in two tables

See Table 5 for measurements in the gas meter cabinet and Table 6 for the measurements outside the gas meter cabinet. Configurations 2, 5 and 6 are missing from these diagrams. These configurations were deleted from the measurement plan during project implementation. Configurations 7/0.5, 7/1.0, 8/0.5 and 8/1.0 were added to the measurement plan during project execution.

The final concentration of each measurement is indicated by colour. The final concentration is the concentration at the time the sensors show a stable value. Not in all measurements this stable situation is reached because the gas outflow is cut off when one of the sensors has reached the 50% LEL value. In these measurements, extrapolation was used to estimate whether the final concentration is greater or less than 100% LEL. By carrying out the measurements in different configurations, it is possible to understand the dispersion and the effect of ventilation on the concentration build-up.

Table 5: Final concentration in the gas meter cabinet at configuration 1, 3 and 4

Configuration code		1	3	4
Grilles gas meter cabinet		Close	Open	Open
Connecting door hall/room		Close	Close	Open
Ventilation container unit		No	No	No
Configuration measured with gas outflow:	Hydrogen (dm ³ /h)	50	50	50
		100	100	100
		300	300	300
	Natural gas (dm ³ /h)	50	50	50
		100	100	100
		300	300	300

Final concentration < 50% LEL
 Final concentration ≥ 50% LEL and <100% LEL
 Final concentration ≥ 100% LEL

Table 6: Final concentration **outside** gas meter cabinet (hall and room)

Configuration code		1	3	4	7	7/0.5	7/1	8/0.5	8/1
Grilles gas meter cabinet		Close	Open	Open	Open	Open	Open	Open	Open
Connecting door hall/room		Close	Close	Open	Open	Open	Open	Open	Open
Ventilation container unit		No	No	No	One slot	Inlet at bottom 18 m/h ³	Supply at the bottom 36 m/h ³	Top drain 18 m/h ³	Discharge at top 36 m/h ³
Configuration measured with gas outflow:	Hydrogen (dm ³ /h)	50	50	50	50	50	50	50	50
		100	100	100	100	100	100	100	100
		300	300	300	300	300	300	300	300
		1000	1000	1000	1000	1000	1000	1000	1000
	Natural gas (dm ³ /h)	50	50	50	50	50	50	50	50
		100	100	100	100	100	100	100	100
		300	300	300	300	300	300	300	300
		1000	1000	1000	1000	No measurement	1000	1000	1000

Final concentration < 50% LEL
 Final concentration ≥ 50% LEL and <100% LEL
 Final concentration ≥ 100% LEL

4.3 The limit of 100% LEL

The reader of above tables may think that the colours can be used to compare the risk of hydrogen with that of natural gas. However, this is not the case, because, for example, 100% LEL of hydrogen carries a different (smaller) risk than 100% LEL of natural gas. For at low gas concentrations (<8-10% vol), the risk of ignition of hydrogen is lower than that of natural gas, and the effect when ignited is also lower [6].

Nevertheless, a limit of 100% LEL has been used in this report. There are two reasons for this:

- Since gas outflow stops at 50% LEL, the 100% LEL limit can still be extrapolated with some reliability. For higher concentrations, this is no longer possible.
- This concentration is a safe choice for both gases: if this concentration is not reached, there is no risk of ignition.

4.4 Construction of profiles and determination of final concentration

The measurement results underlying Table 5 and Table 6 are discussed in chapter 5 and 6. This section explains how the respective measurement graphs are constructed and how it is deduced from them whether the final concentration becomes ≥ 100% LEL.

In Figure 12 are the measured hydrogen concentration profiles of the sensors in the gas meter cabinet and in the 10 m³ and 26 m³ space (hall and room). This is the experiment with a hydrogen effluent of 50 dm³/h, opened gas meter cabinet vents and without ventilation of the container. The door between the hall and the room was closed during the experiment. The figure shows the measured gas concentration (in % LEL) as a function of time.

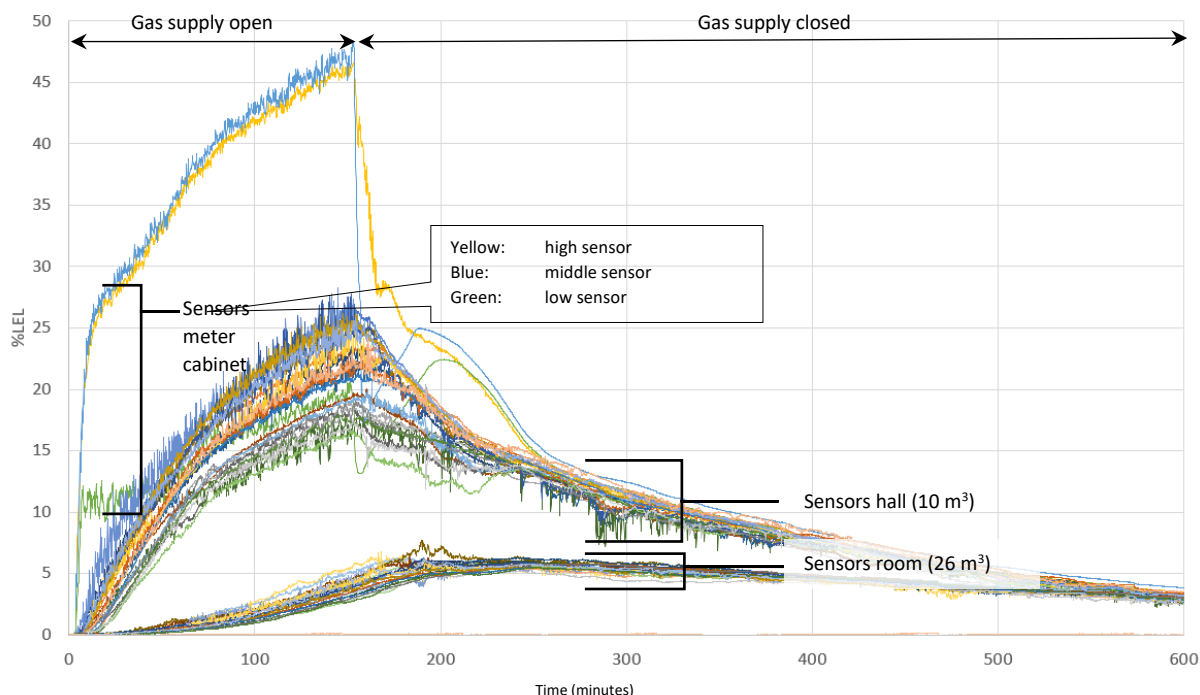


Figure 12: Measured profiles of hydrogen (outflow 50 dm³/h). Conditions: no ventilation facilities to outside air; the ventilation grilles in the gas meter cabinet door opened (configuration 3, see section 5.2).

The sensors in the gas meter cabinet, hall and room can be recognised as groups in this figure: the gas meter cabinet profiles are the steepest, followed by the hall and then the room profiles. Since the gas is released in the gas meter cabinet, this is also to be expected.

The moment one of the sensors measures a concentration of 50% LEL (here: the light blue profile with the highest concentration), the gas supply is shut off. However, the equilibrium situation has not yet been reached by then as concentrations are still rising at that time. The equilibrium concentration must therefore be extrapolated from the gradient until the gas supply closes.

Example of extrapolating, illustrated on Figure 12:

- Gas meter cabinet: The concentration in the gas meter cabinet certainly reaches 50% LEL but the profiles are unlikely to reach 100% LEL if the gas continues to flow out → light purple shading in Table 5.
- Hall/room: final concentration remains below 50% LEL → no shading (white) in Table 6.

4.5 Measurement data

The measurement graphs are included in full in Appendix V. The same graphs are additionally arranged schematically in Appendices III (gas meter cabinet) and IV (hall and room). This representation makes it easier to compare the figures.

As mentioned earlier, the following sections discuss the graphs underlying Table 5 and Table 6. The measurement results inside the gas meter cabinet are discussed in Chapter 5 and the results outside the gas meter cabinet in Chapter 6.

5 Section 1: Measurements in the gas meter cabinet

This section discusses the measurement results in the gas meter cabinet. These measurements were carried out under conditions where the container as a whole has no ventilation facilities: the ventilation slots are closed and no supply or exhaust fan is used. Despite this, some non-intentional ventilation of the container does take place through seams and cracks. However, because little fresh air enters the container, this can be considered the "worst case" situation for the gas meter cabinet.

Measurements in the gas meter cabinet were carried out in three variants:

- with sealed grilles from the gas meter cabinet (configuration 1),
- with open grilles and with closed connecting door (configuration 3), and
- with open grilles and with open connecting door (configuration 4).

Note: At the same time as the measurements in the gas meter cabinet, the concentration *outside* the gas meter cabinet was also measured in the hall and room. These results are discussed in chapter 6.

The measurement graphs can be found in Appendix III in a matrix showing from left to right the different configurations and from top to bottom the increasing gas outflows (50, 100 and 300 dm³/h) at which were measured. The same graphs are also shown in Appendix V in larger format.

The following sections discuss the results. This includes whether 50% LEL is reached (which is the concentration at which gas effluent is stopped) and an estimate of whether 100% LEL is reached over time, based on extrapolation.

In the discussion below, some measurement graphs from the appendices have been copied between the texts to avoid too much flipping back and forth.

5.1 Closed ventilation grilles in the gas meter cabinet (configuration 1)

In this experiment, the vents in the meter door (see also Figure 10) were taped off. This is contrary to the ventilation requirements in gas meter cabinet standard NEN 2768 + A1. However, a small amount of air can flow in and out of the gas meter cabinet door along cracks in the gas meter cabinet door. During the experiment, the door between the hall and room was closed.

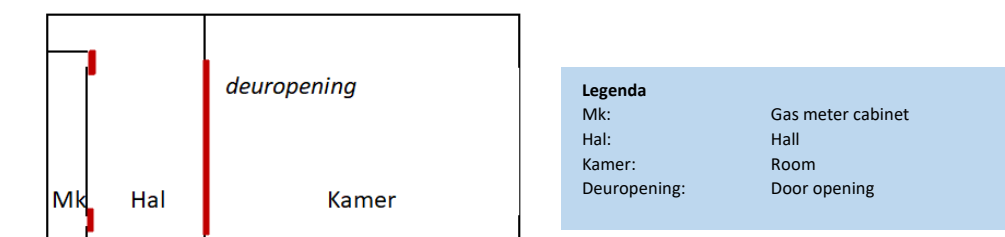


Figure 13: Configuration 1 (side view)

Hydrogen

Figure 14 shows the evolution of hydrogen concentration for the sensors in the gas meter cabinet.

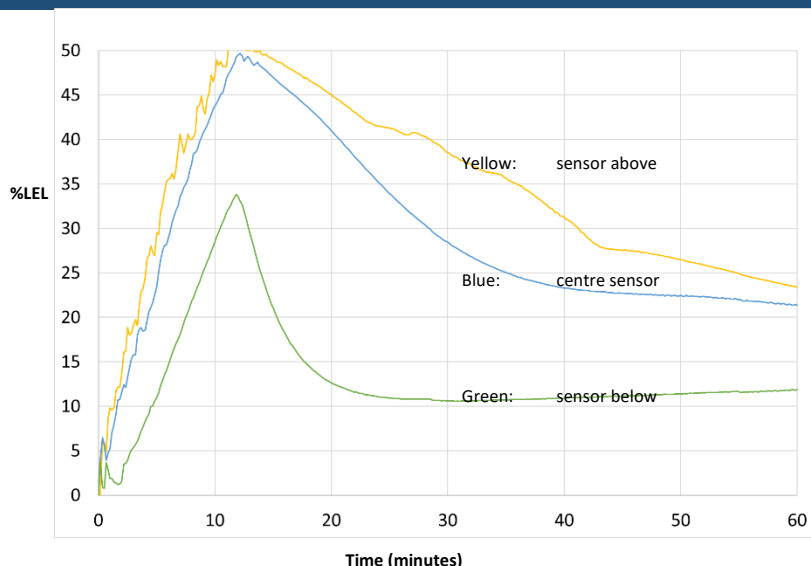


Figure 14: Measured concentration profiles of hydrogen where the vents in the gas meter cabinet door were closed. After about 12 minutes, the supply is closed (50 dm³/h).

After opening the hydrogen supply (50 dm³/h), the hydrogen concentration in the gas meter cabinet increases rapidly, see Figure 14. The concentration reaches a value of 50% LEL after 12 minutes, after which the gas supply is terminated.

The rising parts of the graphs (that is during gas supply) are more or less linear. This makes sense, because with little air entering the gas meter cabinet, the concentration is mainly determined by the flow rate of the gas supply.

After closing the hydrogen supply, the concentration in the gas meter cabinet decreases due to air entering through gaps. It follows from extrapolation that the concentration would rise to > 100% LEL after some time if the hydrogen supply had not been broken off. However, to what value this concentration would rise (the final concentration) cannot be extrapolated; for that, the final value is too far outside the measured range.

The experiment was repeated at 100 and 300 dm³/h. In Figure 15 are the profiles of 300 dm³/h.

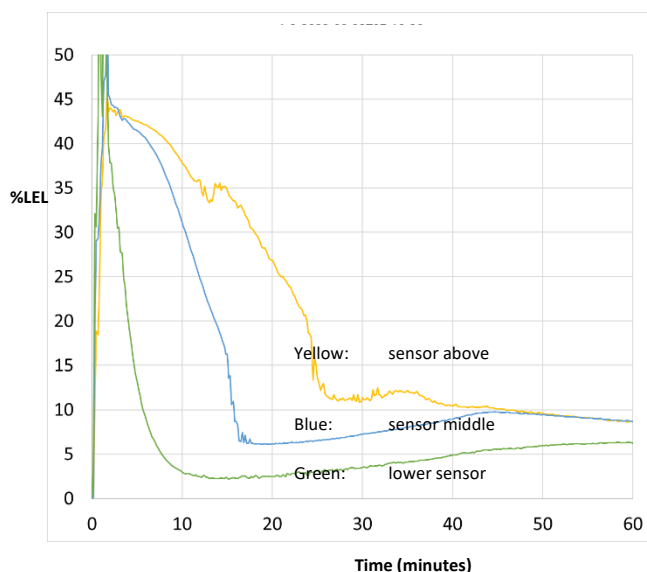


Figure 15: Measured concentration profiles of hydrogen where the vents in the gas meter cabinet door were closed (300 dm³/h).

As might be expected, the higher the hydrogen supply, the faster the rise. At a leakage flow rate of 300 dm³/h (comparable to a 1 mm drill hole in a pipe), the concentration has risen to 50% LEL within 2 minutes. Within 5 minutes, a concentration >100% LEL can be expected if the hydrogen supply is not stopped.

Thus, with closed grilles in the gas meter cabinet, hydrogen concentration will rise to > 100% LEL at a gas outflow of 50 dm³/h (similar to a leaky threaded joint) and above. The higher the outflow, the faster the increase. The final concentration cannot be determined from these measurements.

Natural gas

After opening the natural gas supply (50 dm³/h), the concentration in the gas meter cabinet reaches 50% LEL after 25 minutes. In deviation from hydrogen, the profiles do not run completely linear but bend slightly towards the horizontal after about 12 minutes. See Figure 16.

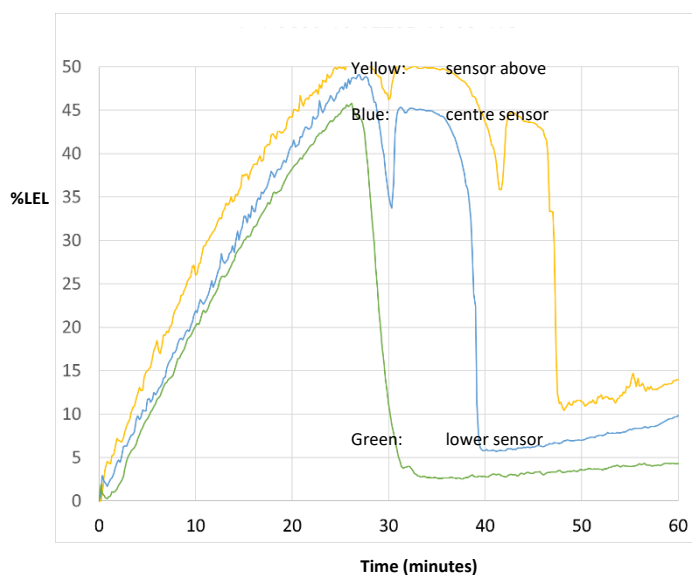


Figure 16: Measured concentration profiles of natural gas where the vents in the gas meter cabinet door were closed. (50 dm³/h).

Because of this deflection towards the horizontal, the profiles are more difficult to extrapolate than for hydrogen (Figure 14). However, probably 100% LEL is reached after some time here too. The final concentration cannot be determined. After closing the hydrogen supply, the concentration in the gas meter cabinet decreases due to air entering through seams and cracks.

This experiment was also repeated at 100 and 300 dm³/h. See Figure 18 for the profiles at 300 dm³/h.

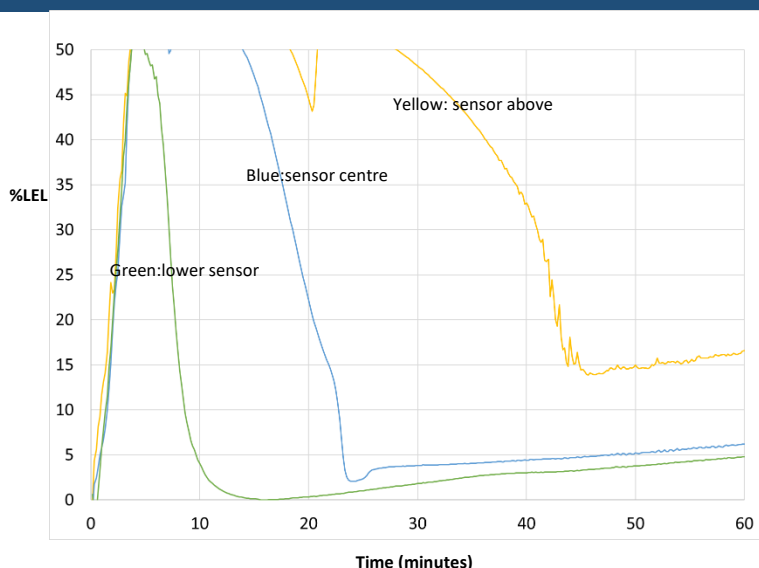


Figure 17: Measured concentration profiles of natural gas where the vents in the gas meter cabinet door were closed. (300 dm³/h)

Again, the higher the natural gas supply, the faster the rise. At a gas supply of 300 dm³/h, a concentration >100% LEL can be expected within 10 minutes.

Hydrogen versus natural gas

For all measurements, 50% LEL and probably 100% LEL is reached faster with hydrogen than with natural gas at the same gas supply. This does not mean that the risk is higher with hydrogen, see section 4.3.

In large part, the (seemingly) faster increase in hydrogen is because LEL of hydrogen is lower than that of natural gas (4.0% and 5.8%, respectively). In other words:

- 1% full hydrogen is 25% LEL, but
- 1% full of natural gas is 17% LEL.

A second reason for a faster increase in hydrogen profiles is that hydrogen accumulates more at the top of the gas meter cabinet than natural gas due to its lower density, and thus mixes less with air; at least at low gas outflows: in Figure 14 (hydrogen) the lower profile (lower sensor) proceeds significantly lower than the higher profiles; in Figure 16 (natural gas), the profiles move in parallel.

At higher gas outflows (300 dm³/h), the sensors do keep pace with each other, both for hydrogen and natural gas outflows.

5.2 Effect ventilation grilles in gas meter cabinet (configuration 3)

The door between the hall and room is closed. The vents in the meter cabinet door are open.

NOTE: Except for configuration 1, the grilles of the gas meter cabinet were opened in all measurements. This is not mentioned separately for each experiment below.

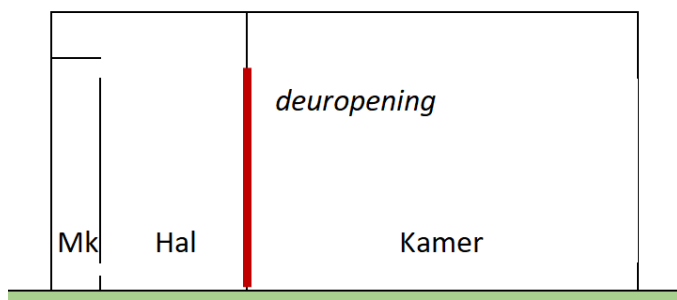


Figure 18: Configuration 3

Hydrogen

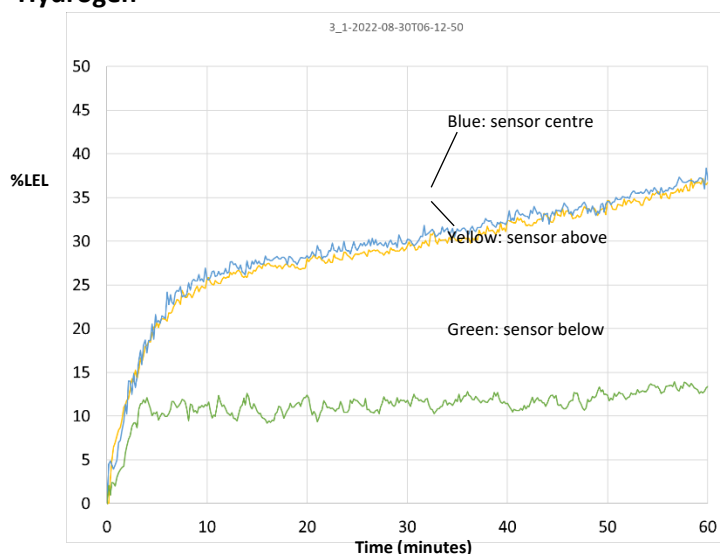


Figure 19: Measured concentration profiles of hydrogen where the connecting door was closed (50 dm³/h);

After a rapid increase to 20% LEL in the first 4 minutes at the top and middle of the gas meter cabinet, the profiles bend: the gas is diluted by air supply from the hall. The concentration at the bottom of the gas meter cabinet increases slightly during the first hour from about 11% LEL after 5 minutes to 13% LEL after 60 minutes. There seems to be a constant supply of air from the hall towards the lower sensor.

The final concentration in the gas meter cabinet is unlikely to exceed 100% LEL. When compared with the situation with closed gas meter cabinet grilles (Figure 14), it appears that opened grilles have a great effect on reducing hydrogen concentration as the concentration now remains below 100% LEL.

Even at an outflow of 100 dm³/h, the influence of ventilation grilles in the gas meter cabinet is readily discernible (Appendix IV). The profiles deflect towards the horizontal. The final concentration here is difficult to estimate; it is likely that a concentration of 100% LEL is eventually reached.

