

International Conference on Hydrogen Safety 2023

The Effect of Natural Ventilation Through Roof Vents  
Following Hydrogen Leaks in Confined Spaces





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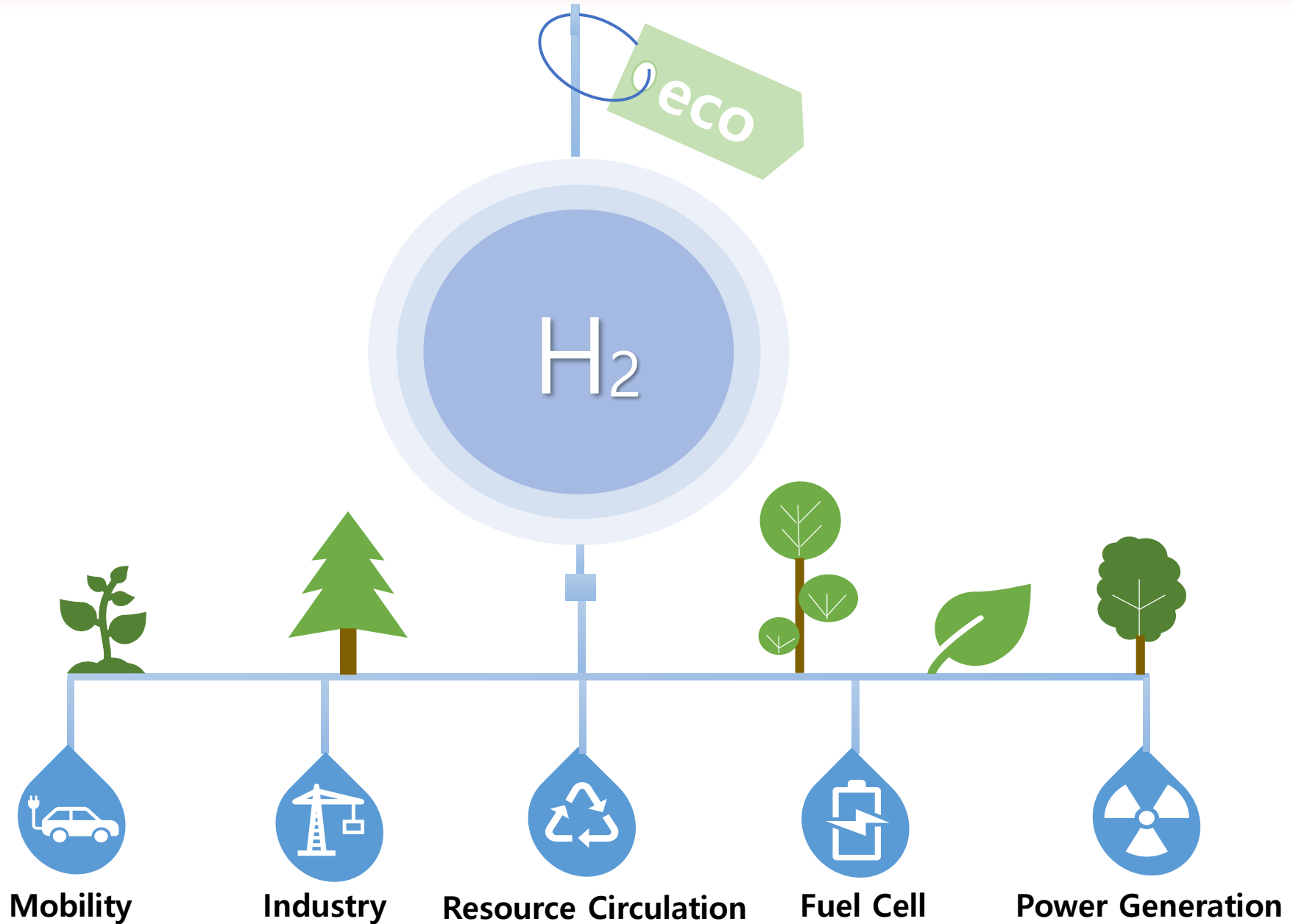
## ● Conclusion