At an outflow of 300 dm³/h, the profiles hardly deflect at all. The graphs curve somewhat less steeply than with taped gas meter cabinet grilles but the effect of the grilles is small. The ventilation is far too low to dissipate the supplied gas flow rate.

Natural gas

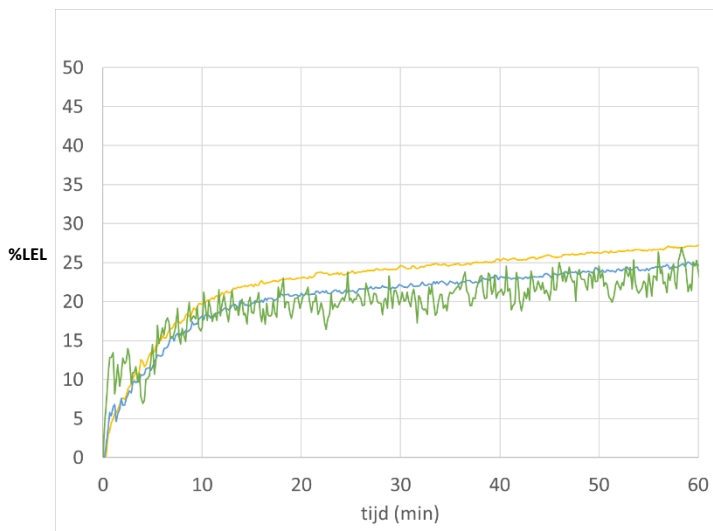


Figure 20: Measured concentration profiles of natural gas where the connecting door was closed (50 dm³/h)³

At natural gas outflows of 50 dm³/h, the sensors at the bottom, middle and top show almost the same profile among themselves. This is a clear difference from the concentration build-up for hydrogen (Figure 19) where the lower profile differs strongly from the other two. As with hydrogen effluent 50 dm³/h, the 100% LEL of natural gas is not reached.

For natural gas outflows of 100 and 300 dm³/h, the concentration profile in the gas meter cabinet flattens earlier than for hydrogen but 100% LEL is likely to be reached eventually.

Summary hydrogen versus natural gas

For both hydrogen and natural gas:

- The presence of grilles in the gas meter cabinet, built according to NEN 2768 + A1 is an effective measure to reduce the gas concentration in the gas meter cabinet.
- At an outflow of 50 dm³/h, the final concentration does not exceed 100% LEL at any of the three sensors.
- At an outflow of 100 dm³/h or 300 dm³/h, the final concentration is likely to exceed 100% LEL if the hall is not ventilated.

At 50 and 100 dm³/h hydrogen outflows, the lower profile (lower sensor) progresses significantly lower than the higher profiles; for natural gas, the profiles are more similar.

At an outflow of 300 dm³/h, the lower, middle and upper profiles show approximately the same gradient among themselves for both hydrogen and natural gas.

5.3 Effect open connecting door (configuration 4)

In this experiment, the door between the hall and room was opened.

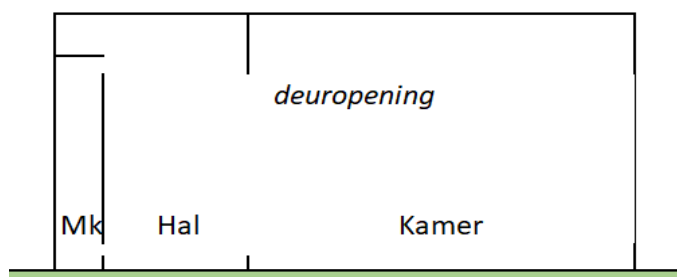


Figure 21: Configuration 4

Hydrogen

See Figure 22 for an outflow of 50 dm³/h.

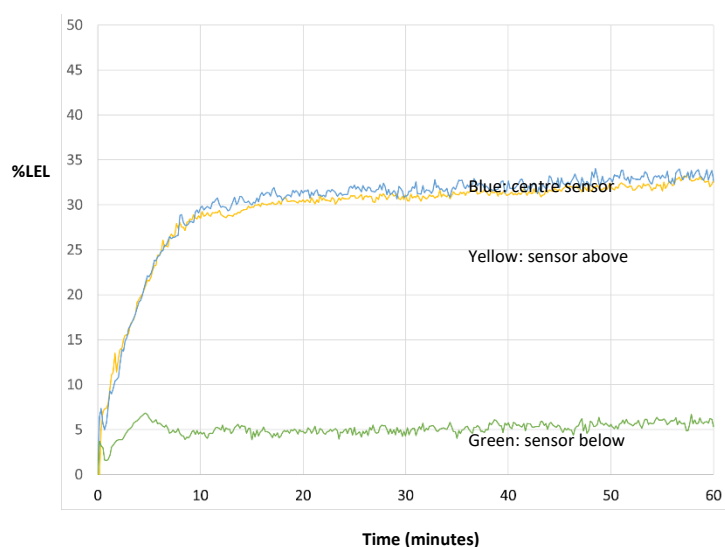


Figure 22 Measured concentration profiles of hydrogen where the connecting door was open (50 dm³/h)

More air is now available for ventilation of the gas meter cabinet than with a closed connecting door. Compared to a closed connecting door (Figure 19), the concentration at the bottom becomes 5% LEL instead of 10% LEL and at the top becomes 33% LEL instead of 37% LEL. Thus, the effect on the maximum concentration (at the top of the gas meter cabinet) is limited.

The final concentration remains <100% LEL at each sensor. At outflows of 100 and 300 dm³/h, a similar concentration build-up occurs as with the connecting door closed (see Appendix III).

Natural gas

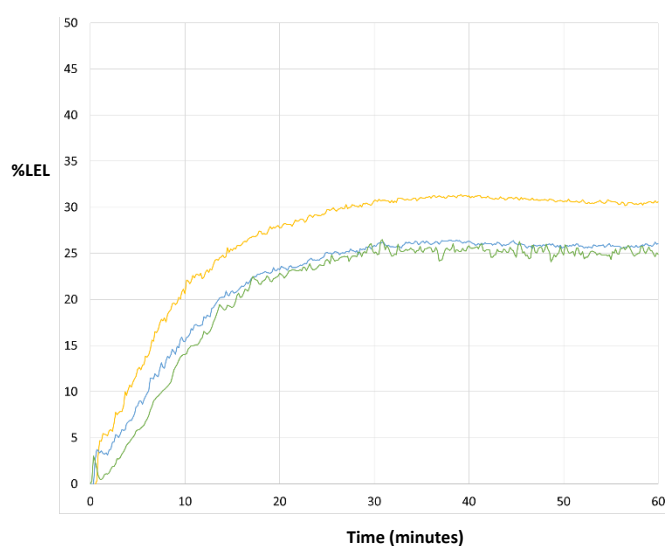


Figure 23 Measured concentration profiles of natural gas where the connecting door was closed (50 dm³/h).

The three sensors broadly follow the same profile. This means that when natural gas escapes, the gas is more mixed with air than hydrogen. The final concentration remains below 100% LEL. At 100 and 300 dm³/h, the final concentration is above LEL.

Summary hydrogen versus natural gas

With the connecting door open, the concentration in the gas meter cabinet rises several percent lower than when the connecting door is closed (configuration 3; section 5.2) if the rest of the container is not ventilated.

6 Section 2: Measurements outside the gas meter cabinet

The measurements outside the gas meter cabinet can be subdivided as follows:

- No ventilation of the container. These are the same experiments as those in chapter 5 but now the measurement results are not discussed in the gas meter cabinet but in the hall and room (configuration 1, 3 and 4).
- Ventilation with vent in the side wall of the container (configuration 7).
- Ventilation with forced supply of outside air (configuration 7/0.5 and 7/1.0).
- Ventilation with forced air exhaust from the container (configuration 8/0.5 and 8/1.0).

Note: In the measurements at the last three bullets, the concentration in the gas meter cabinet was not measured.

The measurement graphs are in Appendix IV in a matrix and also in Appendix V in larger format.

6.1 Closed grilles in the gas meter cabinet (configuration 1)

The vents in the gas meter cabinet door are taped. However, a small amount of air from the hall can flow in and out of the gas meter cabinet through cracks in the gas meter cabinet door. The door between hall and room is closed.

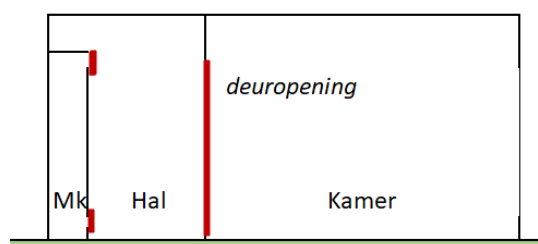


Figure 24: Configuration 1 (side view)

Hydrogen and natural gas

The gas outflow lasts a short time in these experiments because the concentration in the gas meter cabinet goes quickly to 50% LEL. See, for example, the profiles of hall and room at 50 dm³/h (Figure 27).

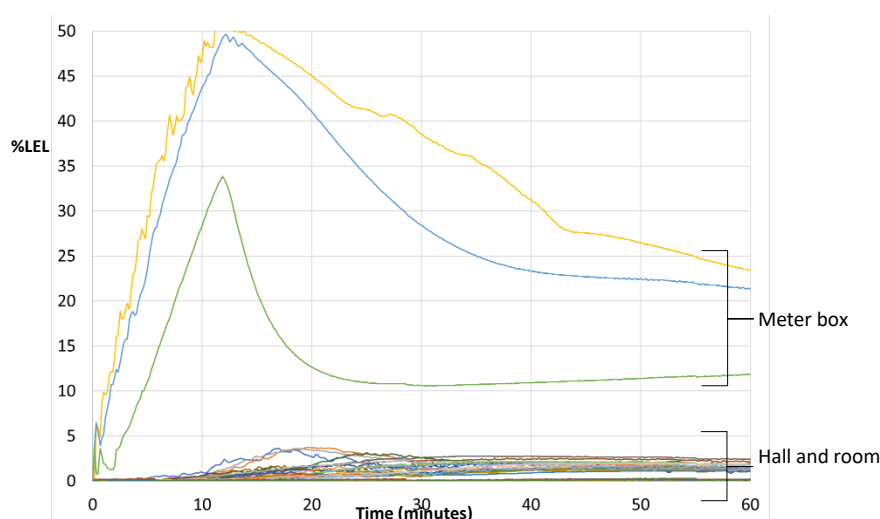


Figure 25: Measured concentration profiles of hydrogen where the vents in the gas meter cabinet door were closed. After about 12 minutes, the supply is closed (50 dm³/h).

During this short time, the concentration of gas in the hall and room is low; the gas is mainly in the gas meter cabinet. Given the short outflow time and low concentrations outside the gas meter cabinet, no statement can be made about the profiles in hall and room after a longer time.

6.2 Effect open grilles in the gas meter cabinet (configuration 3)

The door between the hall and room is closed. The vents in the meter door are open.

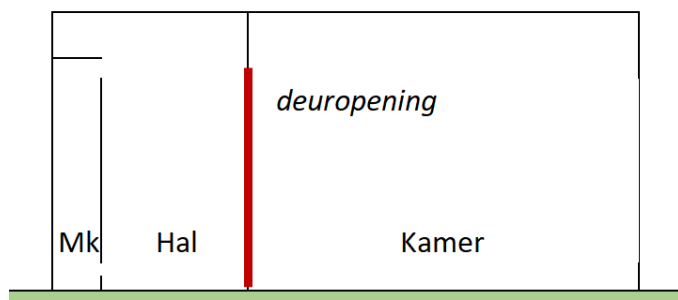


Figure 26: Configuration 3

Hydrogen

See Figure 27 for an outflow of 50 dm³/h.

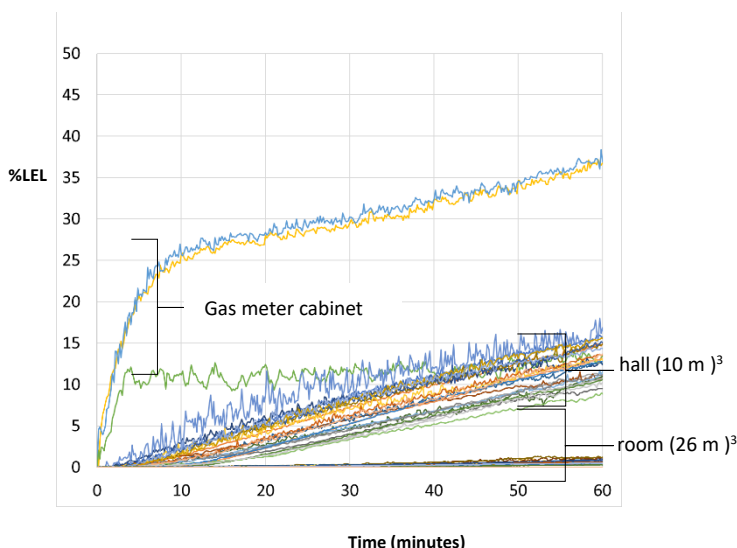


Figure 27: Measured concentration profiles of hydrogen where the connecting door was closed (50 dm³/h);

The hydrogen concentration in the hall rises faster than with sealed meter vents (Figure 25), as the gas can now flow more easily through the grilles into the hall. After 60 minutes, the maximum concentration in the hall is about 17% LEL. The closed dividing door cannot completely prevent the gas from flowing from the hall into the room but the concentration in the room is significantly lower than in the hall, i.e. at most 2% LEL.

In addition to the experiments at 50, 100 and 300 dm³/h, the measurement was also carried out at 1000 dm³/h. At this flow rate, the sensors in the gas meter cabinet were disconnected as the gas outflow would otherwise stop very quickly. This is because the gas meter cabinet sensors would almost immediately measure 50% LEL and shut off the gas supply. Even so, the gas outflow lasted only 3 minutes. See Figure 28.

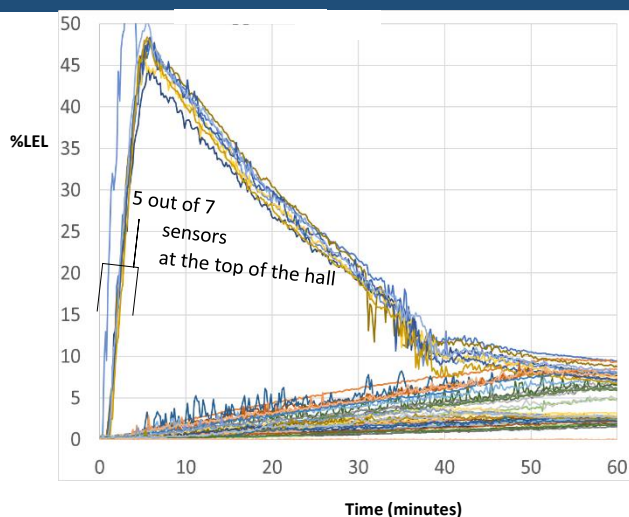


Figure 28: Measured concentration profiles of hydrogen (hall + room) where the connecting door was closed (1000 dm³/h);

Five profiles rise rapidly and almost linearly. These involve five sensors at the top of the hall. After 3 minutes, one of the sensors measures 50% LEL and stops the gas flow. If this did not happen, 100% LEL would also be reached in a short time.

Natural gas

Also for natural gas, the concentration in the hall rises faster with open than with closed gas meter cabinet vents. For an outflow of 50 dm³/h, see Figure 29:

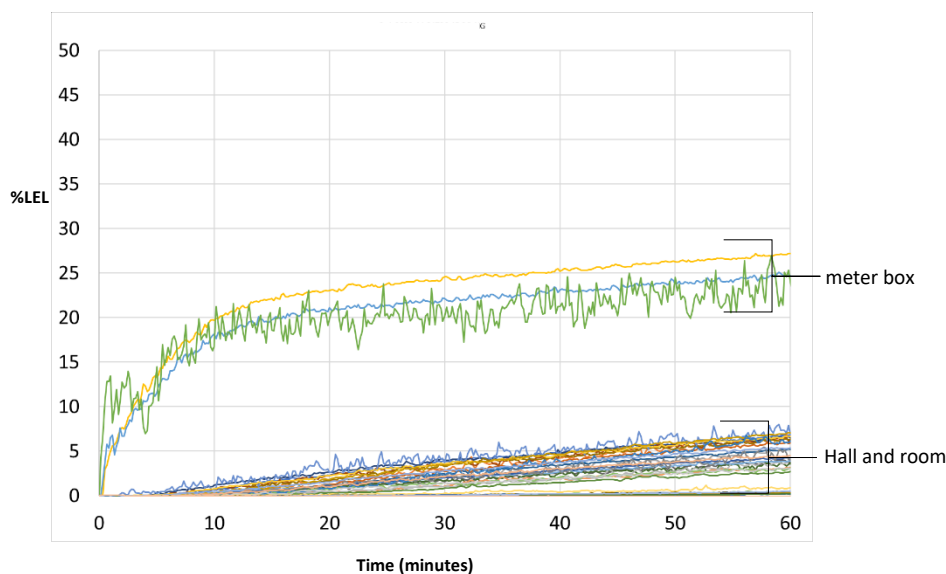


Figure 29: Measured concentration profiles of natural gas where the connecting door was closed (50 dm³/h);

At this gas flow rate, the maximum concentration in the hall becomes about 7% LEL after 60 minutes. This is considerably lower than the 17% LEL measured with hydrogen (Figure 27). This is caused by the fact that the lower ignition limit LEL of hydrogen is 30 percentage points lower than for natural gas (as discussed in 5.1) and because natural gas mixes more strongly with air, making the outliers lower.

The closed connecting door cannot completely prevent natural gas from flowing into the room but the concentration in the room is significantly lower than in the hall, at most 1% LEL.

In Figure 30 the profiles of natural gas (hall and room) at 1000 dm³/h are shown.

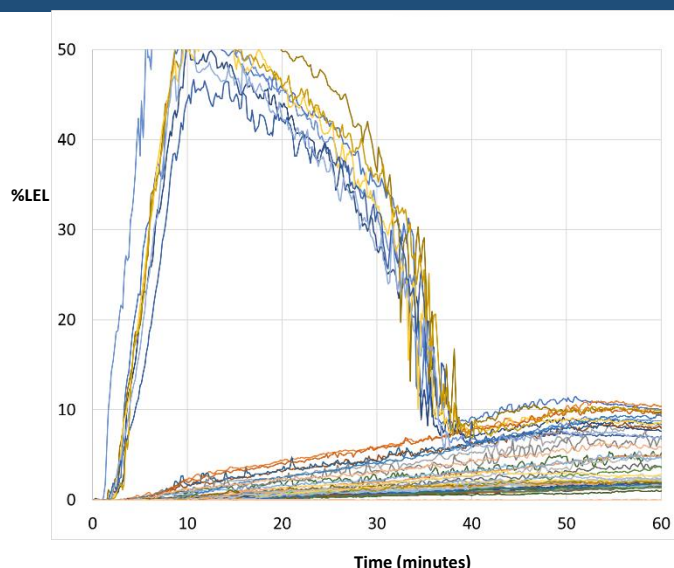


Figure 30: Measured concentration profiles of natural gas (hall + room only) where the connecting door was closed (1000 dm³/h);

Ten profiles rise rapidly and almost linearly. These include eight sensors at the top of the hall and two in the middle. After approximately 6 minutes, one of the sensors measures 50% LEL and the gas outflow stops. Were this not to happen, 100% LEL would also be reached in a short time. As with lower outflows, natural gas appears to mix more strongly than hydrogen: with hydrogen, the fastest rising profiles belong only to sensors near the ceiling; with natural gas they are also sensors in the middle between floor and ceiling.

Summary: hydrogen versus natural gas

Opening the gas meter cabinet vents leaves less gas in the gas meter cabinet (as seen in section 5.2) and logically, the concentration in the hall increases faster. This is true for both hydrogen and natural gas.

For both gases, it is also true that the connecting door provides a significant barrier for the gas-air mixture from the hall to flow into the room.

At the same outflow rate, hydrogen will reach a concentration of 100% LEL locally faster than natural gas. This is because LEL of hydrogen is lower, and because natural gas mixes more strongly with air than hydrogen.

6.3 Effect open connecting door (configuration 4)

In this experiment, the door between the hall and room was opened.

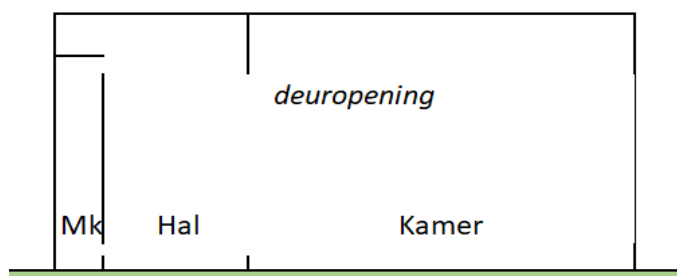


Figure 31: Configuration 4

Hydrogen versus natural gas

By opening the connecting door, the gas (both hydrogen and natural gas) flows more easily from the hall to the room. This can be seen most clearly in the measurements at 1000 dm³/h. See Figure 33, with hydrogen profiles on the left and natural gas profiles on the right. For both gases, the profiles high, medium and low in the container are shown in separate figures.

It can be seen that the gas builds up in the room from top to bottom because the sensors at the top measure the strongest rise. At the top layer, moreover, the difference between sensors in the hall and in the room can be clearly seen. This is because the doorway does not extend to the ceiling: as the gas in the hall builds up from top to bottom (Figure 32), it takes some time for the gas to flow through the doorway into the hall.

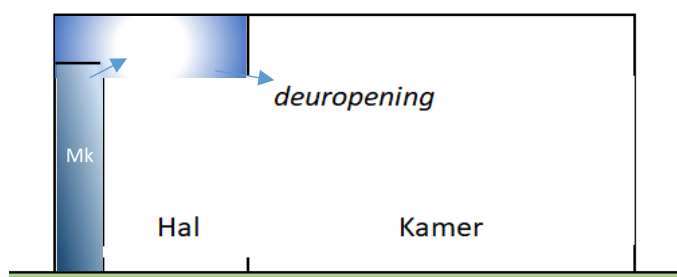


Figure 32: The space fills with gas from top to bottom (schematic view)

The graphs of the sensors in the centre (Figure 33, centre) both have one anomalous profile, which is higher than the rest. The sensor in question is located in front of the doorway where the gas flows from the hall to the room.

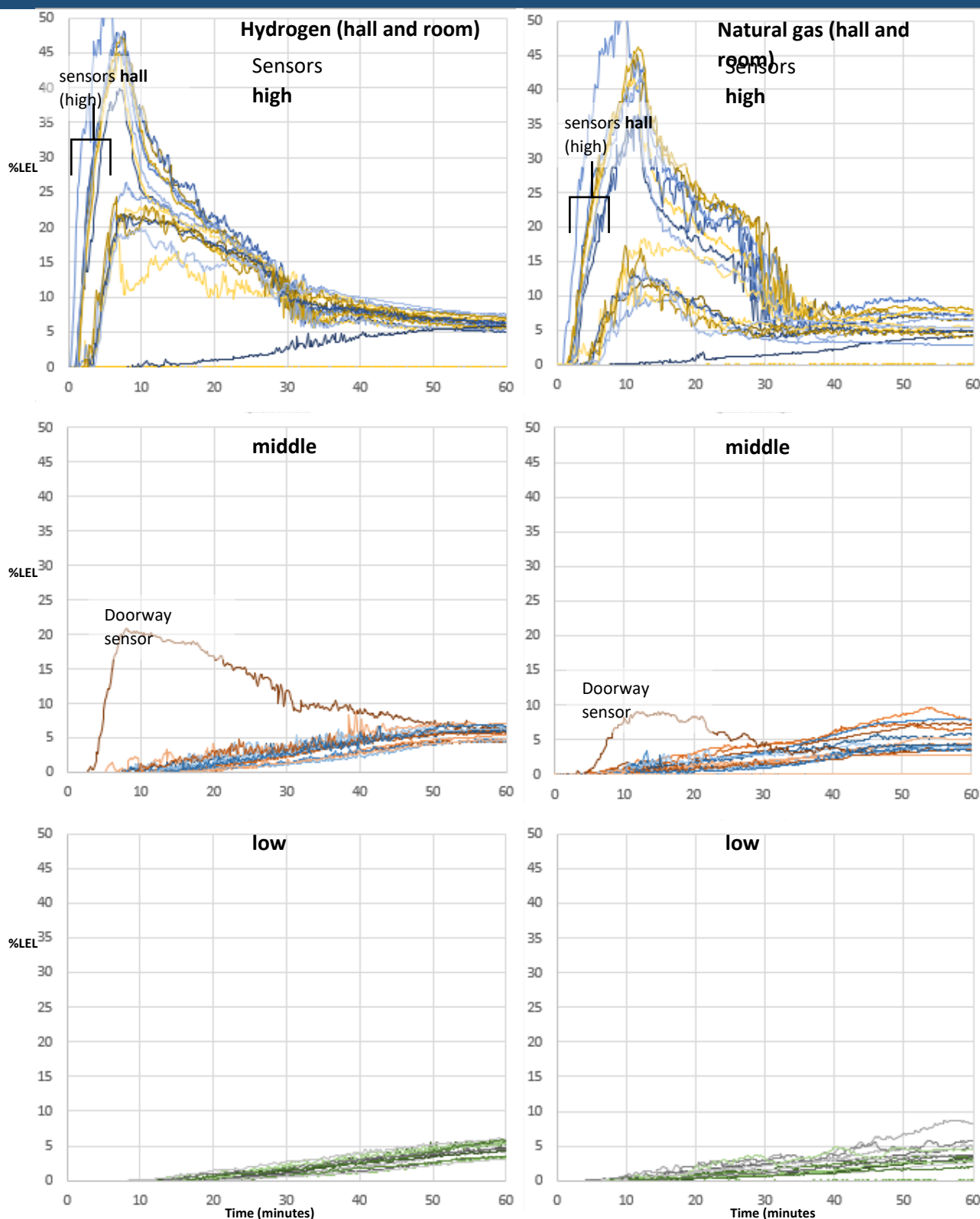


Figure 33:: Measured concentration profiles of hydrogen and natural gas (hall + room only) where the connecting door was open (1000 dm³/h).

6.4 Effect of natural ventilation in the container (configuration 7)

To study the effect of ventilation inside the container on the concentration curve, a ventilation opening on the side of the container was opened (slot with 9 holes). The ventilation opening used is - seen from the entrance door- located at the top left, the rear grille (i.e. in the hall).

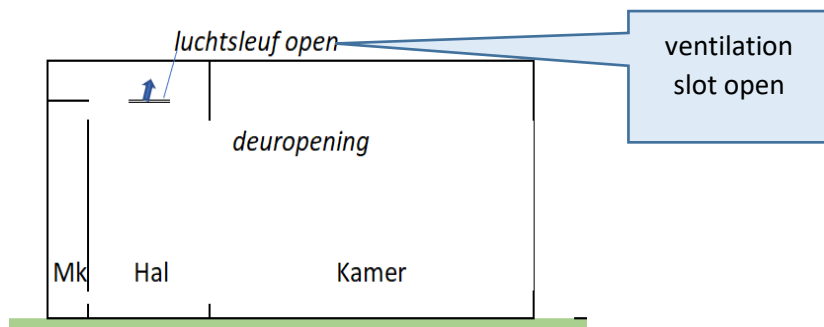


Figure 34: Configuration 7

The concentration profiles show that the differences between them increased from place to place with the installation of a ventilation slot. For this, see the different profiles of configuration 4 versus configuration 7 (Appendix IV) and the example in Figure 35..

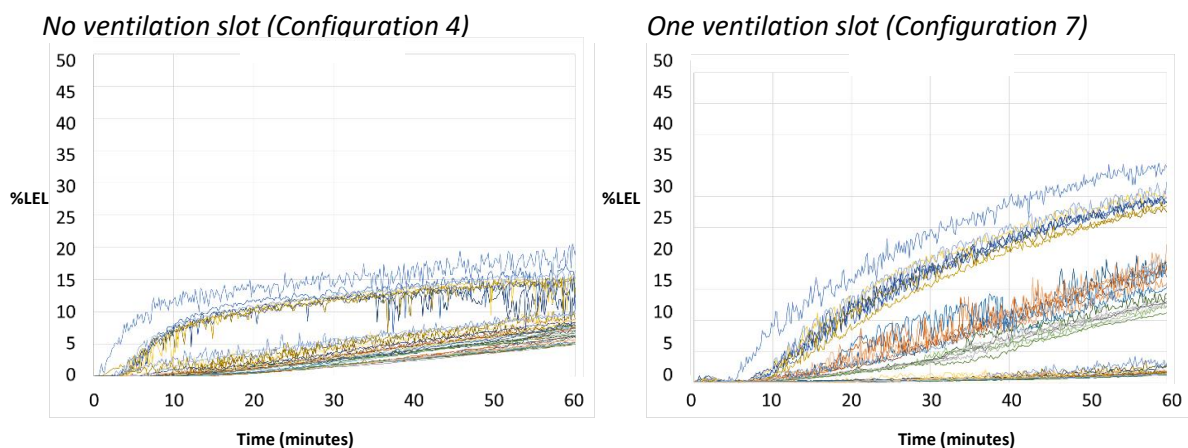


Figure 35: Hydrogen concentration trend over one hour, (hydrogen, 100 dm³/h). Scale Y-axis: 50% LEL

The low profiles in the right figure are the profiles of the room, the high profiles are the profiles of the hall. The profiles in configuration 7 are slightly higher on average than configuration 4, so it seems that after ventilation is applied, there is not *more* ventilation, but rather *less*.

Perhaps the differences are caused by the stratification of hydrogen gas. In the *absence of* ventilation, there is little airflow. A layer with a high concentration of gas forms at the ceiling, above the range of the highest sensors (which therefore do not detect this high concentration). Due to its low density, the hydrogen has a strong buoyancy pressure, causing some of the gas to "escape" through seams in the roof without being detected by the sensors.

With the *presence* of a ventilation slot, the upper layer of gas moves more so that it mixes better with air, and so that it can no longer leak away in high concentrations. The sensors now also register this gas as it comes lower.

In this scenario, this would mean that the gas would be discharged at a slower rate in the presence of a vent slot.

With natural gas, ventilation with a vent slot is higher than without a vent slot, though. This may be due to less stratification with natural gas.

6.5 Effect of forced supply ventilation in the container (configuration 7/0.5 and 7/1.0)

With natural ventilation, the ventilation rate is difficult to set. To have more influence on the ventilation rate, a fixed set air flow rate was blown into the container in the experiments at configuration 7/0.5 and 7/1.0. Instead of the natural air supply along the bottom of the door, air was blown in through a slotted air supply. Air was blown in at flow rates of 18 m³/h and 36 m³/h. If no other outside air enters, this leads to ventilation rates of 0.5/h and 1.0/h, respectively.

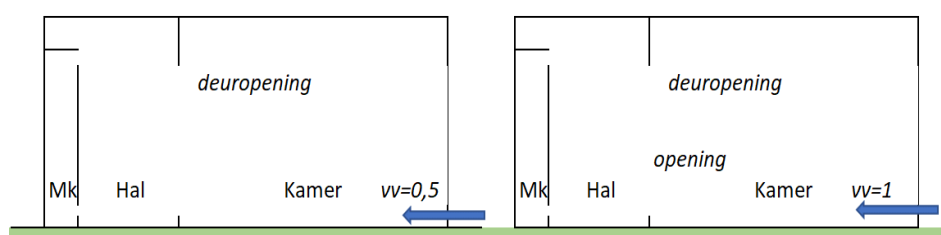
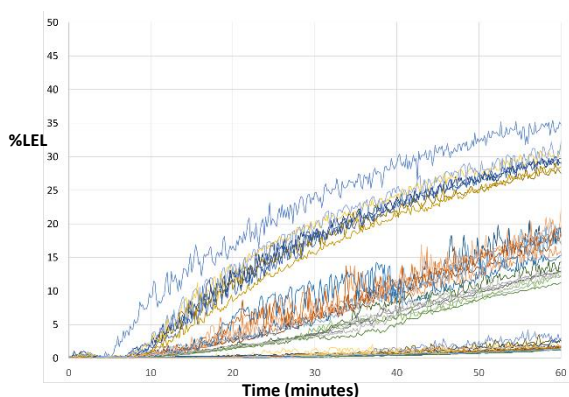


Figure 36: Configuration 7/0.5 and 7/1.0

In Annex IV it can be seen that the concentration profiles with blown-in air differ much less from each other than with a single ventilation slot. Compare, for example, in Figure 37 the profiles with one vent slot (left) with those without a vent slot and with supply of 18 m³/h (right), at hydrogen:

One ventilation slot open (Configuration 7)



No ventilation slot open, supply air 18 m³/h (Configuration 7/0.5)

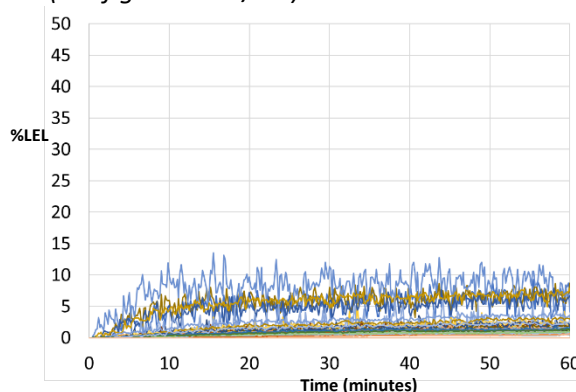
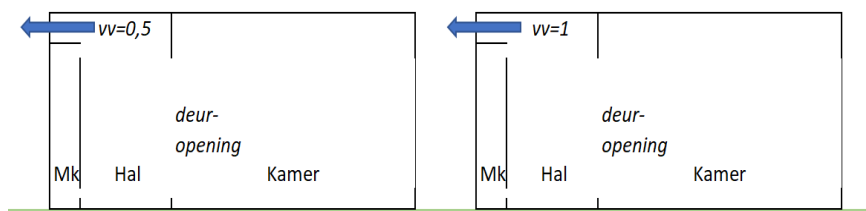


Figure 37: Hydrogen concentration trend over one hour, (hydrogen, 100 dm³/h). Scale Y-axis: 50% LEL

The forced ventilation causes the profiles of hydrogen to be closer together and much lower. The same phenomenon can be seen with natural gas. So blowing air in low leads to a much lower gas concentration than natural ventilation.

6.6 Effect of forced exhaust ventilation in the container (configuration 8/0.5 and 8/1.0)

A second way to influence the ventilation rate (besides the forced supply of air as in section 6.5) is a forced *exhaust* of air. Through one of the ventilation slots, air was extracted with an exhaust rate of 18 m³/h and 36 m³/h (ventilation rate 0.5 and 1.0 respectively). See page 15 for technical details.



In Annex IV the profiles are shown at a gas outflow of 1000 dm³/h, for both hydrogen and natural gas.

In Figure 38 and Figure 39 the air supply and air exhaust are shown side by side:

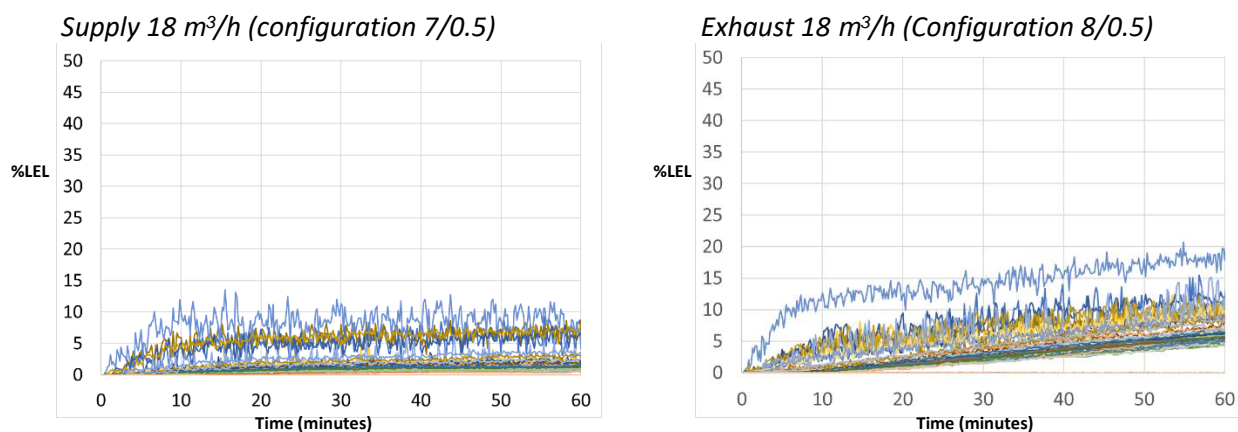


Figure 38 Hydrogen concentration gradient over one hour, (hydrogen, 100 dm³/h).

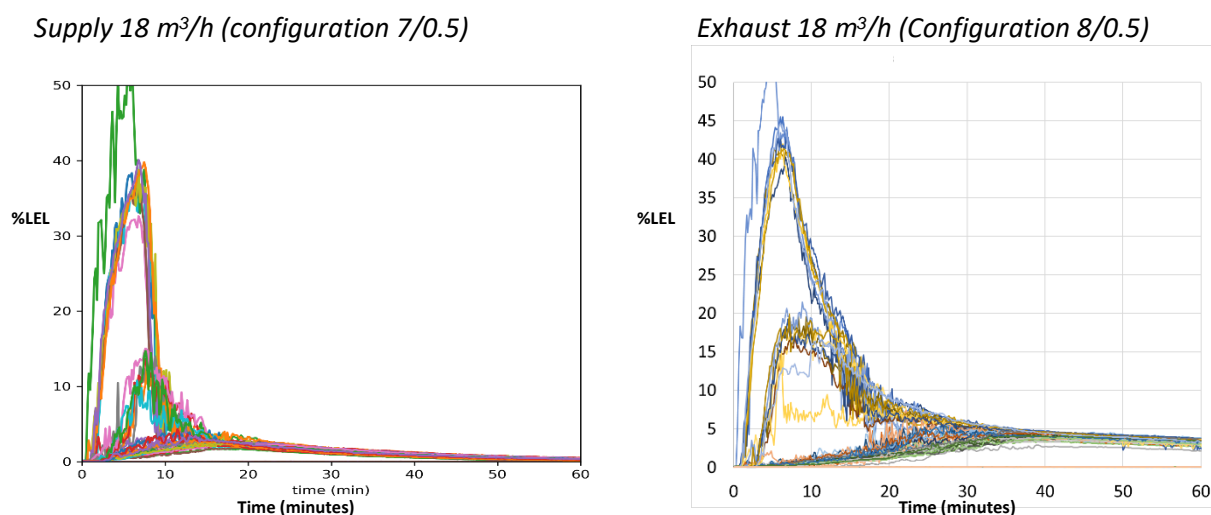


Figure 39: Hydrogen concentration gradient over one hour, (hydrogen, 1000 dm³/h).

The figures show that the differences between them within the container are greater when air is extracted than when air is blown in. When blowing in (left), there are also a number of sensors that

measure 0% LEL. This could indicate that with extraction, stratification within the container is less affected than with blowing in air.

7 Determination of ventilation rate based on measured concentration profiles

7.1 General

In some experiments, the ventilation rate was calculated retrospectively based on the average gas concentration. The results are given in Appendix VI and in Table 7. The methodology and theoretical background are in Appendix II. A brief explanation with an example is in the blue box.

Example to determine ventilation rate

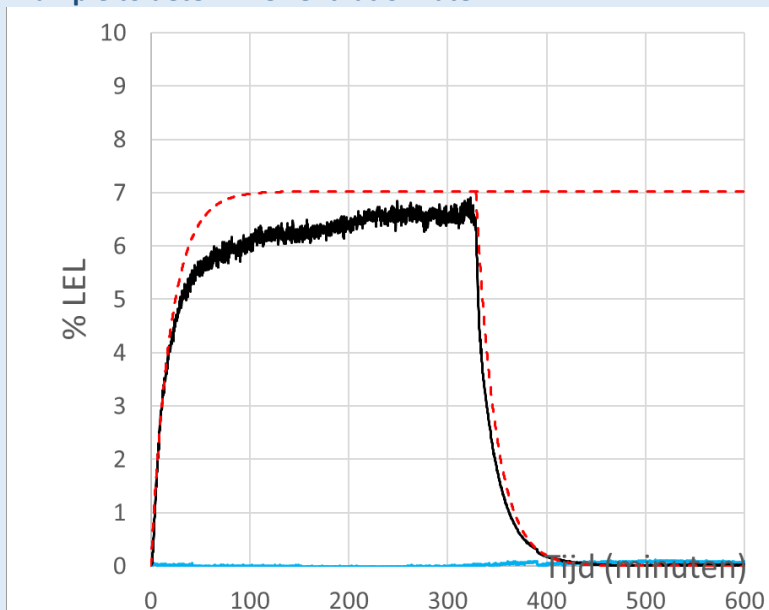


Figure 40: Configuration 7/0.5, hydrogen, 300 dm³/h air supply 18 m³/h.

Black: average measured concentration. Red: fit theoretical profiles at a ventilation rate $R=3.0$.

The black curve is the average concentration in the container. After about 330 minutes, the gas supply stops and the concentration drops. The red dashed profiles are the theoretical curves fitted in the figure by varying the ventilation rate. The best-fitting curves were found at a ventilation rate of 3.0.

The theoretical curves assume constant ventilation and homogeneous mixing. In reality, however:

- ventilation will fluctuate slightly (due to the influence of wind, for example), and
- the gas is not homogeneously mixed with air.

This explains that the theoretical curve does not fully coincide with the measured curve.

In this example, it seems that the rising theoretical curve should be set lower, at about 6.5% instead of 7% LEL. That means a slightly higher ventilation rate of $R=3.0$. However then the *falling* curve again deviates significantly from the measured curve.

The ventilation rate is thus chosen at the best-fit curves; both rising and falling. The final average concentration then follows from the ventilation rate combined with the gas effluent, and the content of the container (formula 2 in Appendix II).

Table 7: Ventilation rate and final concentration determined from measured concentrations

Configuration	Gas type	Gas supply	Ventilation		Final average concentration
		dm/h ³	<i>Determined by fitting theoretical and measured curves (see previous blue box)</i>		<i>Calculated from ventilation rate (see previous blue box)</i>
				1/h	%LEL
3	hydrogen	50		0,14	25
3	hydrogen	100		0,40	17
3	hydrogen	300		0,15	132
3	natural gas	50		0,20	12
3	natural gas	100		0,15	31
3	natural gas	300		0,15	91
3	natural gas	1000		0,15	269
4	hydrogen	50		0,09	38
4	hydrogen	100		0,25	27
4	hydrogen	300		0,40	51
4	natural gas	50		0,40	6
4	natural gas	100		0,15	31
4	natural gas	300		0,08	163
4	natural gas	1000		0,10	375
7	hydrogen	100		0,2	34
7	hydrogen	300		0,2	100
7	natural gas	100		0,5	10
7	natural gas	300		0,2	69
7/0,5	hydrogen	300		3,0	7
7/0,5	natural gas	300		4,0	4
7/1,0	hydrogen	300		3,0	7
7/1,0	natural gas	300		4,8	3
8/0,5	hydrogen	1000		0,6	111
8/0,5	natural gas	1000		0,5	91
8/1,0	hydrogen	1000		1,7	40
8/1,0	natural gas	1000		1,0	47

The average final concentration from Table 7 was calculated using Formula 2 (Appendix II). Figure 41 is a graphical representation of the relationship: ventilation rate - final average concentration.

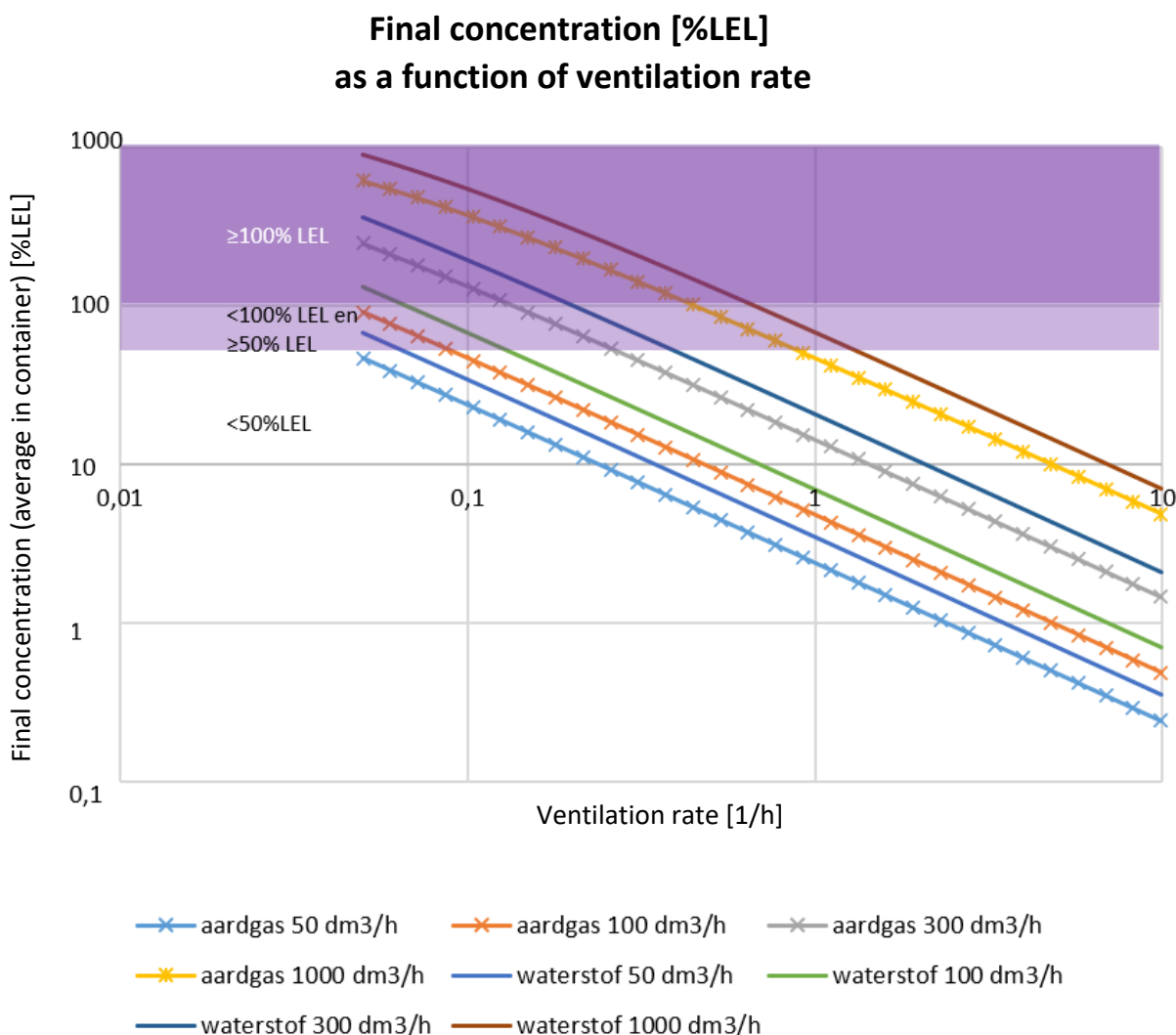


Figure 41: Final concentration as a function of ventilation rate.