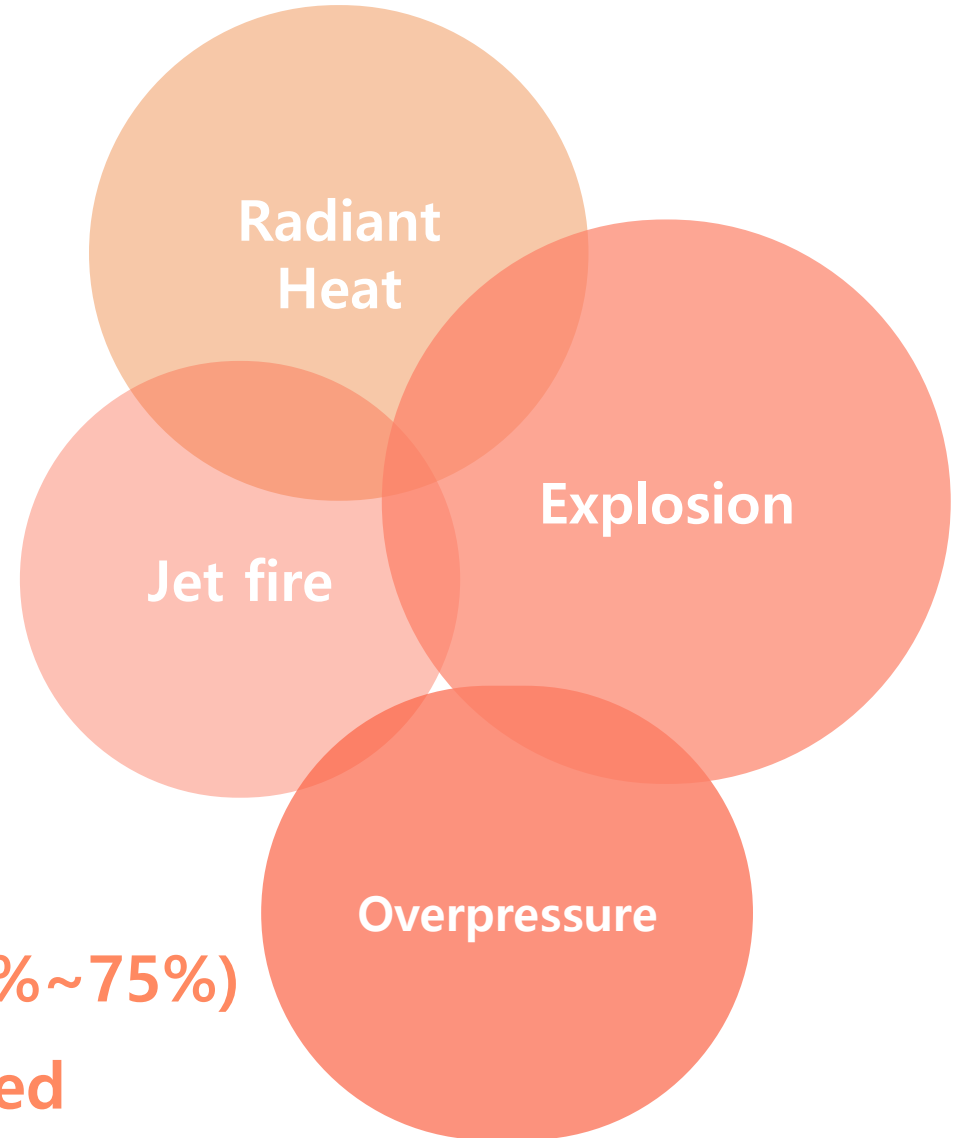
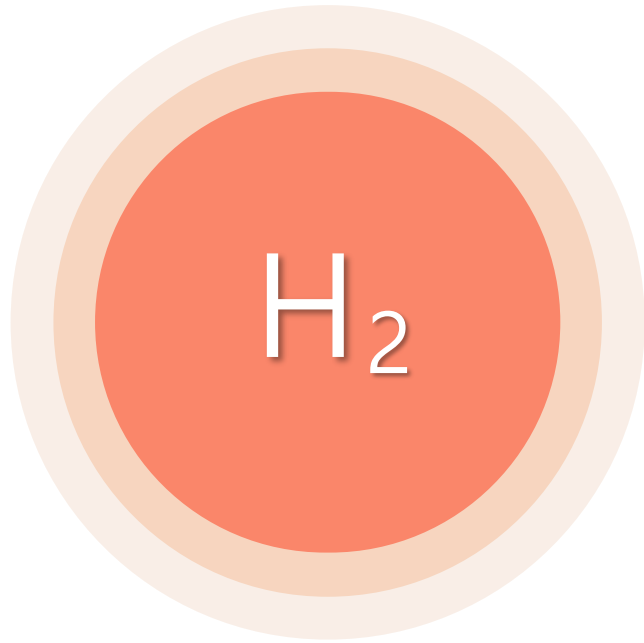






# Introduction of Hydrogen

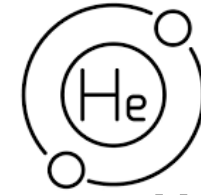




- Flammable gas
- Wide range of inflammability (4%~75%)
- Very fast flame propagation speed

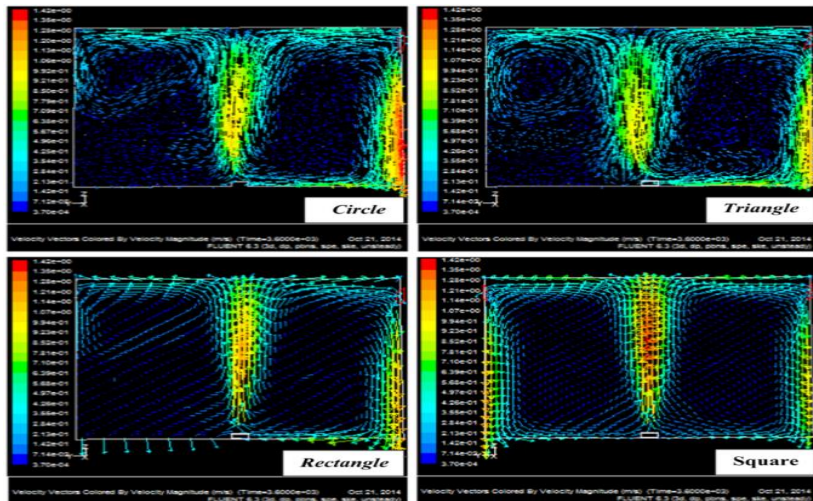
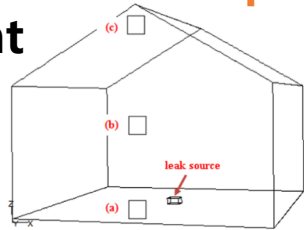


**Safety Matters**



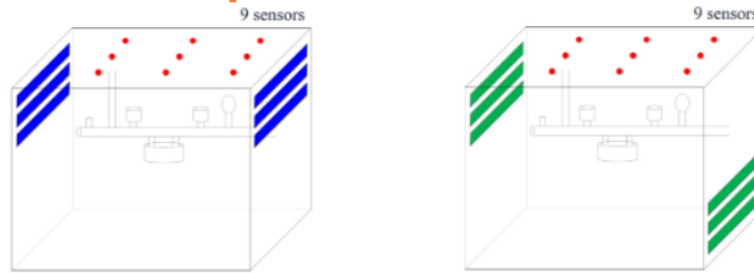
Yassine et al.(2015)

Ventilation performance according to the **shape** and **height** of the vent



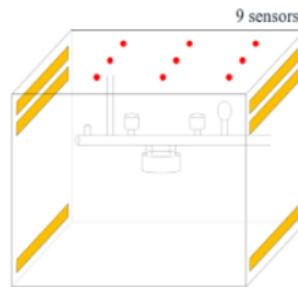
Lee et al.(2022)

Ventilation performance according Various **combination** of vent to vent **position** and size