In the figure, three concentration zones are marked with purple, pink and white. Note that this refers to the **average** final concentration in the entire container. In chapter 4 the same classification is used, but there it refers to the maximum **local** concentration (i.e. at the location of the sensor with the highest gas concentration).

7.2 Effect of natural ventilation on ventilation rate.

At Table 8 shows the ventilation rates of the situation without ventilation (configuration 4) and with one ventilation slot (configuration 7) side by side.

Table 8: The influence of a ventilation slot on the ventilation rate.

Gas type	Gas flow	Ventilation rate calculated afterwards	
		Configuration 4 No ventilation	Configuration 7 With one ventilation slot
	dm/h ³	1/h	1/h
Hydrogen	100	0,25	0,20
	300	0,40	0,20
Natural gas	100	0,15	0,50
	300	0,08	0,20

As in section 6.4 it can be seen that hydrogen ventilates *less* when the ventilation slot is opened. For with ventilation slot, a ventilation rate of 0.20/h was observed twice, but without ventilation slot, the ventilation rate is *higher*, namely 0.25/h and 0.40/h.

To explain the difference in ventilation rates, the ventilation rates *for each sensor* were calculated *separately* using the available data. The results of these calculations show a strongly varying picture. As a result, no unequivocal explanation can be given for the differences in ventilation rates.

With natural gas, the ventilation rate does tend to be higher with ventilation slot than without.

7.3 Effect of forced air supply on ventilation rate

At Table 8 are the set and calculated ventilation rates side by side (configuration 7/0.5 and 7/1.0), for a gas outflow of 300 dm³/h.

Table 9: Ventilation rate determined from supply flow rate and from measured gas concentrations.

Gas type	Gas flow	Air supply	Ventilation rate	
			Set with the supply air flow rate	Calculated from measured gas concentrations
	dm/h ³	m/h ³	1/h	1/h
Hydrogen	300	18	0,5	3,0
	300	36	1,0	4,0
Natural gas	300	18	0,5	3,0
	300	36	1,0	4,8

For hydrogen, it turns out that ventilation is much stronger than expected: At a set ventilation rate of 0.5, the calculated ventilation rate is 3.0. At a set ventilation rate of 1.0, the calculated ventilation rate increases to 4.0. With natural gas, the calculated ventilation rate is also much higher than expected: 3.0 and 4.8, respectively.

Because the calculated ventilation rate is so much higher than the set ventilation rate, several control calculations were carried out. Using the available data, the ventilation rate was calculated separately for each sensor. The results of these calculations show a strongly varying picture. Consequently, even

on the basis of these calculations, no unequivocal explanation can be given for the differences in ventilation rates.

However, it can be concluded that blowing in air is an effective way of ventilation to keep the gas concentration low.

7.4 Effect of forced return air on ventilation rate

At Table 10 shows the ventilation multiples of (configuration 8/0.5 and 8/1.0) and bi at a gas outflow of 1000 dm³/h side by side.

Table 10: Ventilation rate determined from supply flow rate and from measured gas concentrations.

Gas type	Gas flow	Air supply	Ventilation rate	
			Set with the supply air flow rate	Calculated from measured gas concentrations
	dm/h ³	m/h ³	1/h	1/h
Hydrogen	1000	18	0,5	0,6
	1000	36	1,0	1,7
Natural gas	1000	18	0,5	0,5
	1000	36	1,0	1,0

It follows from the table that the retrospectively determined ventilation rates for hydrogen are much more in the order of magnitude of the *extracted* ventilation rate (configuration 8/0.5 and 8/1.0) than for *supply* air (7/0.5 and 7/1.0)

For natural gas, calculated and blown-in values correspond completely.

8 Discussion of the results of the experiments

8.1 General

HyDelta 1.0 showed that no high concentrations were found at gas releases up to 20 dm³/h. With increasingly large leaks, this will obviously happen at some point. In any case, that limit seems to be above 50 dm³/h. That is considerably higher than the maximum of 1 dm³/h at any one location that is acceptable for natural gas.

This study looked for the limit at which the concentration remains below LEL, as a function of ventilation. As long as this limit is not exceeded, there is a safe situation. Whether, when the lower flammability limit (LEL) is exceeded, there is also an immediately unsafe situation is determined by a number of factors. One of these factors is the probability of ignition. The report 'behaviour of hydrogen during leaks in the gas distribution network' [6] describes that hydrogen in air up to about 8 - 10 vol % has a lower probability of ignition than natural gas at the same concentration and, if it does ignite, the effect is smaller.

With regard to not exceeding the flammability limit (100% LEL), there are some comments to be made.

First, near the leak source there will always be an area where the gas concentration is between the lower and upper flammability limit (LEL and UEL). How large this area is and thus the potential effect upon ignition is determined by the amount of gas efflux.

A second comment concerns the design of the gas meter cabinet. The top of the gas meter cabinet is about 10 cm above the top ventilation grid. However, there are also many other types of rooms in which gas meters hang, whether or not filled with objects that do not belong in a gas meter cabinet (hoovers, storage shelves, etc). The gas may behave differently in these.

Finally, a third observation concerns gas outflows. The studies were carried out with gas outflows of up to 1000 dm³/h. The gas concentrations here remained well below the concentrations (8 - 10 vol %) at which the risks of natural gas and hydrogen are equal. The study does not reveal at what gas outflow this concentration is actually reached.

Nor does it show what the actual effect is in this test setup if a solid gas-air mixture ignites.

8.2 Ventilation of gas meter cabinet according to regulations is essential

In this study, six outflow experiments were conducted in which the ventilation grilles of the gas meter cabinet were taped at 50, 100 and 300 dm³/h and the rest of the container was not ventilated. The gas concentration increases almost linearly with time, reaching 100% LEL in a short time. In the case of natural gas, this mixes directly with air so that the concentration at the bottom and top is almost equal, hydrogen, however, mixes less so that the concentration at the bottom of the gas meter cabinet is about 30% lower than at the top. Even with taped grilles, not all the gas stays in the gas meter cabinet. Gas escapes to the hall through cracks and seams. When the concentration in the gas meter cabinet is 50% LEL, the concentration in the hall is 2-4% LEL (for both natural gas and hydrogen).

If the vents of the gas meter cabinet are open, the gas concentration in the gas meter cabinet rises much less rapidly and at a lower rate than with closed vents. At a gas flow of 50 dm³/h, the concentration in the gas meter cabinet will not reach 100% LEL. This applies to hydrogen and natural gas. Even with a very low ventilation rate of the container ($R = 0.15/h$ for hydrogen, $R = 0.20/h$ for natural gas), the concentration in the gas meter cabinet remains < 100% LEL.

At outflows of 100 and 300 dm³/h, the final concentration in the gas meter cabinet for both gases does exceed 100% LEL.

It follows that applying ventilation in accordance with NEN 2768 + A1 is essential for both natural gas and hydrogen.

8.3 Leakage size limit for hydrogen need not be different from natural gas

The following requirements apply to natural gas (see box):

LEAKPROOFNESS REQUIREMENTS NATURAL GAS:

Gas meter setup: maximum 0.1 dm³/h³

Indoor pipe installation up to 50 dm³ pipe volume:

New construction: 1 mbar pressure drop in 3 minutes, measured with natural gas. For a pipe volume of 50 litres, this is 1 dm³/h. For a pipe volume of 5 litres (a more common pipe volume for homes), it is 0.1 dm³/h.

Existing construction: 5 dm³/h and a maximum of 1 dm³/h at the same location.

Based on paragraph 9.1 it is *technically* justifiable to allow a leakage size of up to 50 dm³/h as the lower flammability limit (LEL) is not yet reached at this point and therefore there is no risk of ignition. Based on the experiments, there is no reason to choose a different limit for hydrogen than the one currently applied for natural gas. No dangerous situations will arise at these leakage sizes. Even a factor of 3 higher (maximum factor of hydrogen compared to natural gas at the same hole size) would not give cause for this.

8.4 Mechanical supply of air is very effective to keep gas concentration low.

This study attempted to make concentration measurements at ventilation rates of 0.5/h and 1.0. This involved an attempt to imitate the airflow of natural ventilation by supplying air through a slit opening near the door.

Here, the build-up of concentrations in the room and hall appears to be slower and the decrease faster than would be expected based on the amount of air supplied. The retrospectively calculated ventilation is much higher than just the air blown in. Possible causes could be:

- The blown-in air induces so much flow velocity in the container that it also leads to the supply of air through other openings.
- When blowing in, areas with high gas concentrations are disproportionately ventilated.

Blowing in air also leads to better mixing. Thus, there are less pronounced low or high concentrations. This is probably a consequence extra air movement in the container caused by the blown-in air.

It follows that mechanical supply of air is very effective in keeping the gas concentration low.

8.5 Mechanical air extraction is also effective.

The experiments show that at a gas outflow in the gas meter cabinet of 300 dm³/h and a ventilation rate of 0.5/h, no gas concentrations exceeding 100% LEL occur in the room outside the gas meter cabinet.

For natural gas, the ventilation rate was found to correspond well to the extracted air flow rate. For hydrogen, the ventilation rate was somewhat higher than the extracted air volume: the largest difference measured was a ventilation rate of 1.7/h at a set air supply of 1/h.

8.6 Layering in hydrogen

In the HyDelta 1.0, in the empty container, stratification of methane (at an outflow of up to 20 dm³/h) was found to be stronger in the gas meter cabinet than for hydrogen. This was not expected based on the physical properties.

In this study under HyDelta 2.0, with higher outflows, hydrogen shows much stronger stratification than natural gas. This leads to zones of higher concentration at the top. This is probably partly why retrospective determination of the ventilation rate does not work as well with hydrogen as with natural gas. This is because that method is based on homogeneity.

9 Conclusions from the experiments

9.1 Ventilation of gas meter cabinet is necessary

With a leakage of 50 dm³/h (indicatively similar to a leaking thread joints), the lower flammability limit (LEL) will not be reached for both hydrogen and natural gas. This only applies if air vents are present in the gas meter cabinet in accordance with the regulations. As long as this flammability limit is not reached, there is no risk of ignition and the situation is safe.

It is recommended that air vents be fitted in gas meter cabinets for hydrogen gas meter arrangements in line with current regulations for natural gas meter cabinets.

9.2 Leakage size limit for hydrogen no different from natural gas

Based on the experiments, there is no reason to choose a different limit for hydrogen than the one currently in place for natural gas. No dangerous situations will arise at these leakage sizes. Even a factor of 3 higher (maximum factor of hydrogen compared to natural gas at the same hole size) would not give cause for this.

9.3 At leak size of 50 to 100 dm³/h no ignitable concentration outside gas meter cabinet

For the space outside the gas meter cabinet, the experiments show that for leaks up to 100 dm³/h (comparable to a loose compression fitting) in the gas meter cabinet, at a ventilation rate of 0.5, no concentrations above 100% LEL arise in the hall (the space in which the gas meter cabinet is located), even if it is not ventilated.

9.4 Leaks outside the gas meter cabinet

The study shows that low ventilation creates strong stratification (especially for hydrogen). "Normal" ventilation not only works in reducing the average concentration, but is also effective in mixing the gas with air. As a result, there will be fewer zones/ dead spots with high concentration. Blowing in air is effective for mixing gas and air. On the other hand, extracting air high in the room ensures that the highest concentration is removed.

It is recommended, where possible, to opt for a system of mechanical ventilation instead of natural ventilation because it does not depend on weather conditions, among other things.

9.5 Differences in ventilation rates

The afterwards determined ventilation rates based on concentration change sometimes give unexpected results and regularly deviate from the set ventilation rates. Some possible causes for this were found, but an unambiguous explanation cannot be given on the basis of the results. The fact is that the ventilation found is only higher (and thus more favourable) than the set ventilation.

9.6 Gas stopper as mitigating measure?

Based on this study, no recommendation can be made on whether or not to apply a gas stopper. This is because the maximum leak size in this study is 1 m³/h. A gas stopper should intervene at a much higher gas flow rate (order of magnitude for 18 m³/h hydrogen) because otherwise the gas stopper will already shut off the gas supply at normal gas consumption of a central heating appliance.

10 Recommendations for further experimental research

10.1 Other types of gas meter cabinets

In this project, experiments were done with one gas meter cabinet. However, there are also many other kinds of rooms in which gas meters hang, whether or not filled with objects that do not belong in a gas meter cabinet. It is worth considering conducting some experiments to see how the gas concentration develops in such a room, and whether a higher concentration can form here.

10.2 Rooms other than a gas meter cabinet

In this project, experiments were only conducted where gas was released in a gas meter cabinet. In practice, gas can also be released in any other small space. It is recommended to do further research on hydrogen release in other small spaces such as a crawl space, “stijgkast” or kitchen sink cabinet.

10.3 Further investigation into unexplained effects

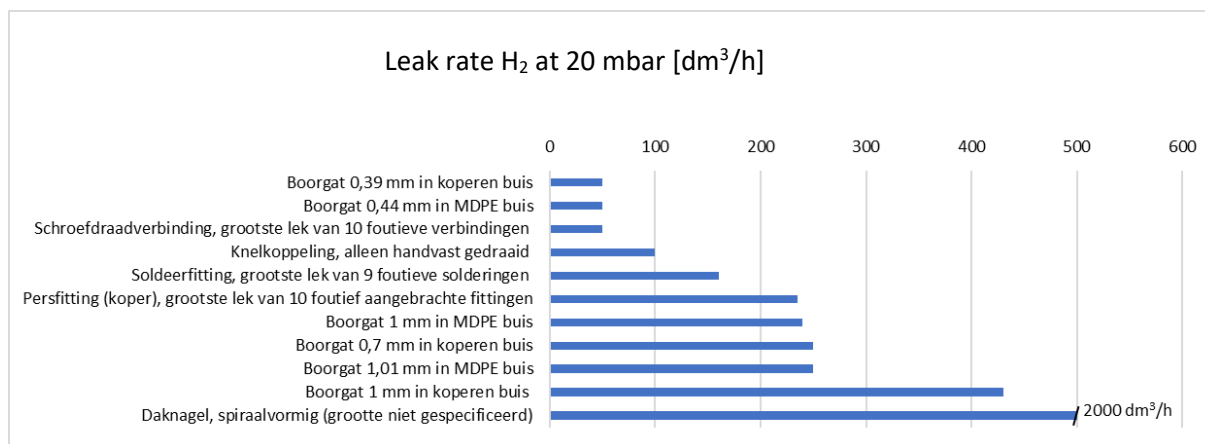
The results showed some unexplained effects, such as lower ventilation after a ventilation grille was added, and much higher measured ventilation (more than factor 4) at set ventilation rates of 0.5 and 1 per hour.

It is worth considering further investigation of this phenomenon through experiments and/or CFD calculations.

Annexes


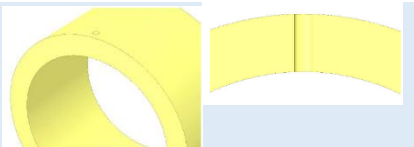

I Practical examples of leaks

To get an impression of leakage sizes at different types of leaks that can occur indoors, a summary of experimentally determined leakage sizes at 20 mbar has been compiled. This was done using a report by Hy4Heat4 [2].

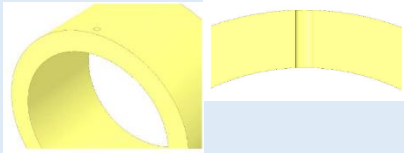


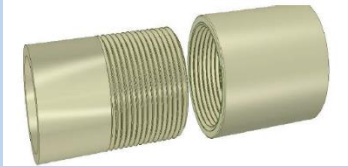



In the Netherlands, gas pressure is typically between 20 and 30 mbar. Therefore, in Table 11 a column has been added for leak size at 30 mbar.

Table 11: Further explanation of various leakage sizes

Type of leak	Leakage rate H ₂ (dm ³ /h) at 20 mbar line pressure	Leakage rate H ₂ (dm ³ /h) at 30 mbar line pressure ⁵	Image
Drill hole 0.39 mm Drilled hole in pipe, copper DN 25, wall thickness 0.7 mm.	50	75	
Drill hole 0.44 mm: drilled hole in pipe, MDPE DN 32, wall thickness 3.3 mm	50	75	
Drilled hole 0.7 mm: Drilled hole in pipe, copper DN 25, wall thickness 0.7 mm.	250	375	

⁵ Values in this column are converted from value at 20 mbar. In all cases there is laminar flow, except for the leak in the last line (roof nail). Here the flow is turbulent.

Type of leak	Leakage rate H ₂ (dm ³ /h) at 20 mbar line pressure	Leakage rate H ₂ (dm ³ /h) at 30 mbar line pressure ⁵	Image
Drill hole 1.01 mm: drilled hole in pipe, MDPE DN 32, wall thickness 3.3 mm	250	375	
Drill hole 1 mm: Drilled hole in pipe, copper DN 25 (wall thickness 0.7 mm).	430	645	
Drill hole 1 mm: drilled hole in pipe, MDPE DN 32, wall thickness 3.3 mm	240	360	
Press-fit (copper) Tested with 10 fittings fitted incorrectly.	Max: 235 Min: ~ 0 Gem: 45	Max: 253 Min: ~ 0 Gem: 68	
Compression fitting (15 mm): Knob fitting (brass), hand-tightened, assembly without pliers .	100	150	
Threaded connection Tested with 9 mismatched fit connections	Max: 50 Min: 0 Gem: 16	Max: 75 Min: 0 Gem: 24	
Solder fitting Tested with 9 mismatched fit connections	Max: 160 Min: ~ 0 Gem: 38	Max: 240 Min: ~ 0 Gem: 54	

Type of leak	Leakage rate H ₂ (dm ³ /h) at 20 mbar line pressure	Leakage rate H ₂ (dm ³ /h) at 30 mbar line pressure ⁵	Image
Large roofing nail (size not specified) Spiral	2000	4500	

II Determination of average ventilation rate

II.1 General

In this section, the method used to determine the average ventilation rate is explained using configuration 3. All ventilation slots to the outside are closed, the vents from the gas meter cabinet (mk) to the hall are open. The door between hall and room is closed. See Figure 42.

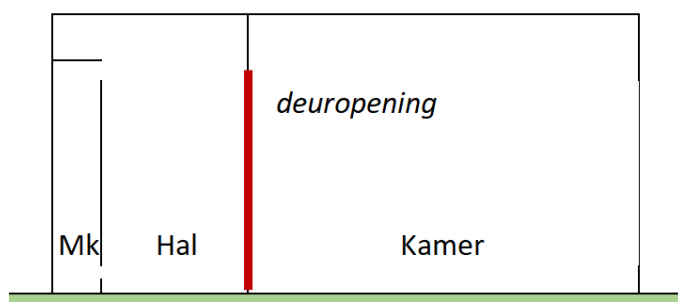


Figure 42: Configuration 3 (side view)

II.2 Ventilation

General

To determine the ventilation rate, the measurements were compared with the theoretical data. For this purpose, a concentration profile was made of the weighted⁶ average concentration in the hall + gas meter cabinet. See Figure 43.

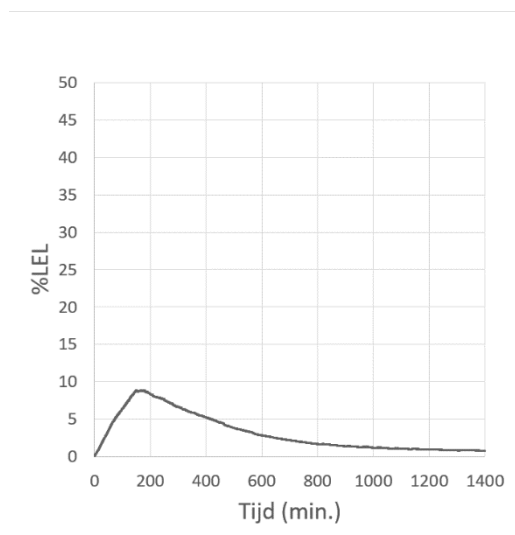


Figure 43: Measured average concentration profile of hydrogen

The average profile is the same as the profile with homogeneous mixing.

⁶ Explanation term "weighted": the number of sensors per m³ is not the same in the hall and the room. The weighted average takes this into account.

Descending part of the graph

Using the decreasing part of the profile, the ventilation rate can be approximated with the simplified assumption that hydrogen and air are homogeneously mixed at all times. From the moment of stopping the gas supply to the container, the gas concentration will decrease according to:

$$Cg(t) = Cg(t_s)e^{-Rt} + Cg_f \quad (1)$$

In which:

$Cg(t)$ = concentration at time t [%]

Cg_f = final concentration [%]

t = time [hours]

t_s = time of stopping gas supply [hours].

R = ventilation rate [1/h], which is the number of times per hour that the air in (part of) the container is refreshed

The gas supply in this experiment stops after 150 minutes. If that moment is chosen as $t=0$ for formula (1), the same figure can show the theoretical curve for homogeneous mixing, converted to % LEL.

The best-fit theoretical curve (Figure 44, red) was found by varying the ventilation rate.

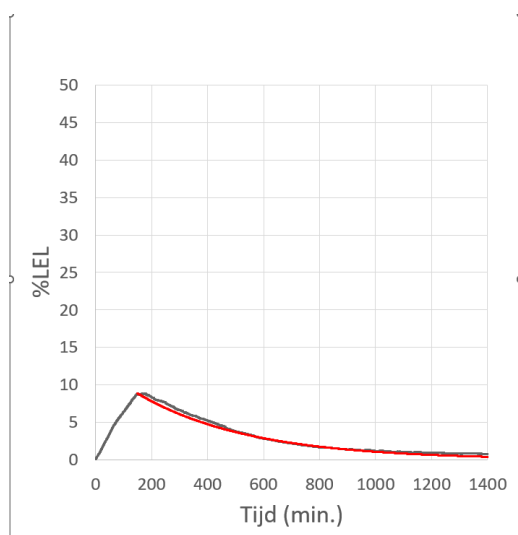


Figure 44: Average concentration profile in gas meter cabinet + hall (sensors 1 to 27) with the gas meter cabinet door closed (hydrogen outflow of 50 dm³/h). Red: theoretically fit graph; ventilation rate 0.15

In this experiment, the ventilation rate is found to be $R = 0.15$.

Rising part of the graph: final concentration at gas supply

Now that the ventilation rate R in this experiment is known, the final concentration (steady-state concentration) can be calculated when mixing homogeneously. It is given by the ratio of gas supply Q_g to the sum of air and gas supply ($RV + Q_g$):

$$Cg(\infty) = 100 \frac{Q_g}{RV + Q_g} + Co \quad (2)$$

In which:

$C_g(\infty)$ = final or steady-state concentration [%].

C_o = background concentration [%]

Q_g = gas supply [m³/h]

t = time [hours]

R = ventilation rate [1/h]

V = volume of space [m³]

$C_g(\infty)$ expressed as % LEL:

$C_g(\infty) / \text{LELH}_2$ = final or steady-state concentration [% LEL].

$$C_g(\infty) = 100 \frac{50 \cdot 10^{-3}}{0,14 \cdot 36 + 50 \cdot 10^{-3}} + C_o \quad (3)$$

Concentration gradient from starting gas supply:

From the start of the gas supply, the concentration increases until the final concentration is reached.

The concentration at time t is given by:

$$C_g(t) = 100 \frac{Q_g}{RV + Q_g} \left(1 - e^{-\frac{RV + Q_g}{V} t} \right) + C_o \quad (4)$$

In which:

$C_g(t)$ = concentration at time t [%]

Q_g = gas supply [m³/h]

t = time [hours]

R = ventilation rate [1/h]

V = volume of space [m³]

Formula (3) distinguishes the term $Q_g / (RV + Q_g)$, which is used to calculate final concentration. The term $\left(1 - e^{-\frac{Q_g + VR}{V} t} \right)$ describes the path towards it as a function of time. The value approaches 1 as time approaches ∞ .

With this formula and the ventilation rate $R = 0.15$ determined for this purpose, the theoretical curve during *gas supply* (Figure 45 , blue) can be added.

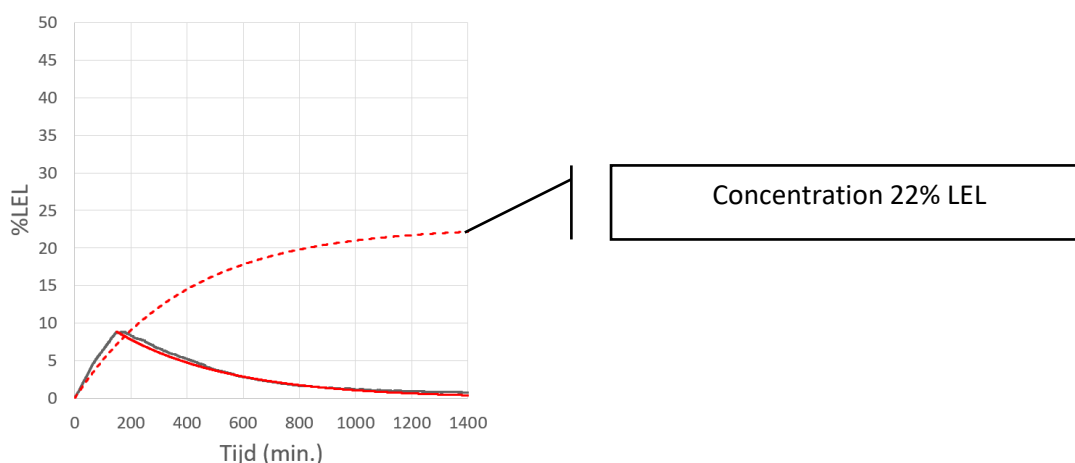


Figure 45: Average concentration profile (hydrogen outflow of 50 dm³/h). Time scale 1400 minutes (ca 23 hours). Red: theoretically fit graph; ventilation rate 0.15

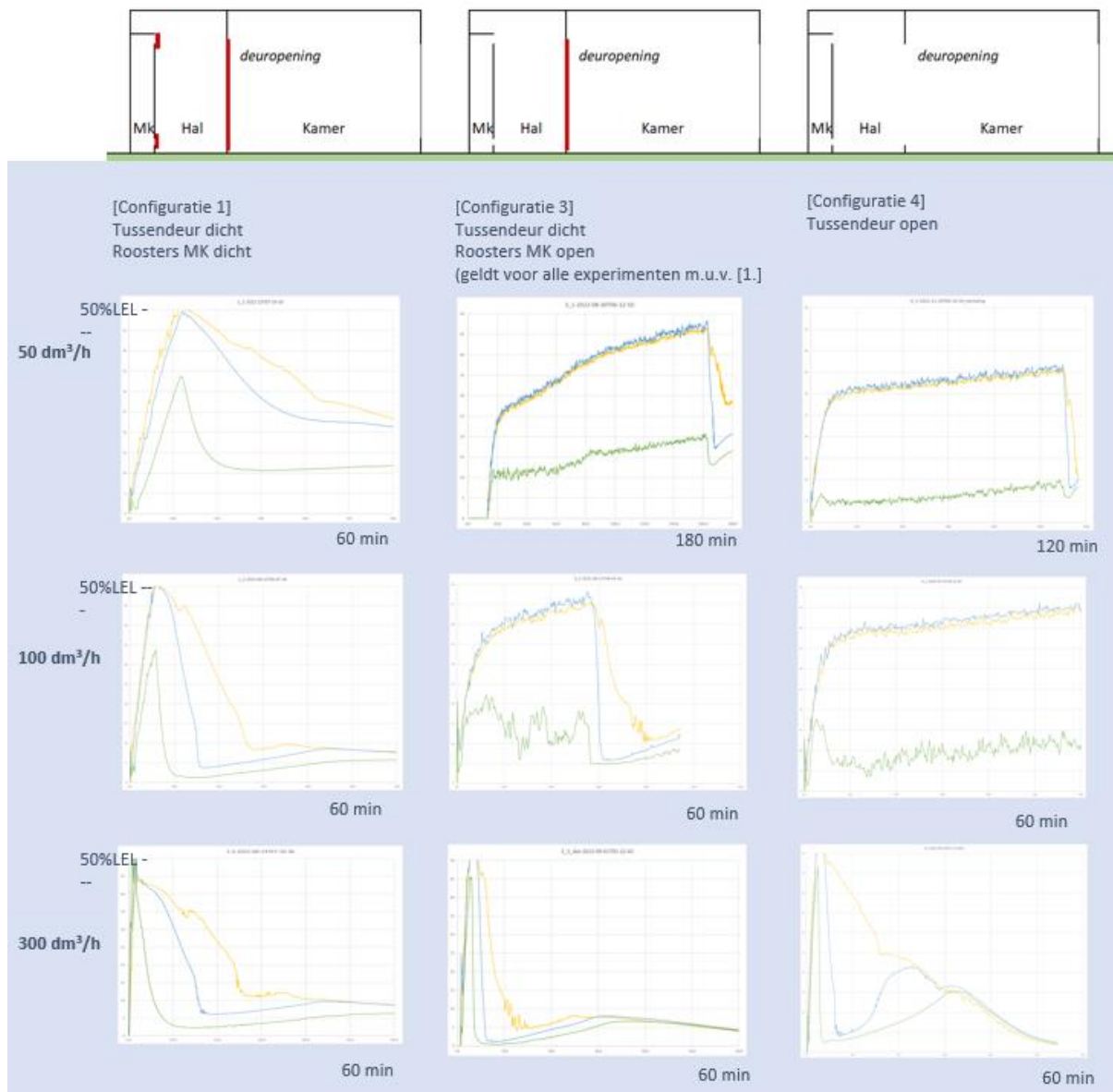
When selecting the ventilation rate, it was assumed that the value during gas supply is the same as after gas supply is terminated. This means that concessions were sometimes made to the ideal line. For example, in the figure above: Ideally, the rising graph would be even steeper, but then the falling part turns out to deviate much more from the measurement graph.

Thus, the ventilation rate is chosen so that the rising part and the falling part fit best.

III Measurements in the gas meter cabinet , schematically arranged

Graphs in large format are in Appendix V.

III.1 Hydrogen configuration 1, 3 and 4 *)

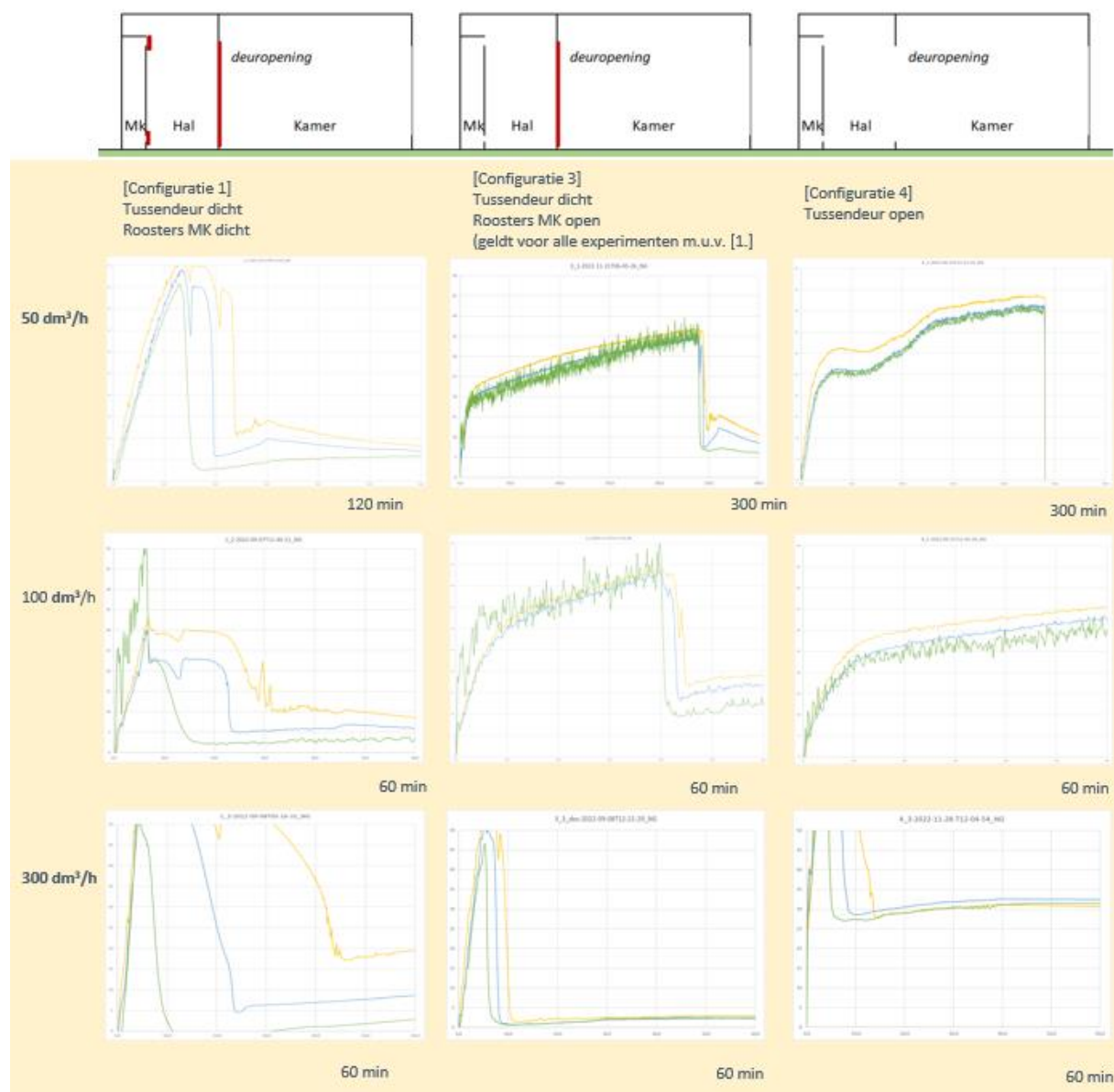


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Legenda

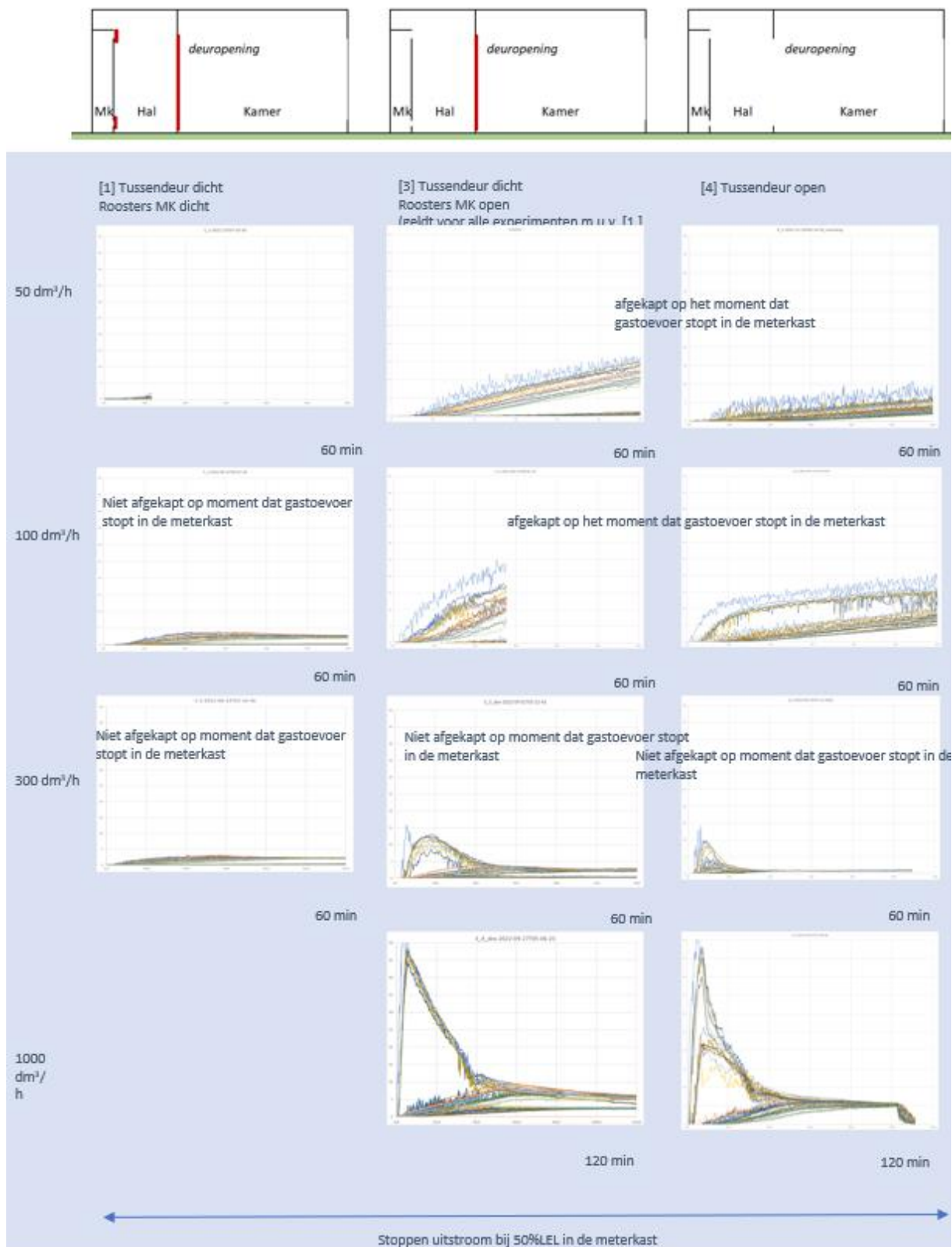
Mk: Gas meter cabinet
Hal: Hall
Kamer: Room
Deuropening: Door opening

III.2 Natural gas configuration 1, 3 and 4



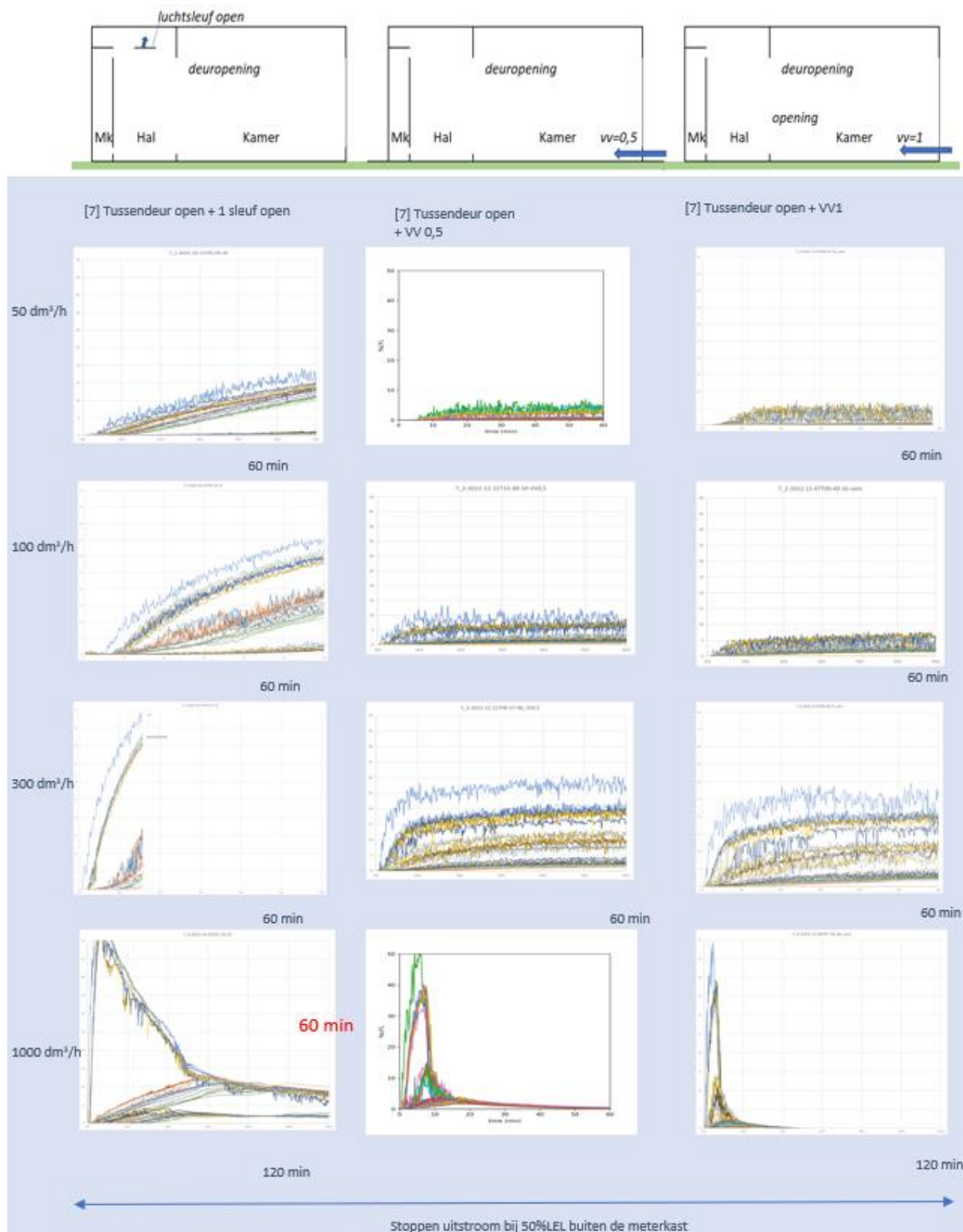
IV Measurements outside the gas meter cabinet , schematically arranged Graphs in large format are in Appendix V.