Up Vent

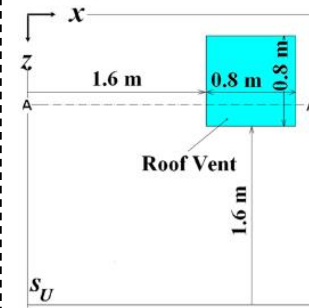
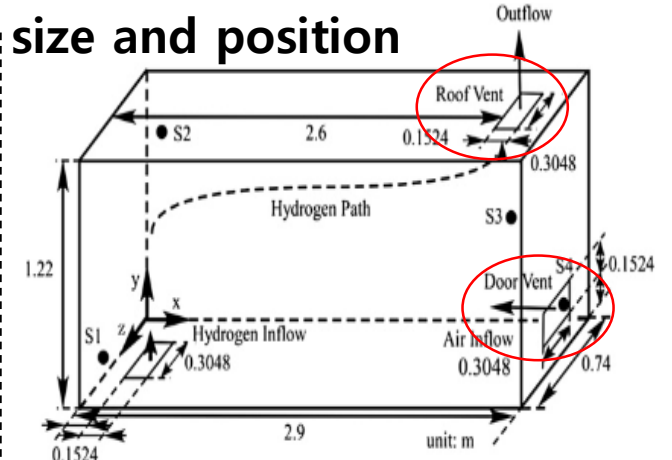
Cross Vent



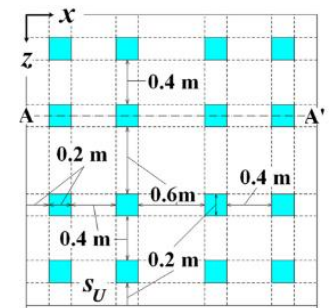
Up-Down Vent

Matsuura et al.(2009)

Ventilation performance according Various **combination** of vent to vent **position** and size

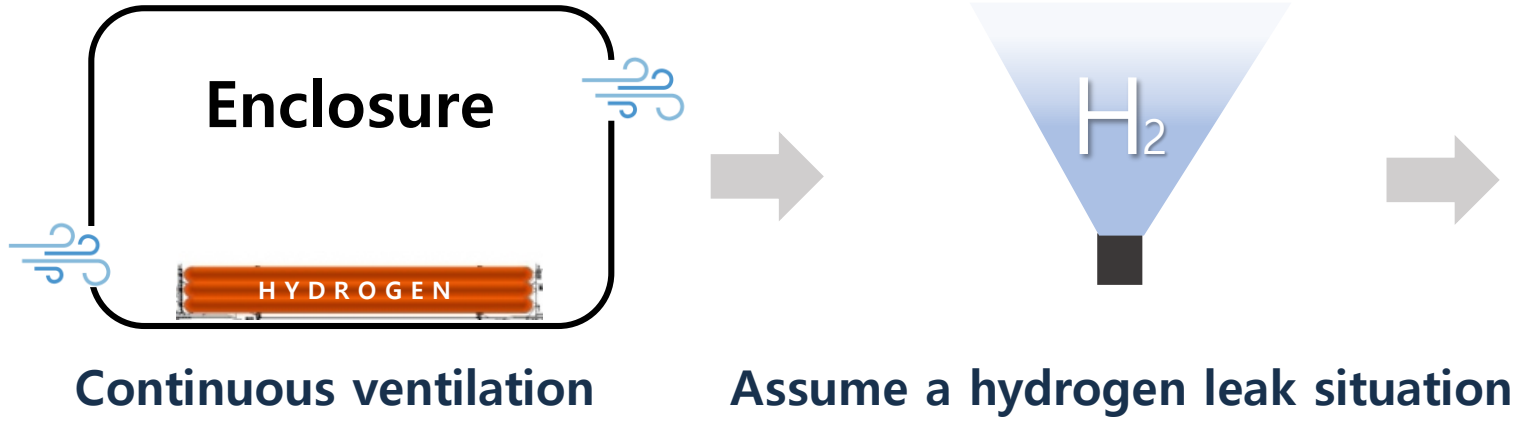


Large single vent

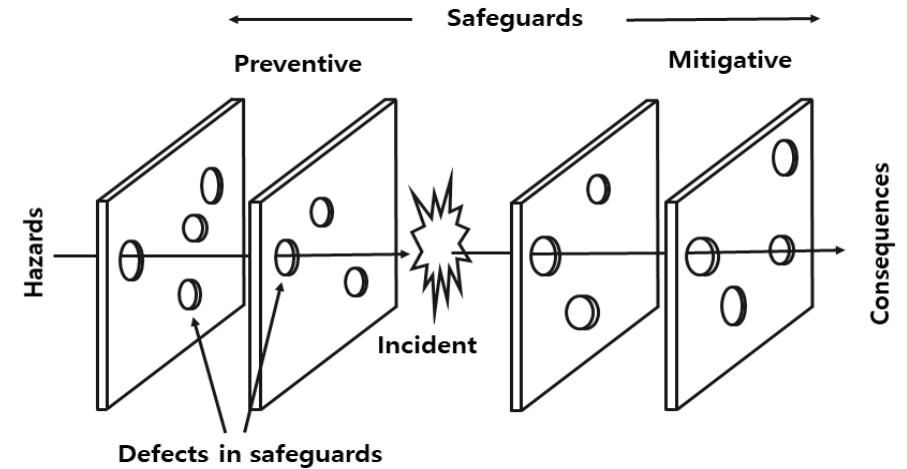
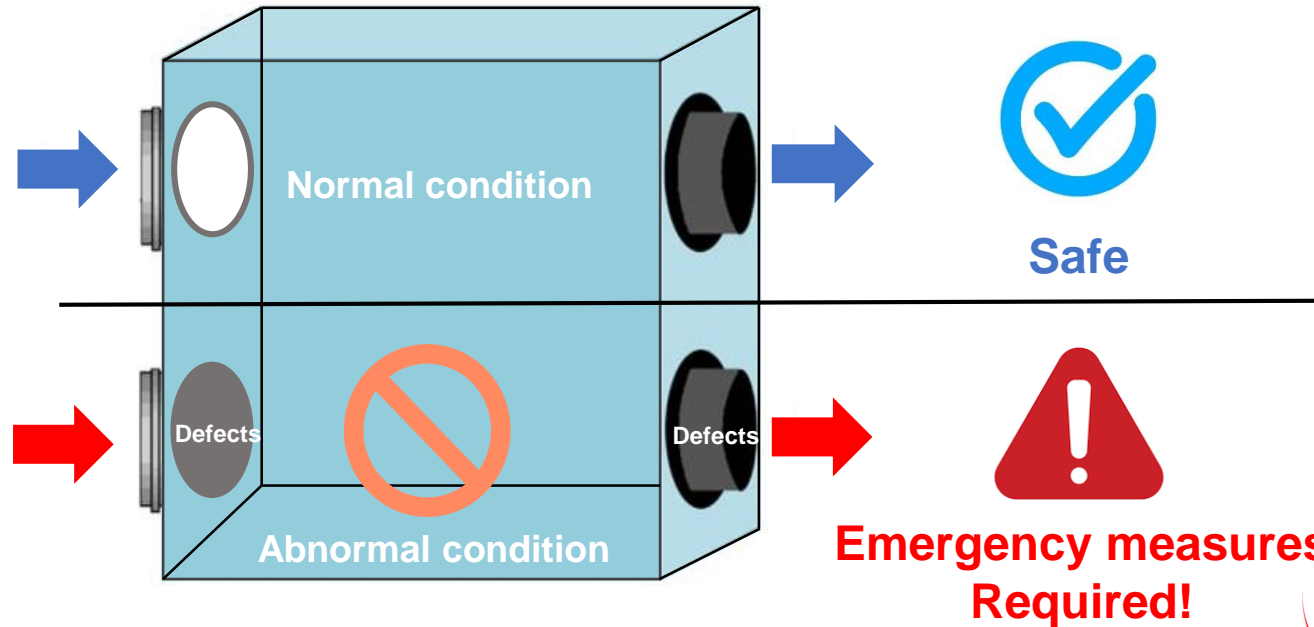
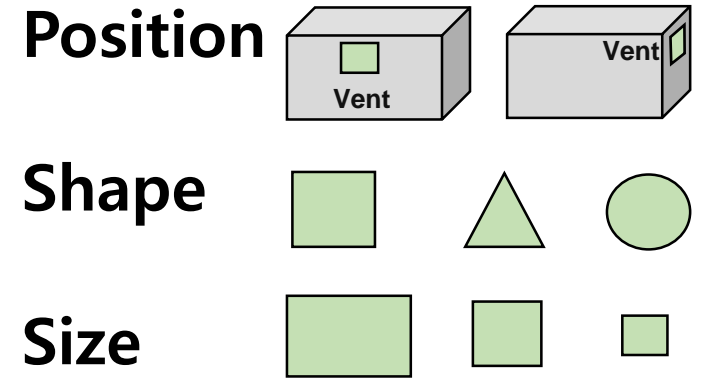