IV.1 Hydrogen configuration 1, 3 and 4 Outflow stopped at 50% LEL in gas meter cabinet



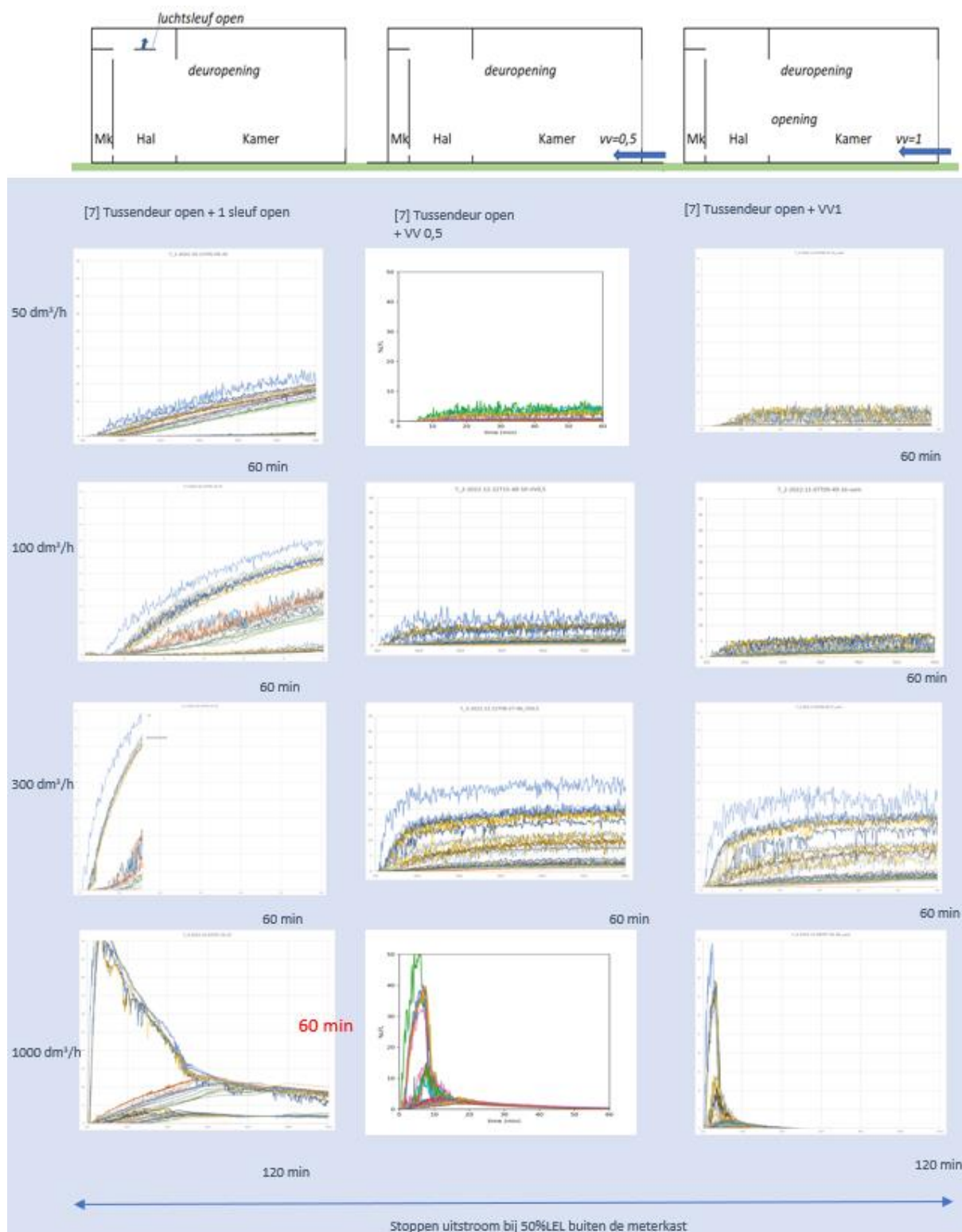
IV.2 Hydrogen configuration 7, 7/0.5 and 7/1.0

Outflow stopped at 50% LEL in gas meter cabinet



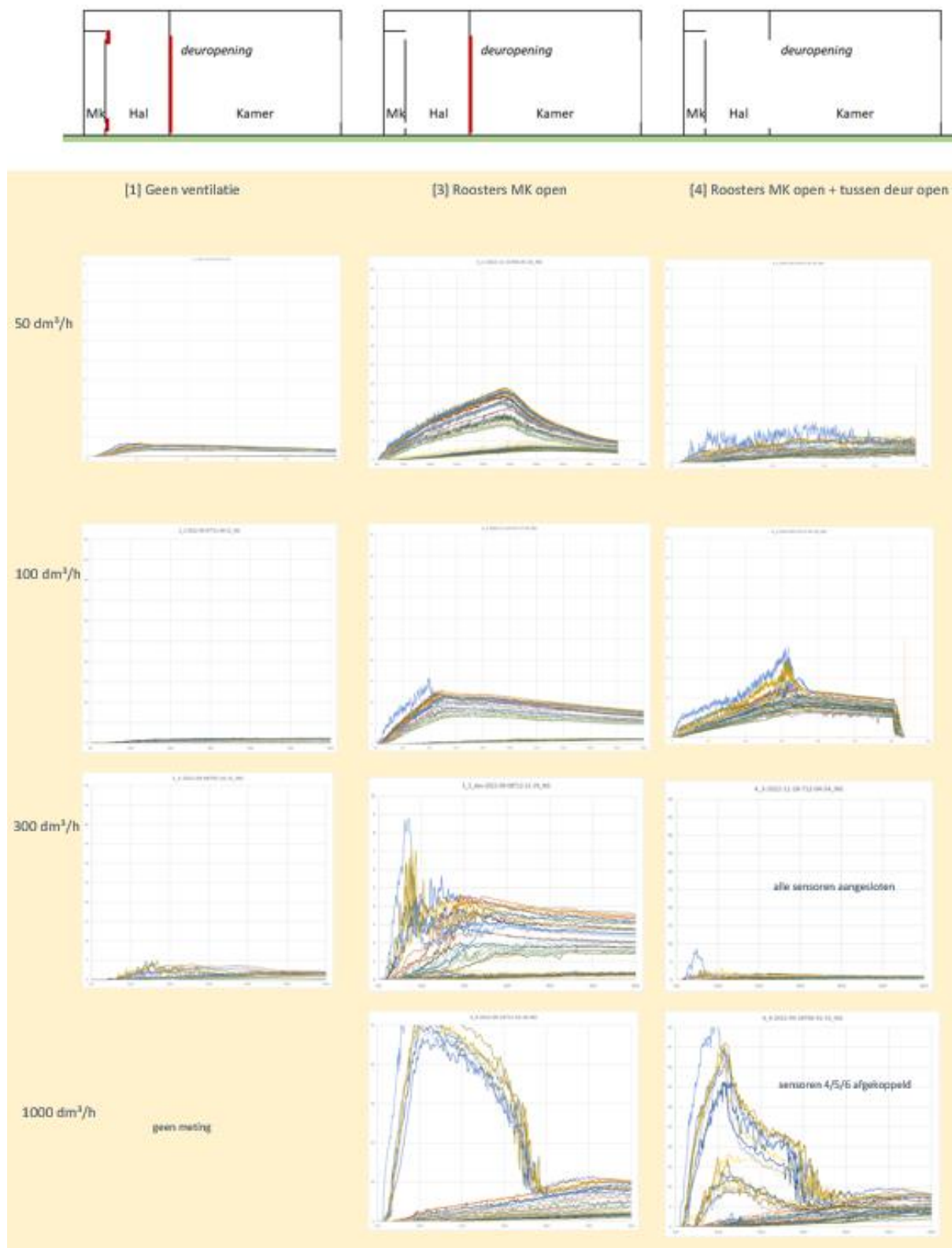
IV.3 Hydrogen configuration 8/0.5 and 8/1.0

Outflow stopped at 50% LEL in gas meter cabinet



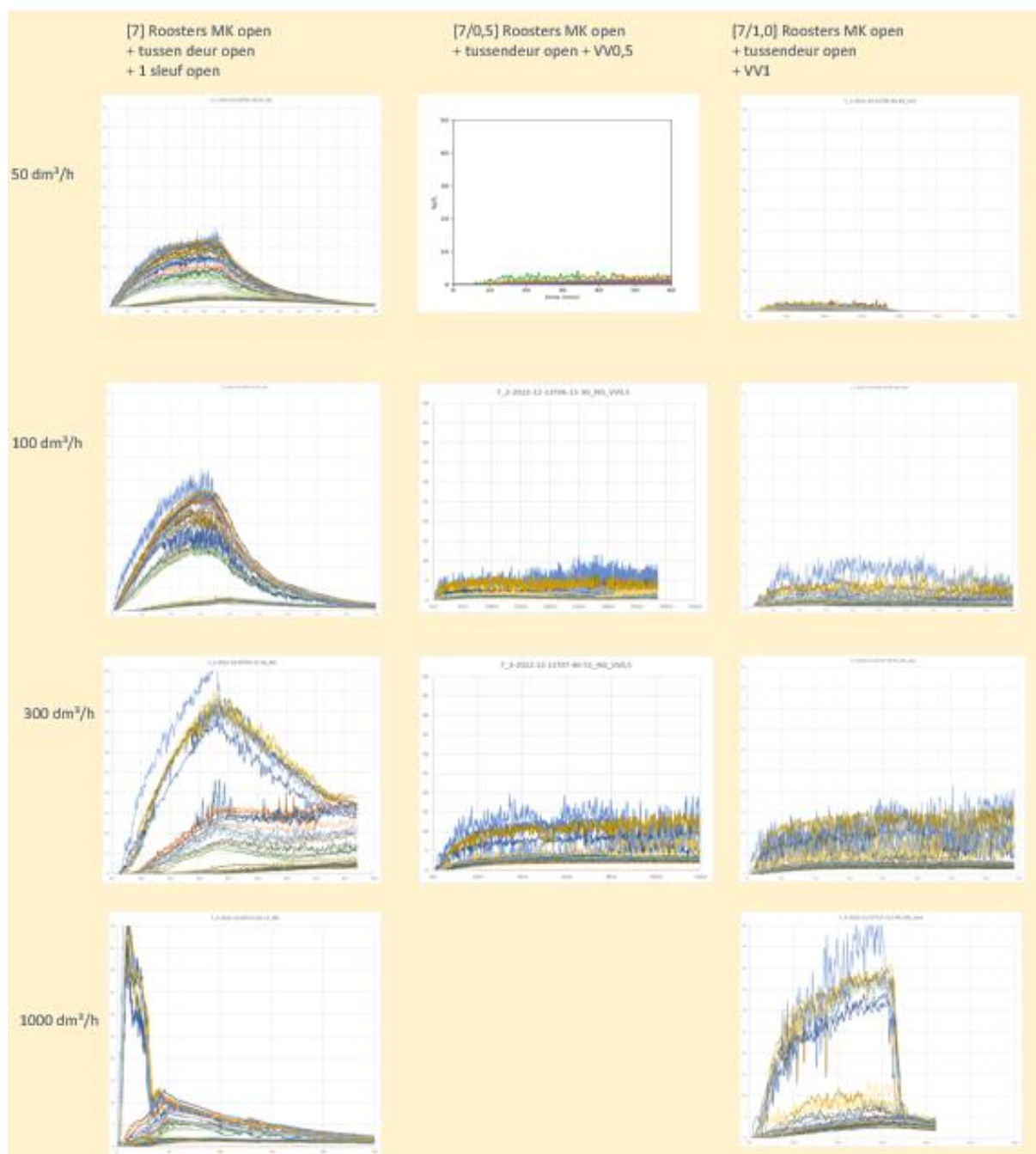
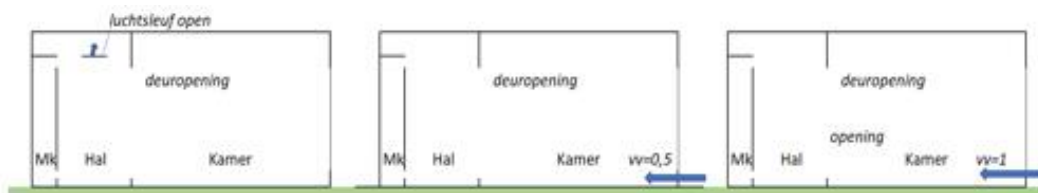
IV.4 Natural gas configuration 1, 3 and 4

Outflow stopped at 50% LEL in gas meter cabinet



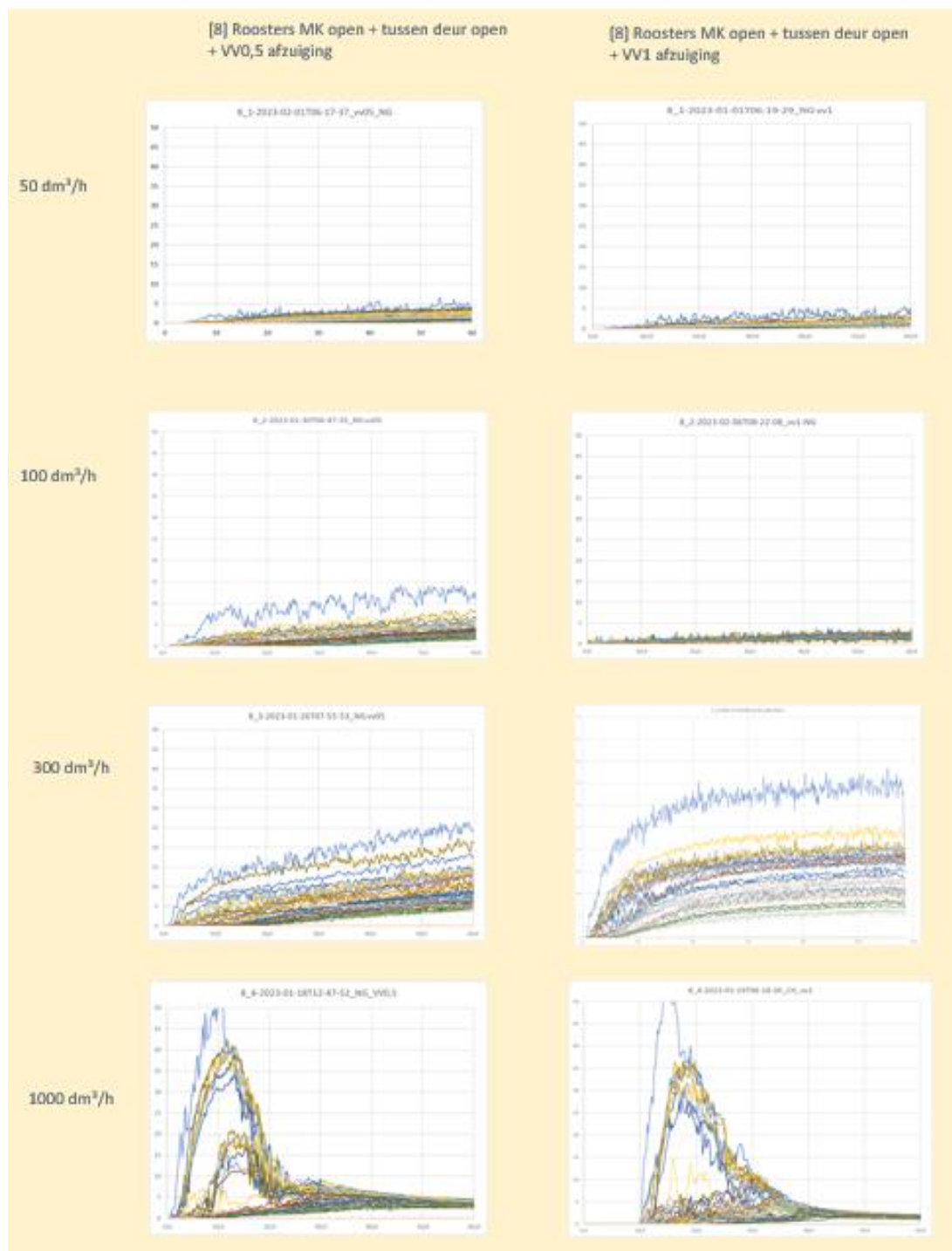
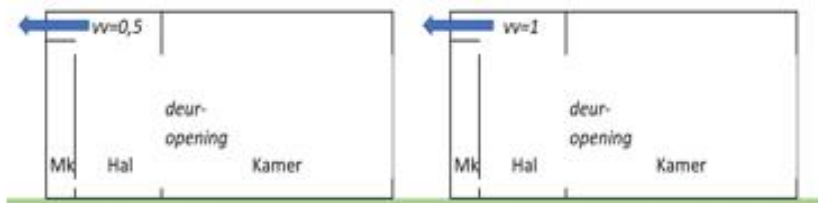
IV.5 Natural gas configuration 7, 7/0.5 and 7/1.0

Outflow stopped at 50% LEL in gas meter cabinet



IV.6 Natural gas configuration 8/0.5 and 8/1.0

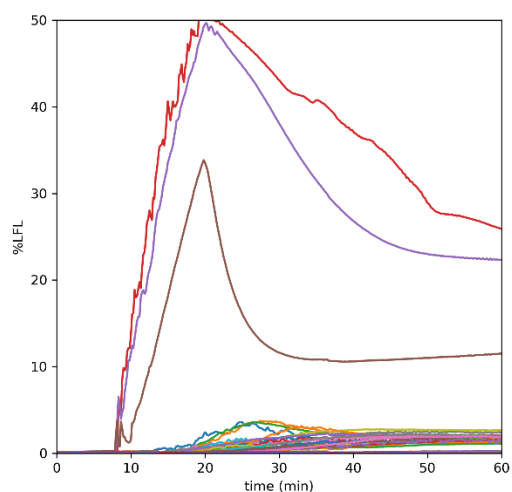
Outflow stopped at 50% LEL in gas meter cabinet



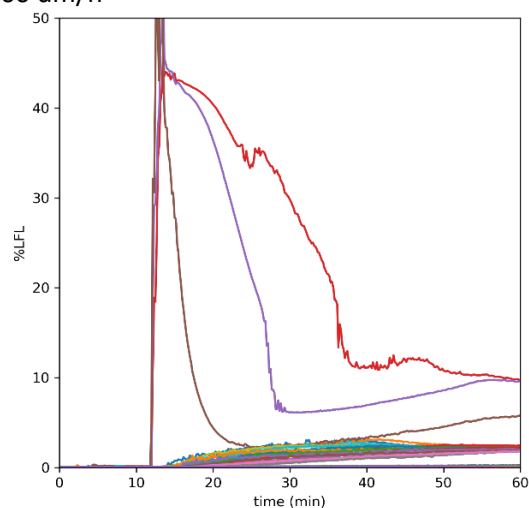
V All measurement graphs

Hydrogen
Configuration 1
Measurements 1-1 to 1-3

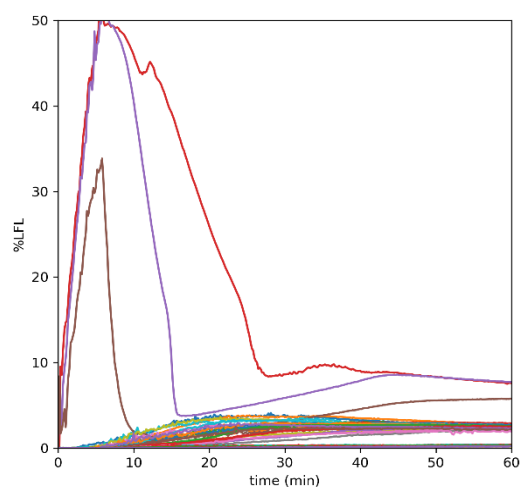
Measurement 1-1
50 dm³/h³



Measurement 1-3
300 dm³/h³

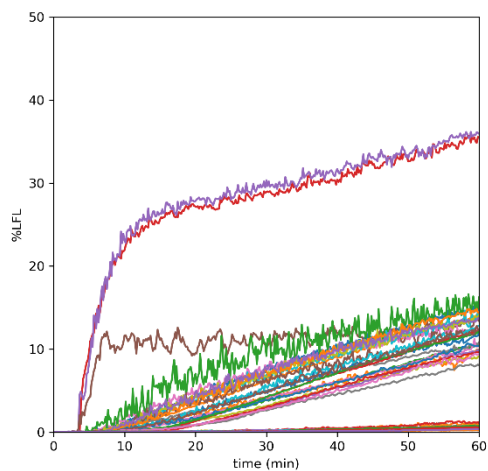


Measurement 1-2
100 dm³/h³

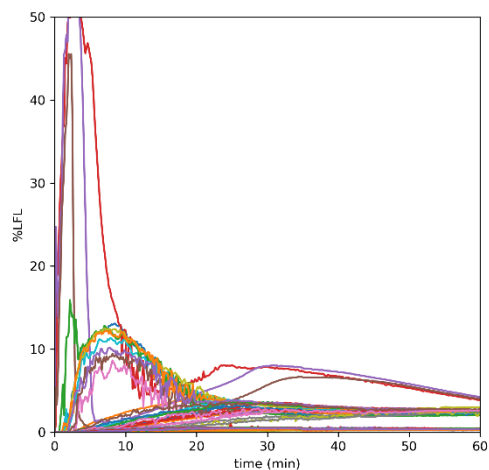


Hydrogen
Configuration 3
Measurements 3-1 to 3-3

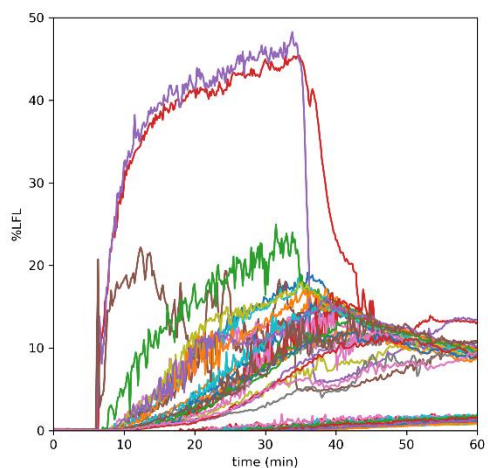
Measurement 3-1
50 dm³/h³



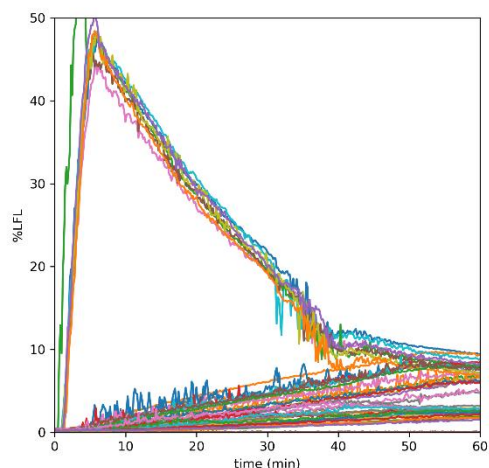
Measurement 3-3
300 dm³/h³



Measurement 3-2
100 dm³/h³

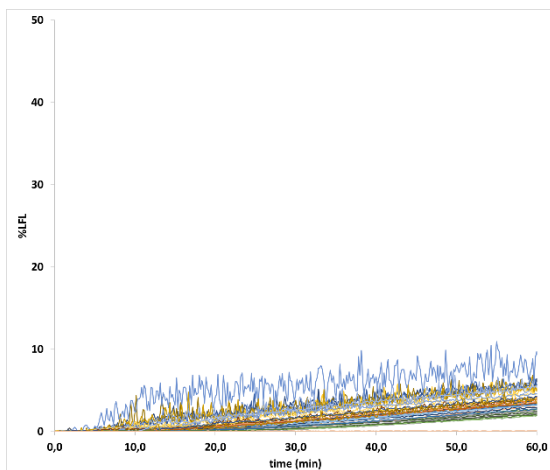


Measurement 3-4
1000 dm³/h³

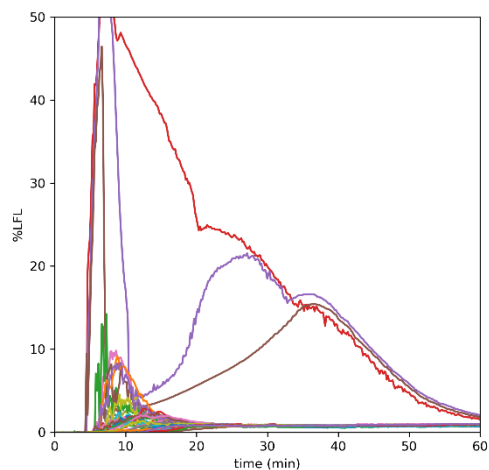


Hydrogen
Configuration 4
Measurements 4-1 to 4-3

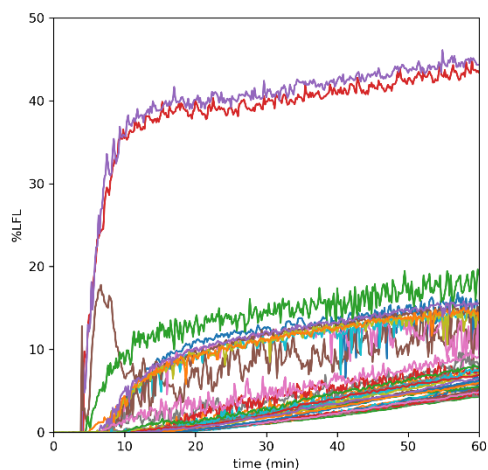
Measurement 4-1
50 dm³/h³



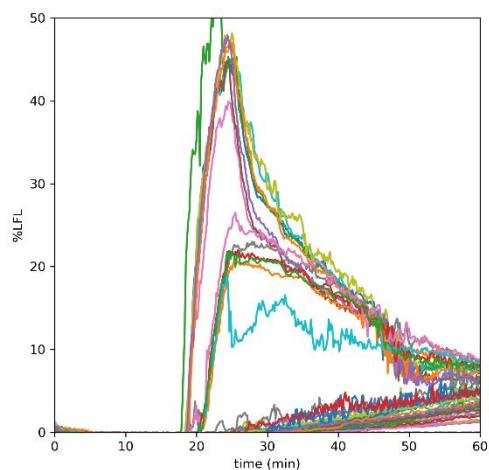
Measurement 4-3
300 dm³/h³



Measurement 4-2
100 dm³/h³

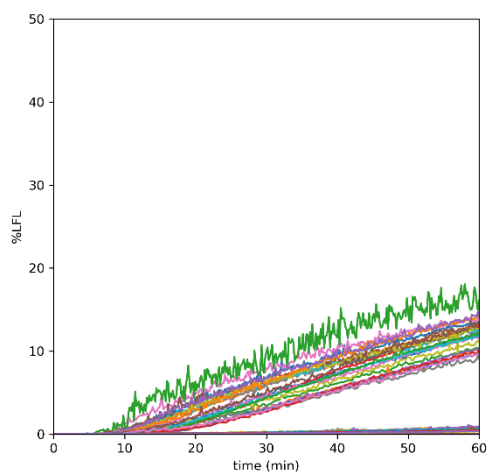


Measurement 4-4
1000 dm³/h³

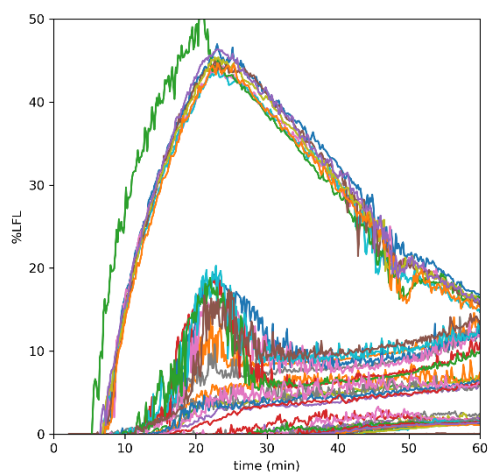


Hydrogen
Configuration 7
Measurements 7-1 to 7-4

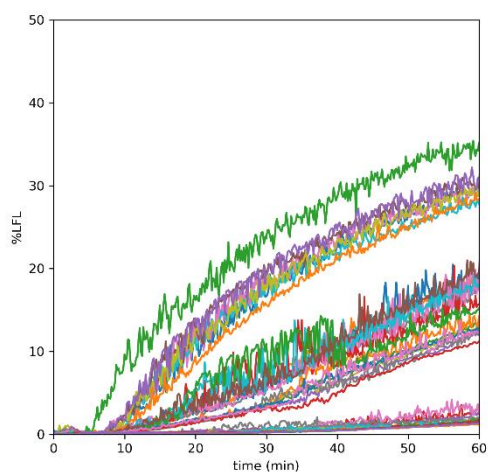
Measurement 7-1
50 dm³/h³



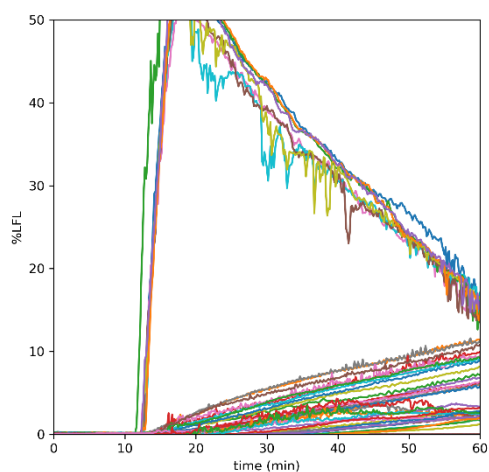
Measurement 7-3
300 dm³/h³



Measurement 7-2
100 dm³/h³



Measurement 7-4
1000 dm³/h³



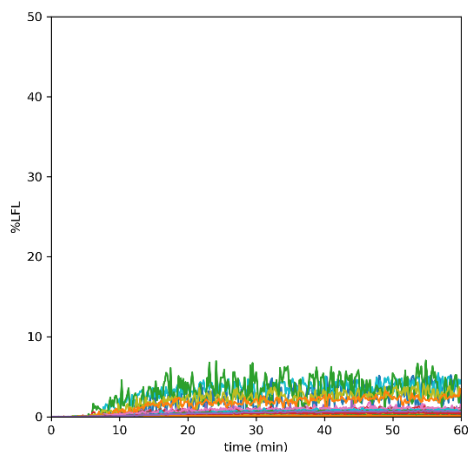
Hydrogen

Configuration 7/0.5

Measurements 7-1 to 7-4 blow-in ventilation rate 0.5

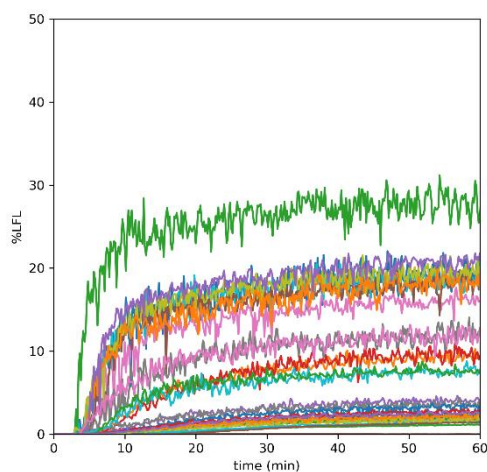
Measurement 7-1

50 dm³/h³



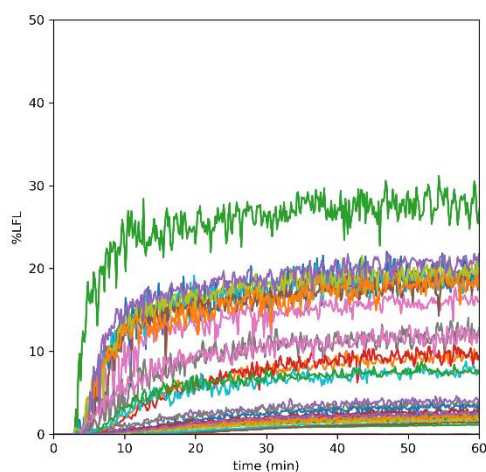
Measurement 7-3

300 dm³/h³



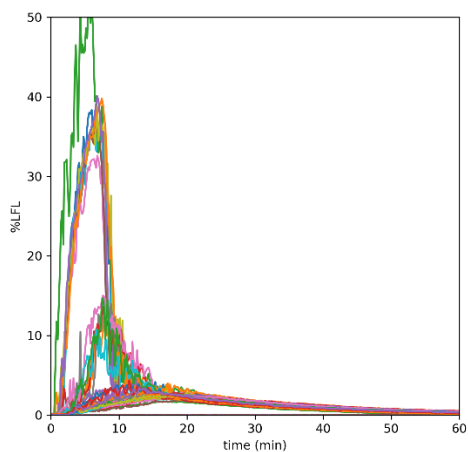
Measurement 7-2

100 dm³/h³



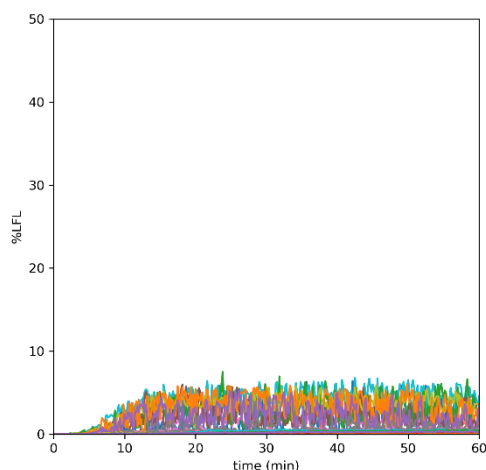
Measurement 7-4

1000 dm³/h³

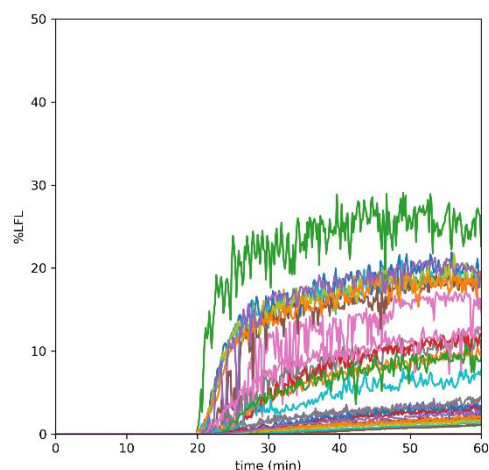


Hydrogen
Configuration 7/1
Measurements 7-1 to 7-4 ventilation rate 1 blow-in

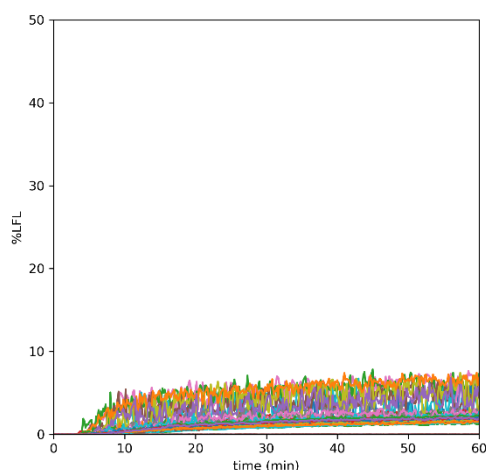
Measurement 7-1
50 dm³/h³



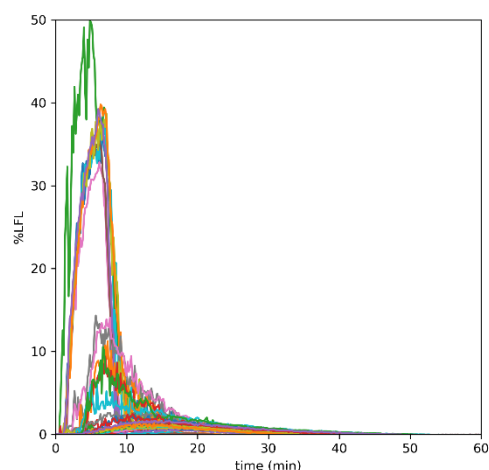
Measurement 7-3
300 dm³/h³



Measurement 7-2
100 dm³/h³



Measurement 7-4
1000 dm³/h³



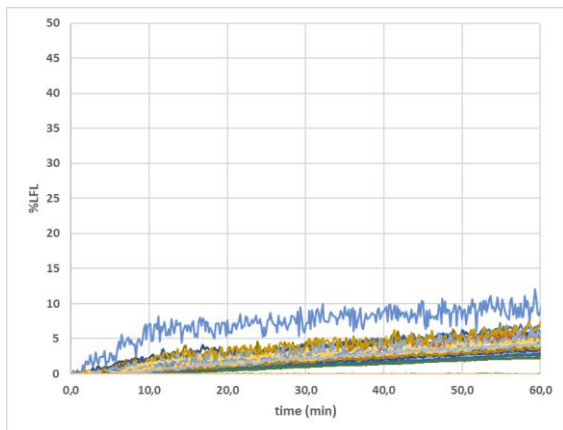
Hydrogen

Configuration 8/0.5

Measurements 8-1 to 8-4 Extract ventilation rate 0.5

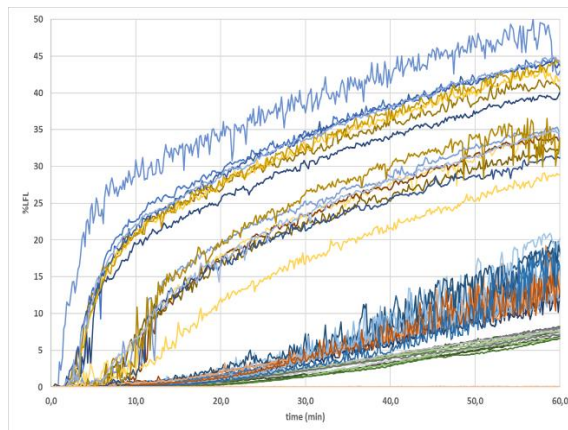
Measurement 8-1

50 dm³/h³



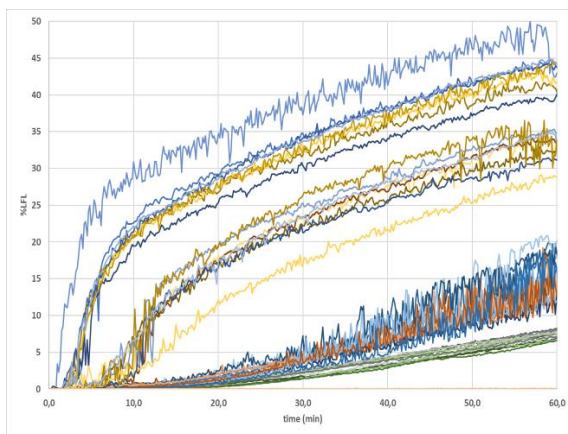
Measurement 8-3

300 dm³/h³



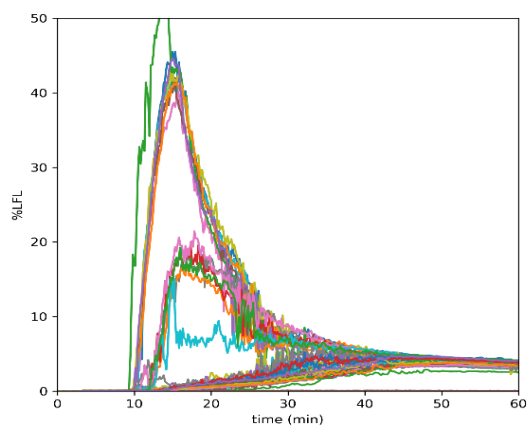
Measurement 8-2

100 dm³/h³



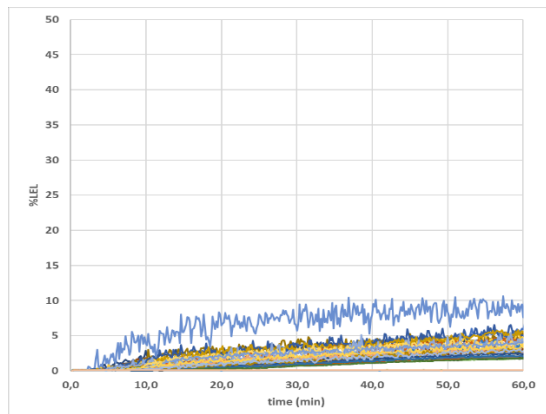
Measurement 8-4

1000 dm³/h³

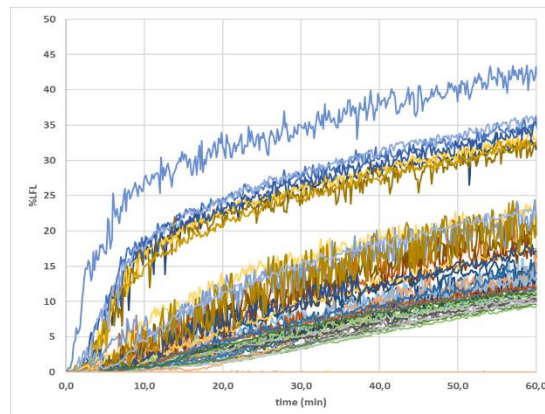


Hydrogen - Measurements 8-1 to 8-4 ventilation rate 1 extracting

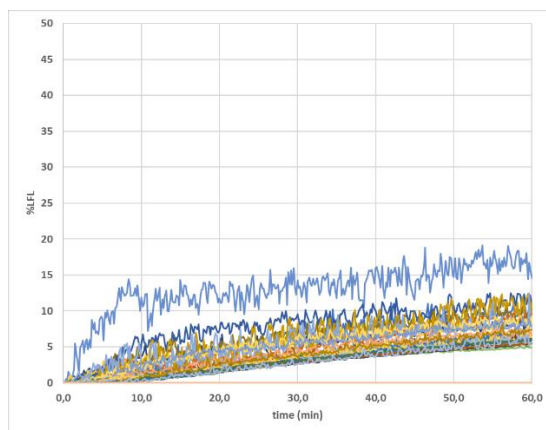
Measurement 8-1
50 dm³/h³



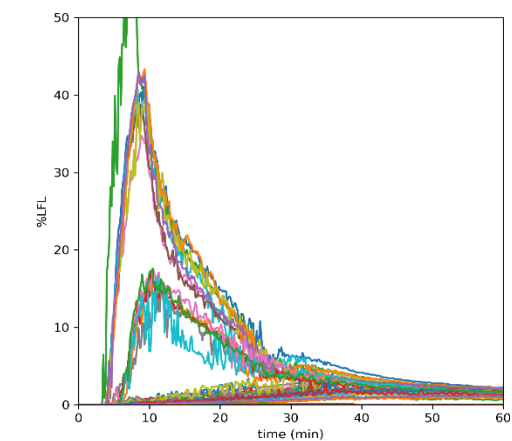
Measurement 8-3
300 dm³/h³



Measurement 8-2
100 dm³/h³

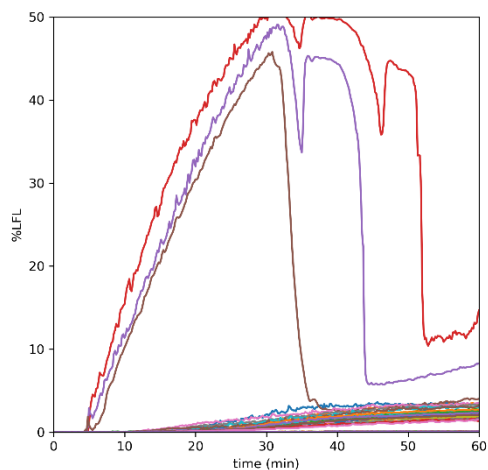


Measurement 8-4
1000 dm³/h³

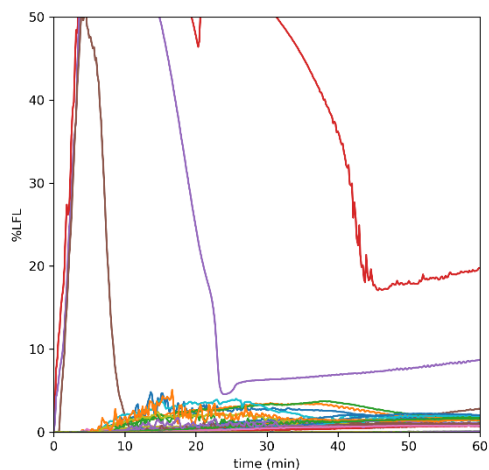


Natural gas
Configuration 1
Measurements 1-1 to 1-3

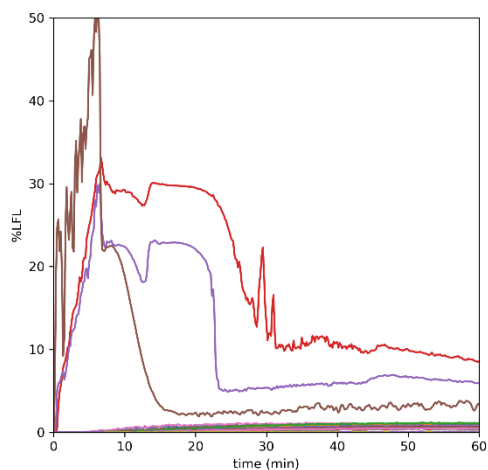
Measurement 1-1
50 dm³/h³



Measurement 1-3
300 dm³/h³

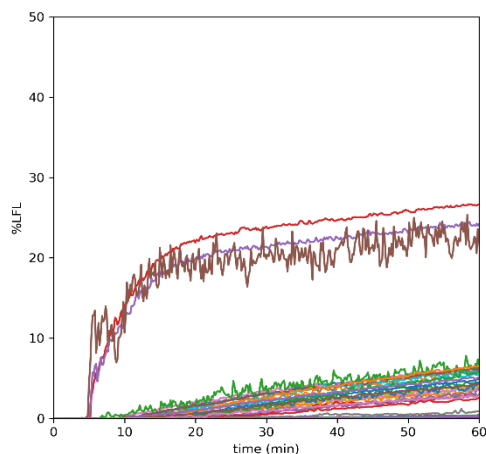


Measurement 1-2
100 dm³/h³

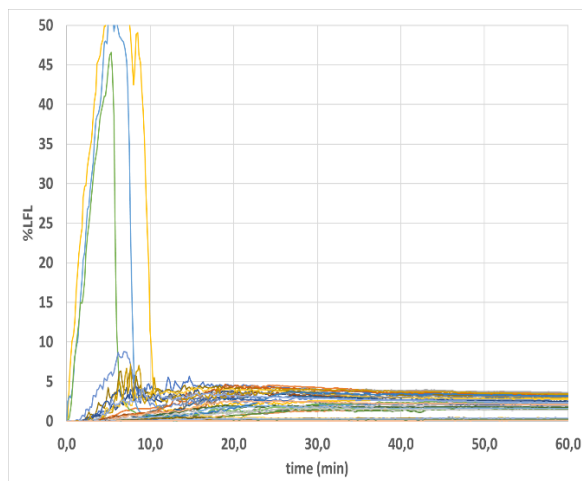


Natural gas
Configuration 3
Measurements 3-1 to 3-3

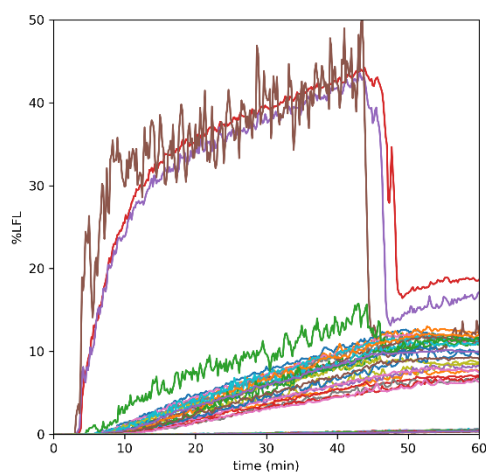
Measurement 3-1
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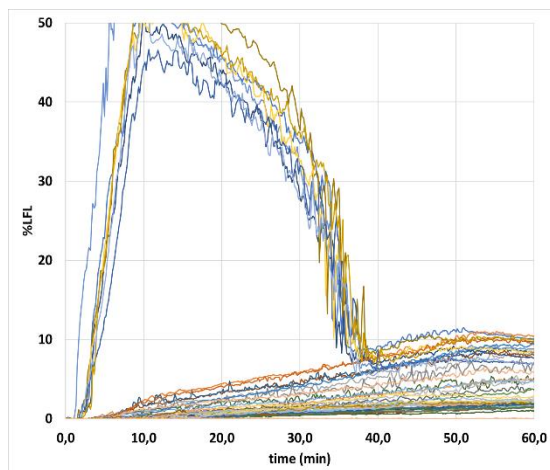
Measurement 3-3
300 dm³/h³