Distributed small vent

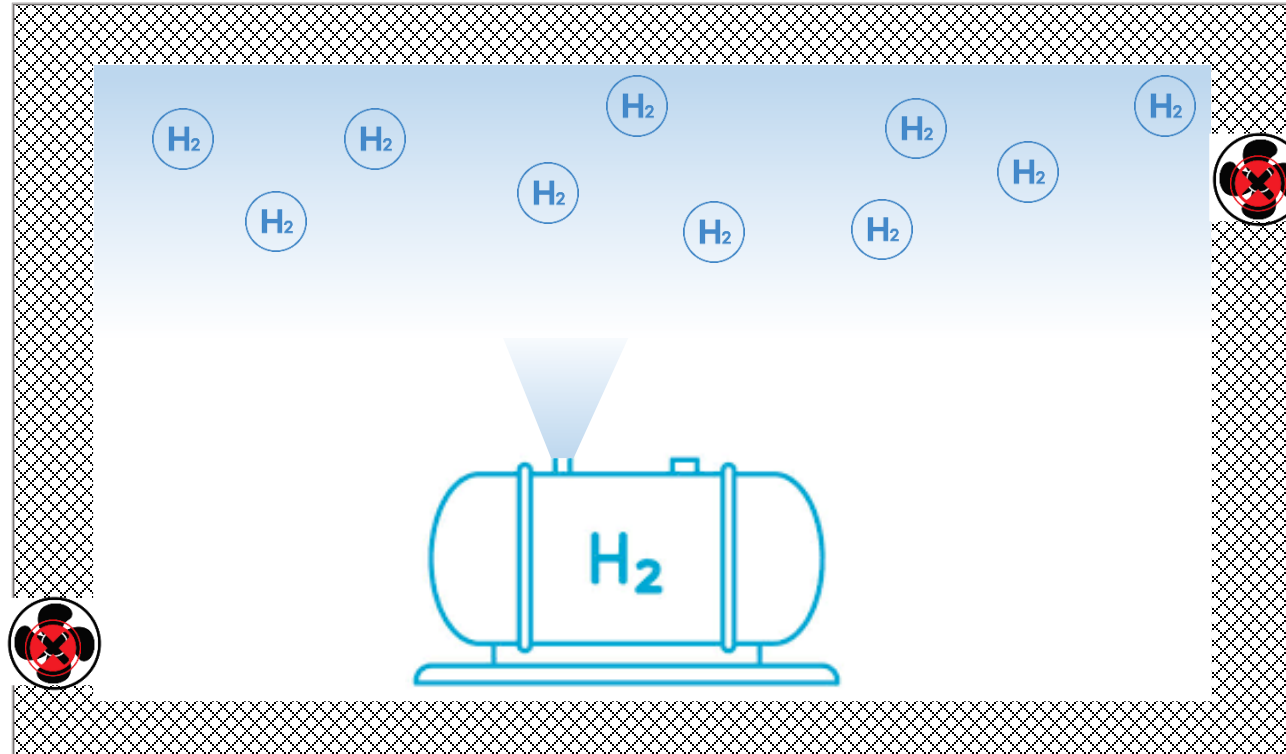
Previous research



Variable of vent



Swiss cheese model  
(Daniel A.Crowl et al, 2019)



- ❖ It is possible that the **natural and forced ventilation system is defective** and ventilation is not properly carried out.
- ❖ In this case, an **inappropriate response** (ex, the possibility of releasing electrical energy) may lead to an explosion due to the **low MIE of hydrogen**.
- ❖ Therefore, it is necessary to consider emergency measures to **safely resolve** the leakage after it has **already accumulated concentration** due to **limited ventilation**

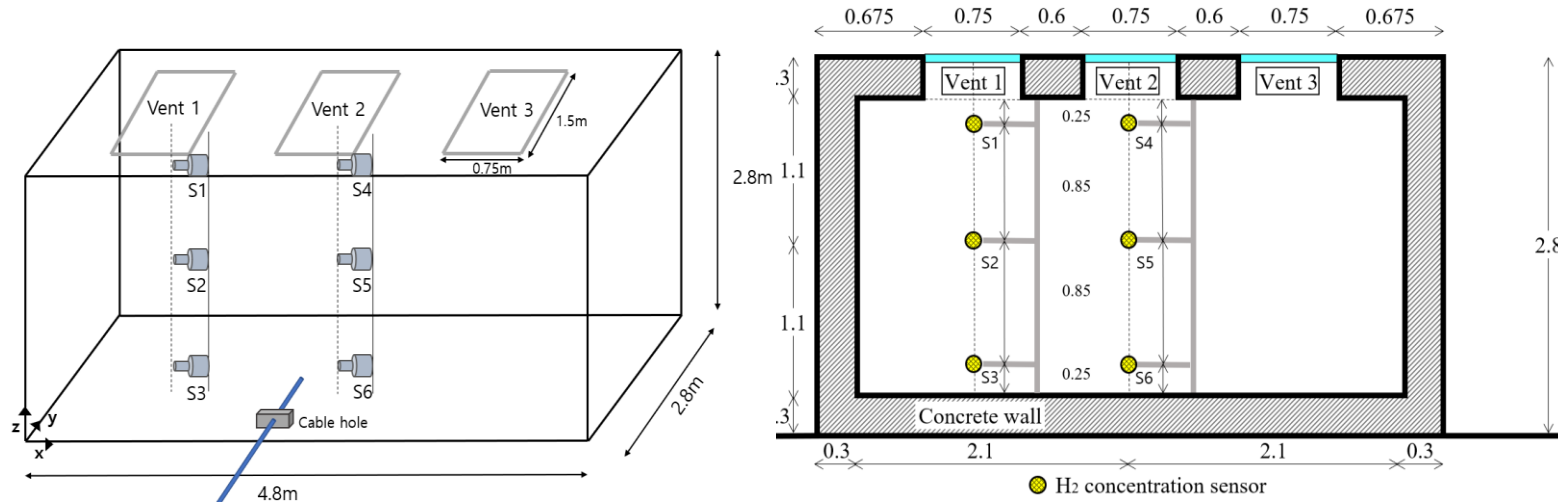




## Experimental Setup

### Experimental objective

- ❖ When hydrogen accumulates in a closed space, determines the time it takes for the internal hydrogen concentration to fall below the standard value through the natural roof ventilation opening.



Schematics of the experimental setup

	X(m)	Y(m)	Z(m)
S1	1.05	1.4	1.95
S2	1.05	1.4	1.1
S3	1.05	1.4	0.5
S4	2.4	1.4	1.95
S5	2.4	1.4	1.1
S6	2.4	1.4	0.25

Locations of six hydrogen concentration sensors

### Equipment

Hydrogen supply system  
(MFC)

- Company: MKP
- Model: TSM-D260
- Flow rate: 2,000~5,000slm
- Working pressure: 8barg

Hydrogen concentration  
sensor

- Company: SGX sensortech
- Model: VQ600

### Characteristics

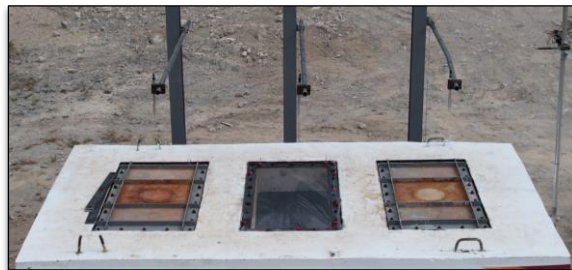
### Specifications of the experimental setup



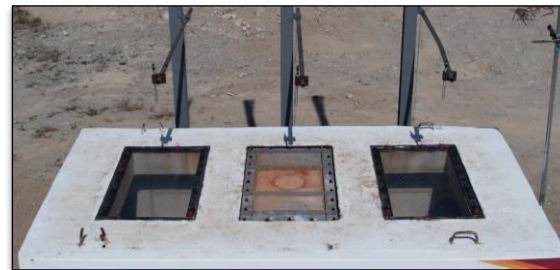


## Cases for nine scenarios investigated in our experiment

	The size of leak hole (inch)	Vent opening position	Vent area (m <sup>2</sup> )	Vent area (Based on floor area)	Leakage flow rate(L/min)
Case1	1/2	Center	1.125	12%	600
Case2		Both side	2.25	24%	
Case3		Whole	3.375	36%	
Case4	1/4	Center	1.125	12%	200
Case5		Both side	2.25	24%	
Case6		Whole	3.375	36%	
Case7	3/8	Center	1.125	12%	400
Case8		Both side	2.25	24%	
Case9		Whole	3.375	36%	



Center open  
(Case 1, 4, 7)



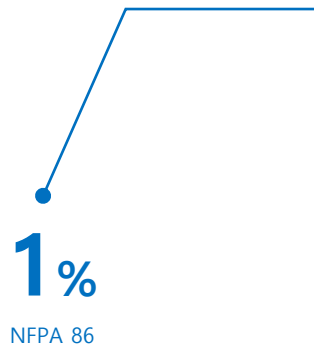
Both side open  
(Case 2, 5, 8)



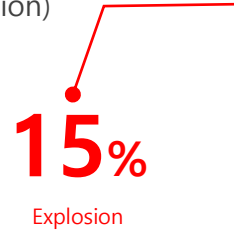
Whole open  
(Case 3, 6, 9)



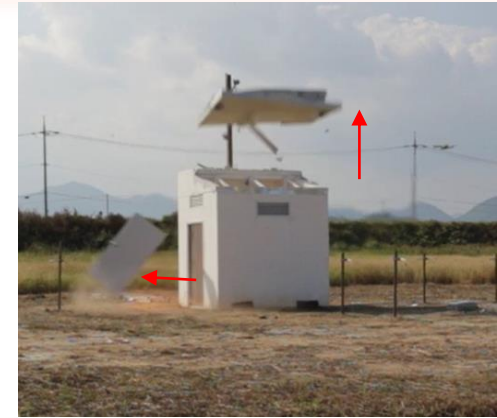
## Experiment Results (Leak Characteristics)