Measurement 3-2
100 dm³/h³

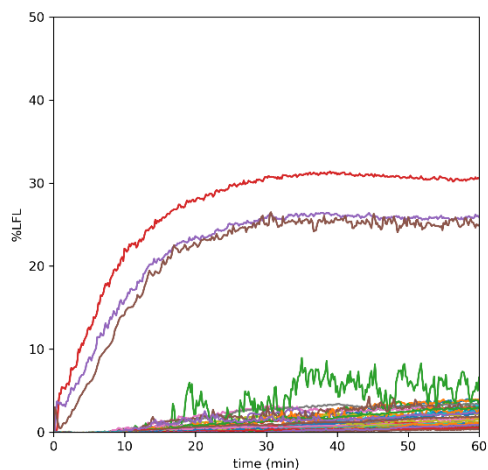


Measurement 3-4
1000 dm³/h³

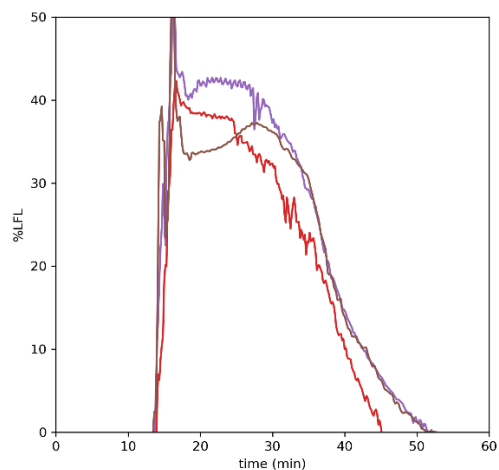


Natural gas
Configuration 4
Measurements 4-1 to 4-3

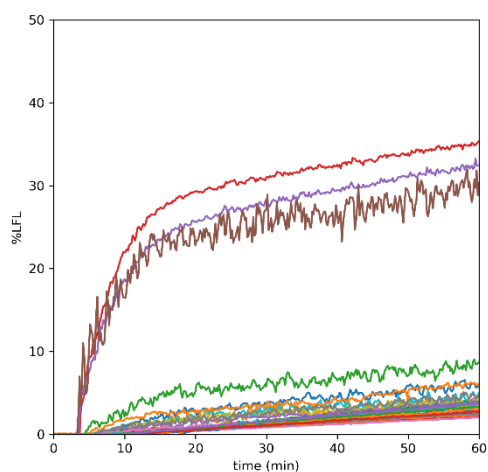
Measurement 4-1
50 dm³/h³



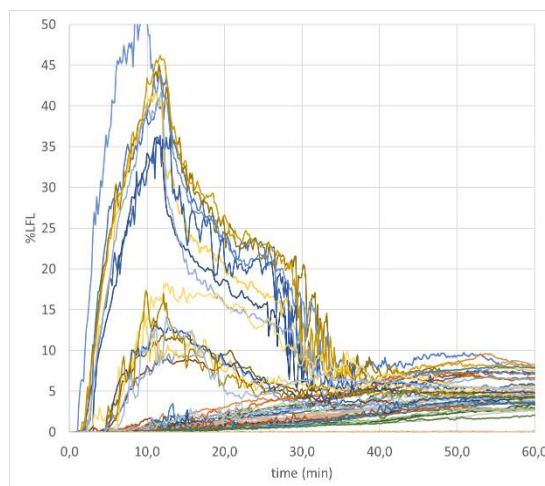
Measurement 4-3
300 dm³/h³



Measurement 4-2
100 dm³/h³

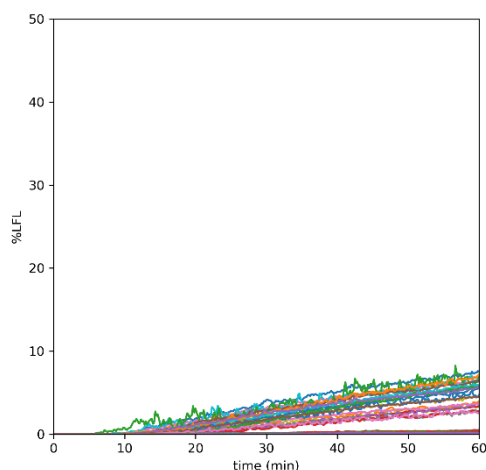


Measurement 4-4
1000 dm³/h³

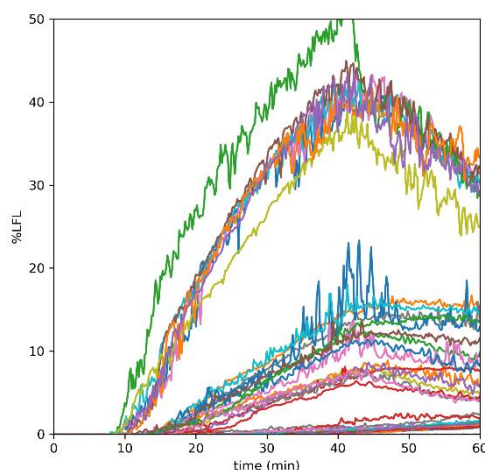


Natural gas
Configuration 7
Measurements 7-1 to 7-4

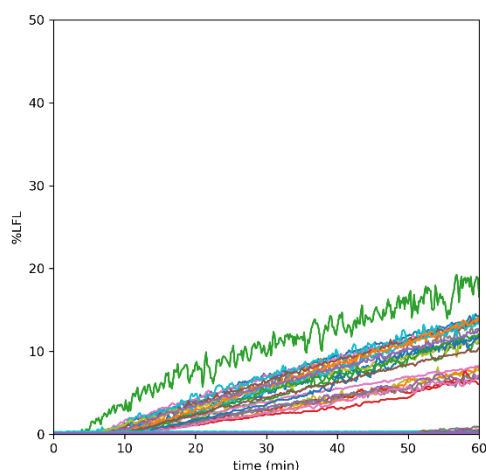
Measurement 7-1
50 dm³/h³



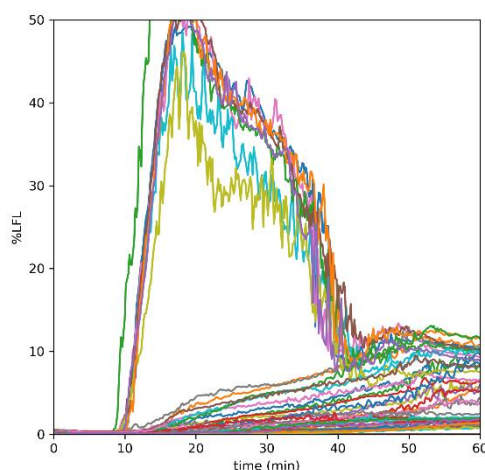
Measurement 7-3
300 dm³/h³



Measurement 7-2
100 dm³/h³



Measurement 7-4
1000 dm³/h³



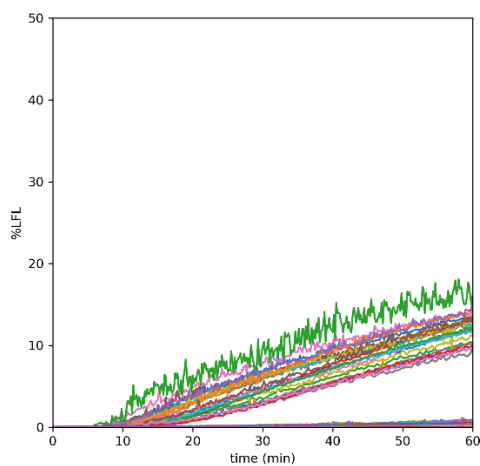
Natural gas

Configuration 7/0.5

Measurements 7-1 to 7-4 blow-in ventilation rate 0.5

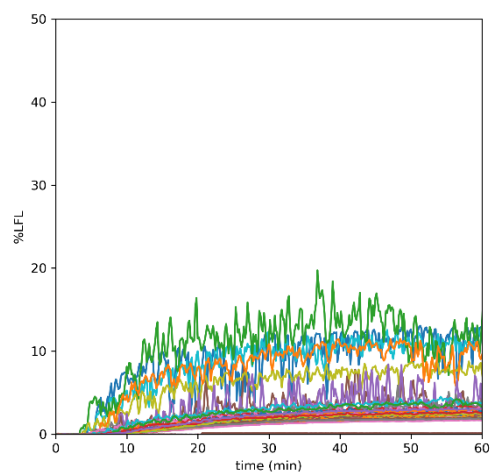
Measurement 7-1

50 dm³/h³



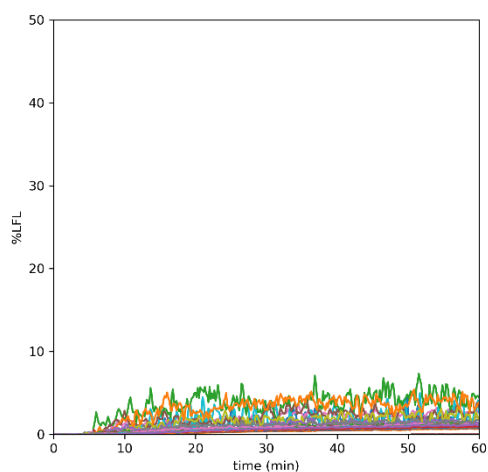
Measurement 7-3

300 dm³/h³



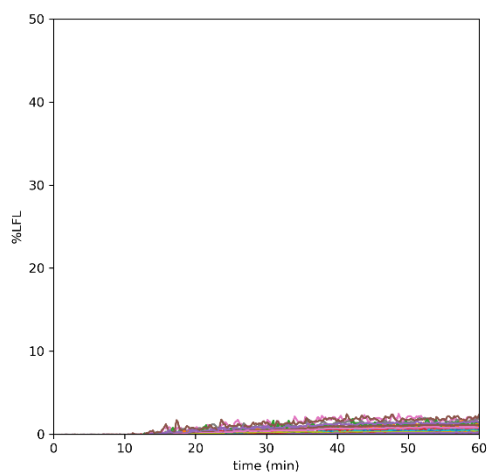
Measurement 7-2

100 dm³/h³

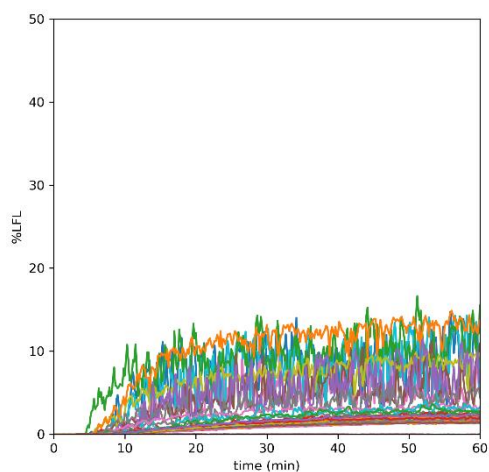


Natural gas
Configuration 7/1
Measurements 7-1 to 7-4 ventilation rate 1 blow-in

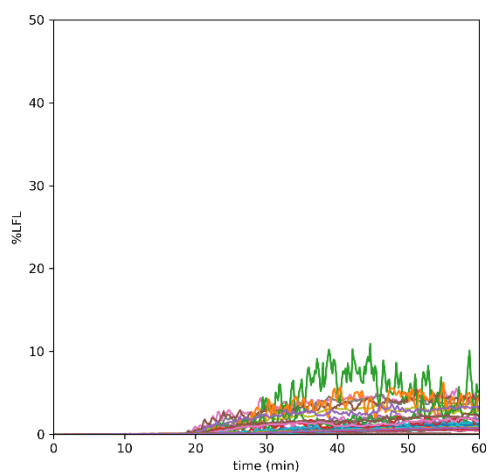
Measurement 7-1
50 dm³/h³



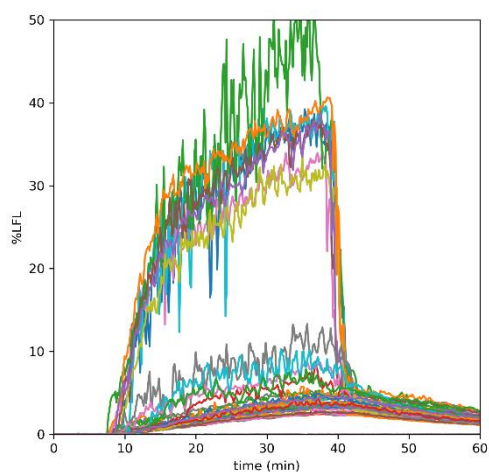
Measurement 7-3
300 dm³/h³



Measurement 7-2
100 dm³/h³



Measurement 7-4
1000 dm³/h³



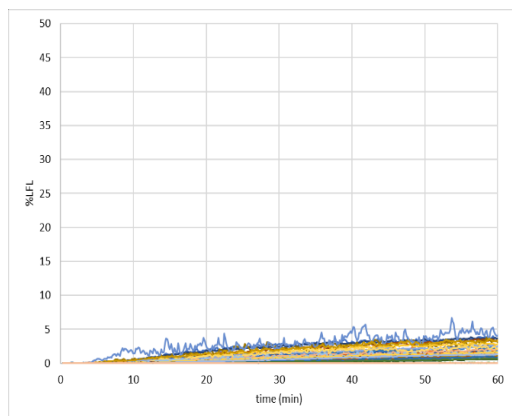
Natural gas

Configuration 8/0.5

Measurements 8-1 to 8-4 Extract ventilation rate 0.5

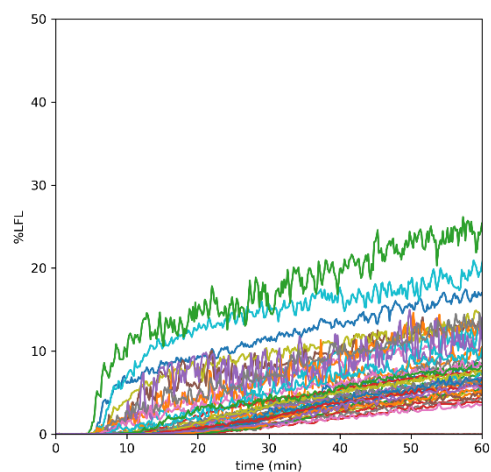
Measurement 8-1

50 dm³/h³



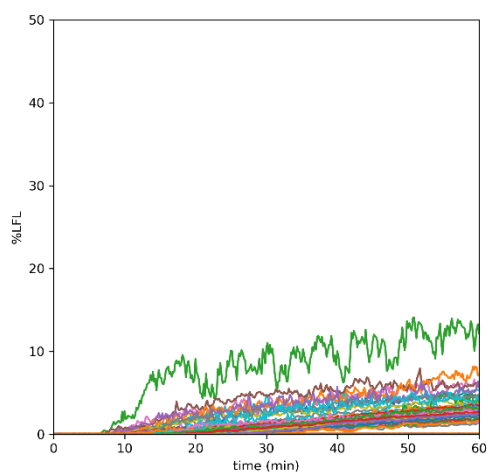
Measurement 8-3

300 dm³/h³



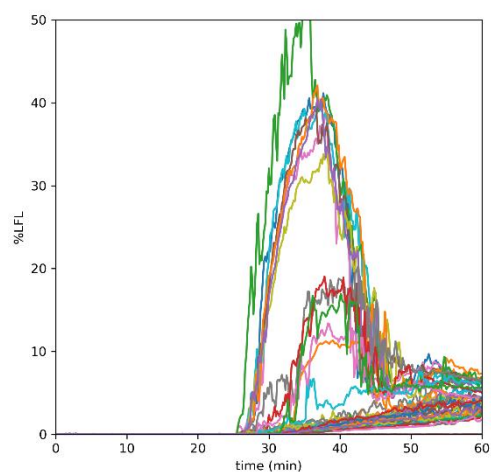
Measurement 8-2

100 dm³/h³



Measurement 8-4

1000 dm³/h³



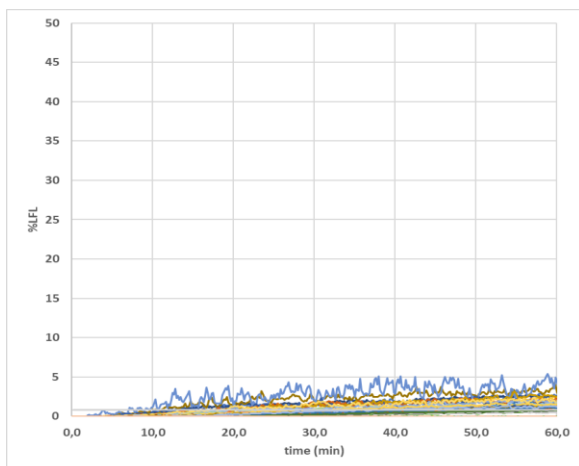
Natural gas

Configuration 8/1

Measurements 8-1 to 8-4 ventilation rate 1 extract air

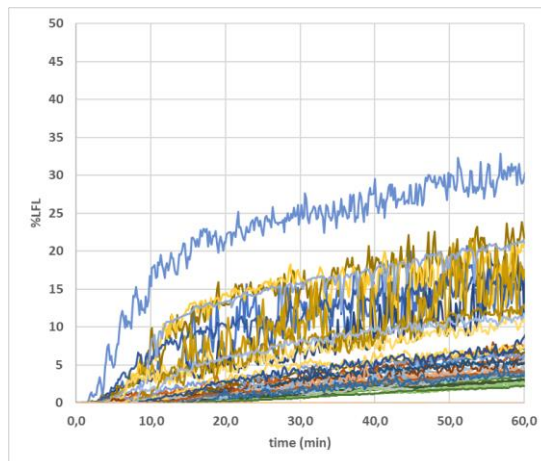
Measurement 8-1

50 dm³/h³



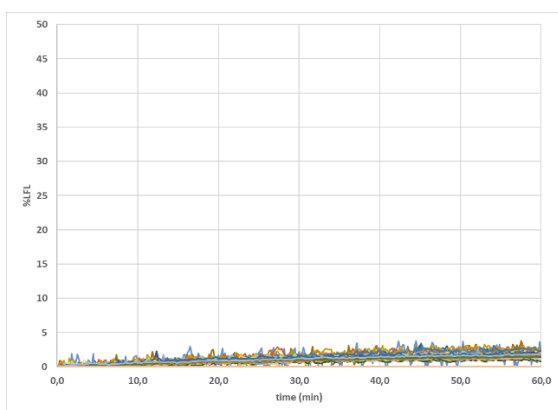
Measurement 8-3

300 dm³/h³



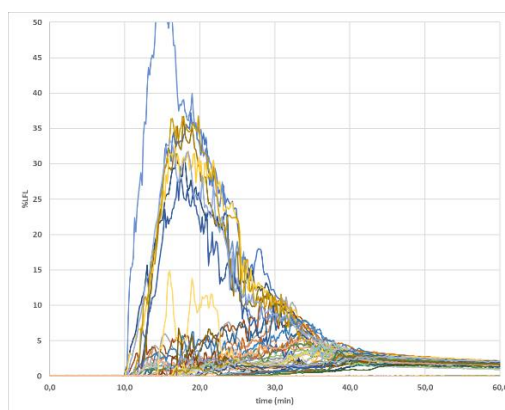
Measurement 8-2

100 dm³/h³



Measurement 8-4

1000 dm³/h³



VI Ventilation rate and final average concentration (calculated)

configuration	gas type	gas supply dm/h ³	ventilation rate determined by inter- and extrapolation	Final average concentration %LEL
3	hydrogen	50	0,14	25
3	hydrogen	100	0,40	17
3	hydrogen	300	0,15	132
3	natural gas	50	0,20	12
3	natural gas	100	0,15	31
3	natural gas	300	0,15	91
3	natural gas	1000	0,15	269
4	hydrogen	50	0,09	38
4	hydrogen	100	0,25	27
4	hydrogen	300	0,40	51
4	natural gas	50	0,40	6
4	natural gas	100	0,15	31
4	natural gas	300	0,08	163
4	natural gas	1000	0,10	375
7	hydrogen	100	0,2	34
7	hydrogen	300	0,2	100
7	natural gas	100	0,5	10
7	natural gas	300	0,2	69
7/0,5	hydrogen	300	3	7
7/0,5	natural gas	300	4	4
7/1,0	hydrogen	300	3	7
7/1,0	natural gas	300	4,8	3
8/0,5	hydrogen	1000	0,6	111
8/0,5	natural gas	1000	0,5	91
8/1,0	hydrogen	1000	1,7	40
8/1,0	natural gas	1000	1	47

VII Gas meter cabinet used for the setup

A wooden gas meter cabinet was used for this project with the dimensions, as specified in NEN 2768+A1. The dimensions of the gas meter cabinet are as indicated in section 5.1.1 "Internal dimensions" (low-rise building with gas connection. The gas meter cabinet is closed on three sides, with a door at the front with ventilation openings. Two ventilation grilles are placed in the door as indicated in section 4.2.2 "Minimum ventilation provision". The photo below shows this gas meter cabinet.



Figure 46: Gas meter cabinet before it was built into the container.

References

- [1] DNV GL, “Rapport proefopstelling verspreiding waterstof in de meterkast,” 2020.
- [2] Hy4Heat, Work Package 7; Safety Assessment: Experimental Testing – Domestic Pipework Leakage..
- [3] DNV, “Investigation into the cross-sensitivity of domestic carbon monoxide alarms to hydrogen,” in *ICHS*, 2021.
- [4] DNV, “Verkennd metingen naar gebruik CO melders voor waterstof detectie - Hydrogreenn,” 2019.
- [5] HyDelta 1.0. A. van de Noort (DNV), “WP1a– Veiligheid en waterstof; D1a_2 –Opzet QRA, effect van ventilatie bij kleine lekkages en aanbevelingen voor maatregelen,” HyDelta, 2022.
- [6] DNV, “Gedrag van waterstof bij lekkages in het distributienet,” 2020.
- [7] KIWA, DNV, “D1a_1_HyDelta_Uitkomsten_onderzoeken_UK,” 2022.