**NFPA 86**  
LEL 25%  
(Management concentration)



**Strong Explosion Start Point**  
(By our previous experiment)



# HYDROGEN CONCENTRATION

0%

4%  
LEL

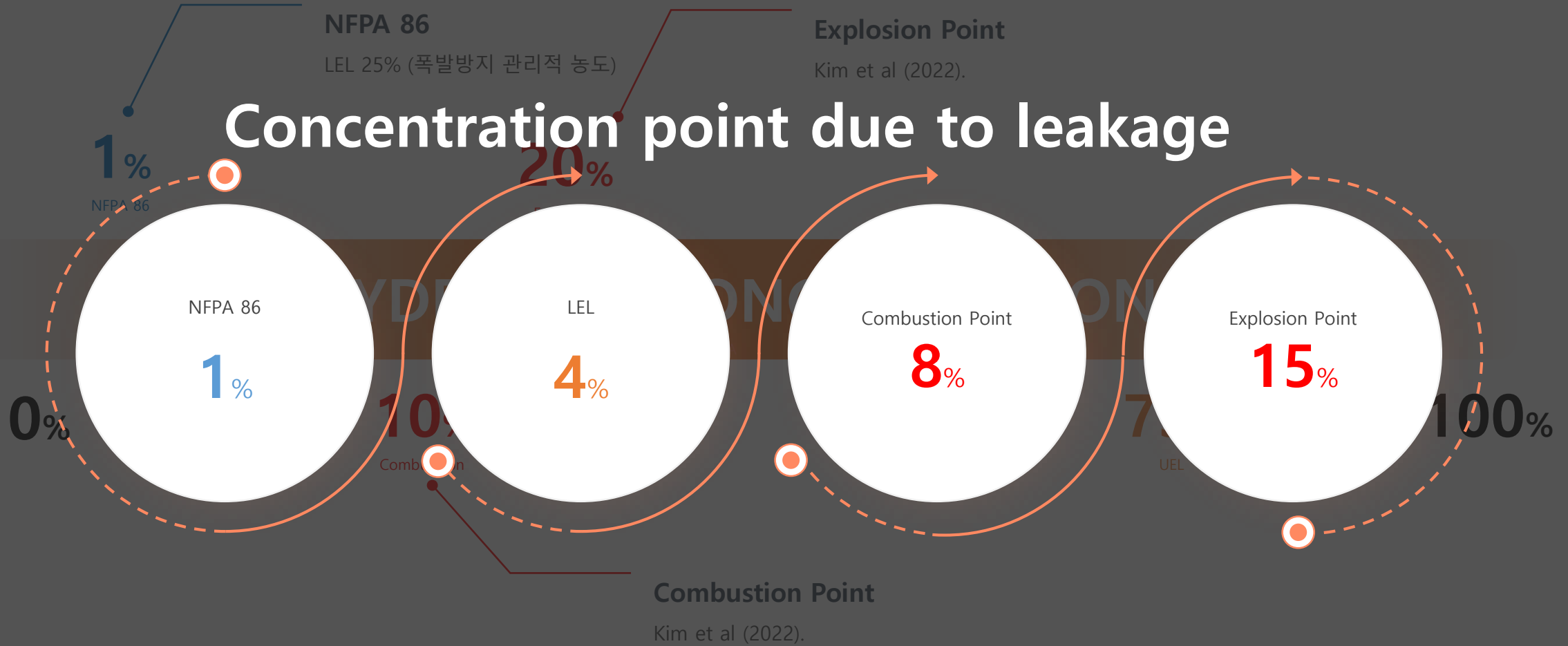
8%  
Combustion

**Fast Combustion Start Point**  
(By our previous experiment)

75%  
UEL

100%

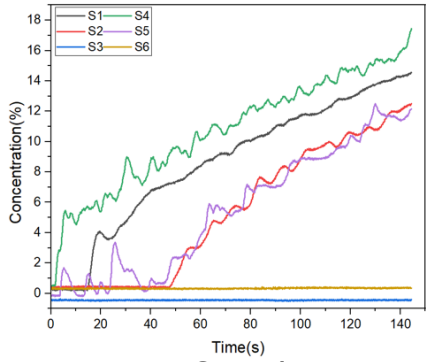




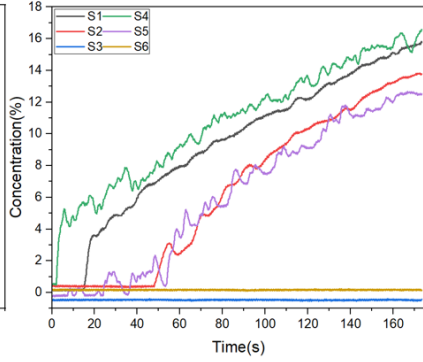


# Experiment Results (Leak Characteristics)

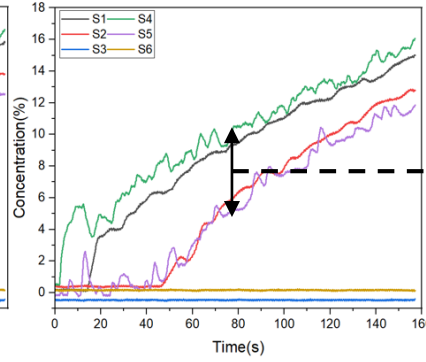
## 1/2 Inch



Case 1



Case 2



Case 3

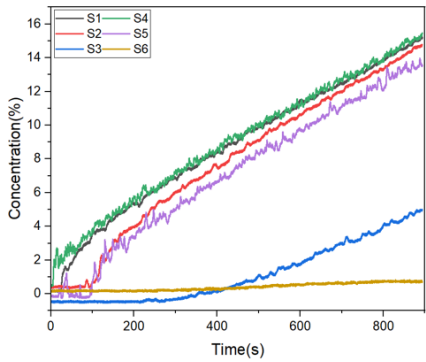
Leakage speed

Slow

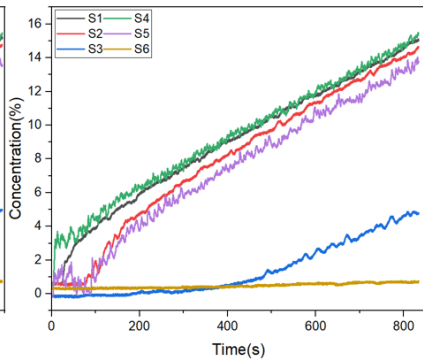
## 1/2 Inch

	Case1	Case2	Case3	Avg
1%	1.9s	2.05s	2.1s	2.0s
4%	4.4s	3.7s	5.25s	4.4s
8%	29.3s	48.4s	44.2s	40.6s
15%	127s	144.5s	138.4s	136.6s

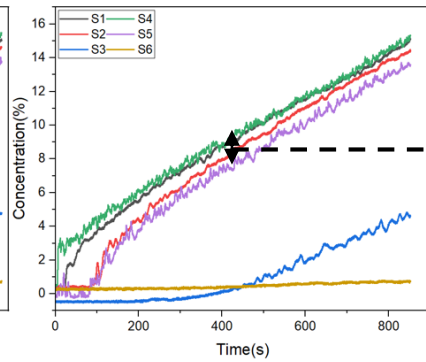
## 1/4 Inch



Case 4



Case 5



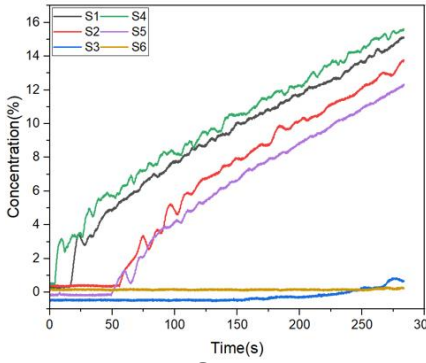
Case 6

Fast

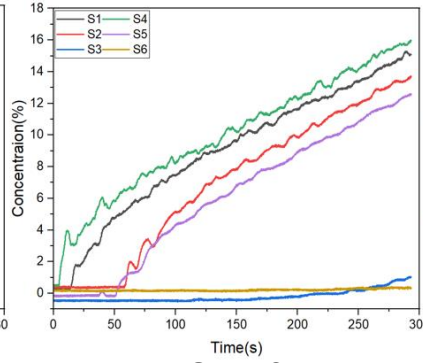
## 1/4 Inch

	Case4	Case5	Case6	Avg
1%	5.9s	4.9s	5.1s	5.3s
4%	105s	71.2s	68.2s	81.4s
8%	363.8s	304s	312s	326.6s
15%	851.6s	811.2s	825s	829.3s

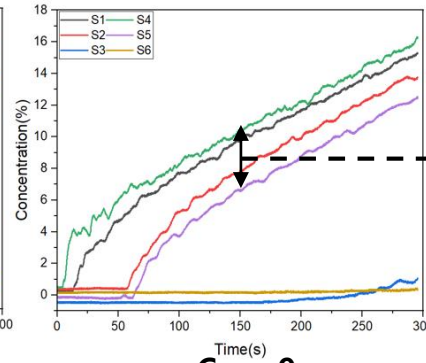
## 3/8 Inch



Case 7



Case 8



Case 9

Midium

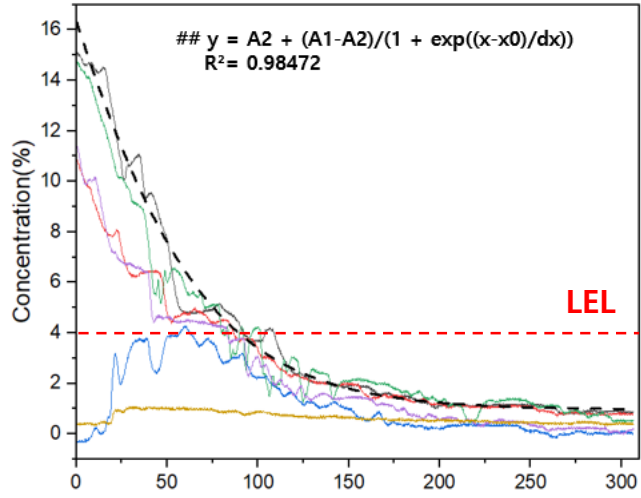
## 3/8 Inch

	Case7	Case8	Case9	Avg
1%	4.4s	5s	6.2s	5.2s
4%	27.6s	23.8s	12.4s	21.3s
8%	87.6s	86.2s	92.4s	88.7s
15%	259.2s	265.7s	267.6s	264.2s

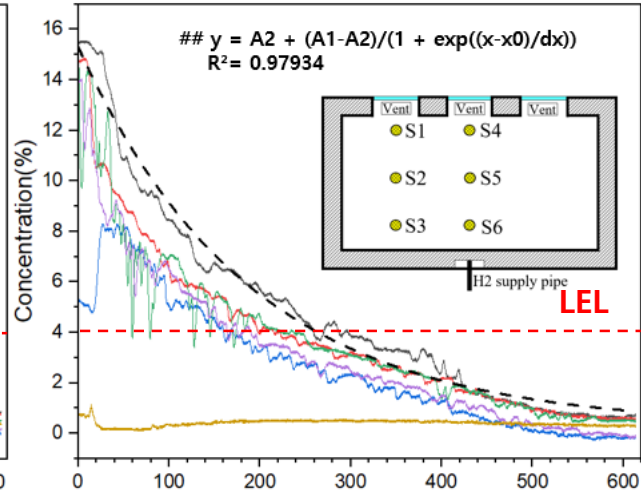


## Hydrogen concentration change over time for a vent area corresponding to 12% of the floor size

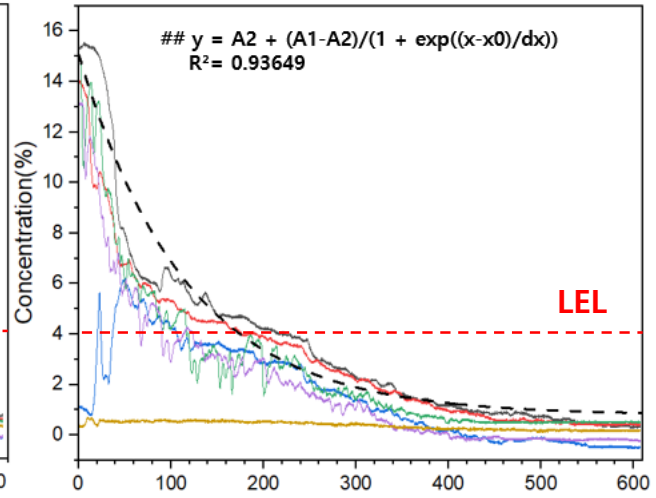
— S1 — S2 — S3 — S4 — S5 — S6 - - - Fitting Curve up to 4%



Case 1

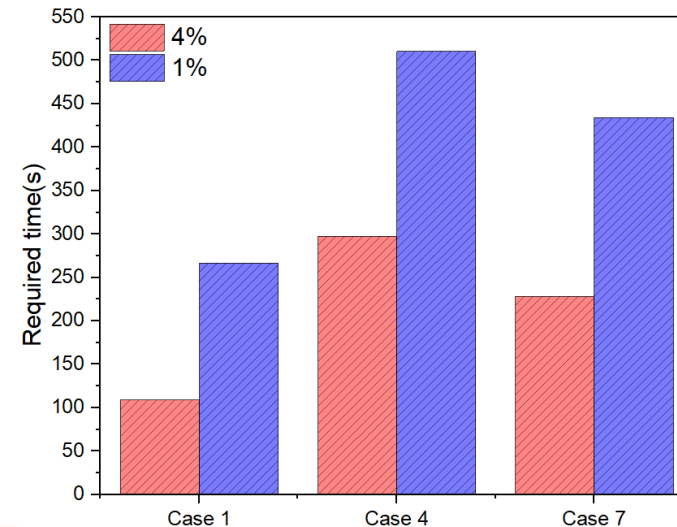


Case 4



Case 7

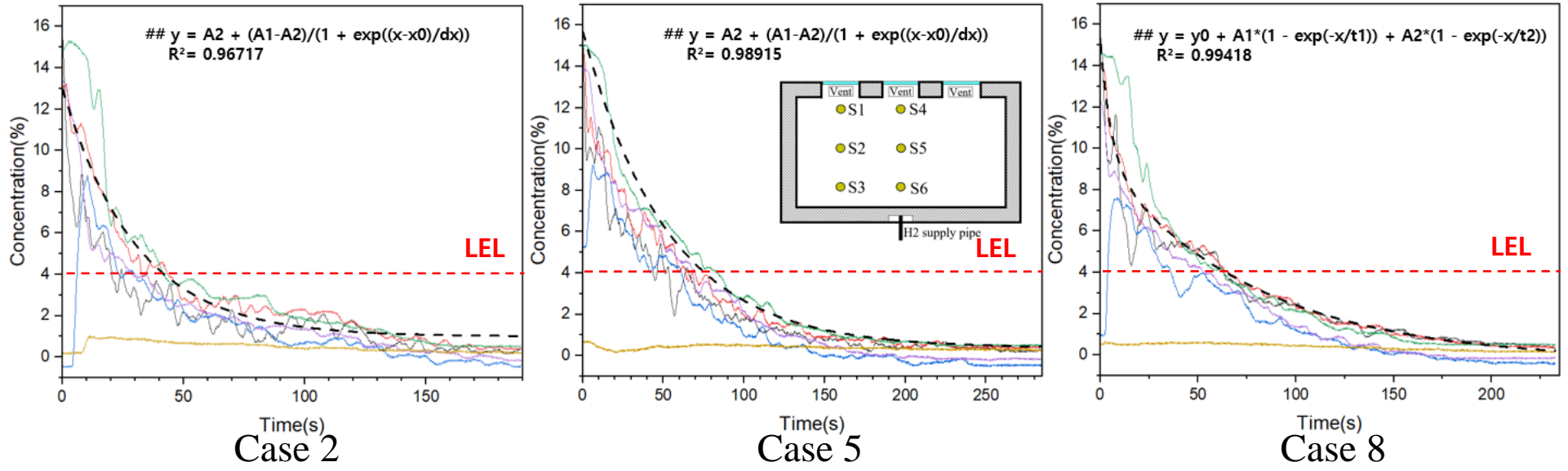
	12%		
	Case1	Case4	Case7
4%	108.8	297.6	228.4
1%	266.6	510.4	434



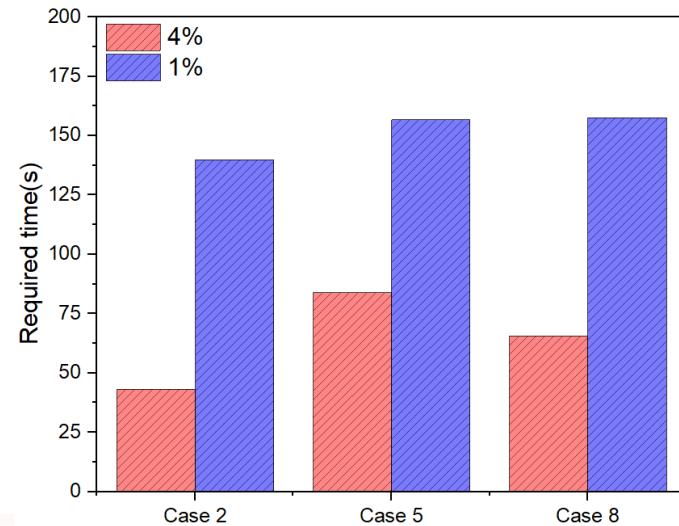


## Hydrogen concentration change over time for a vent area corresponding to 24% of the floor size

— S1 — S2 — S3 — S4 — S5 — S6 - - - Fitting Curve up to 4%



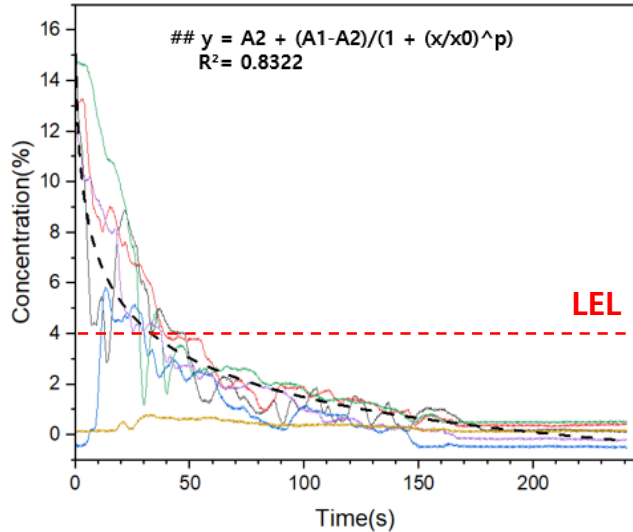
	24%		
	Case2	Case5	Case8
4%	43.2	83.8	65.6
1%	139.8	156.6	157.6



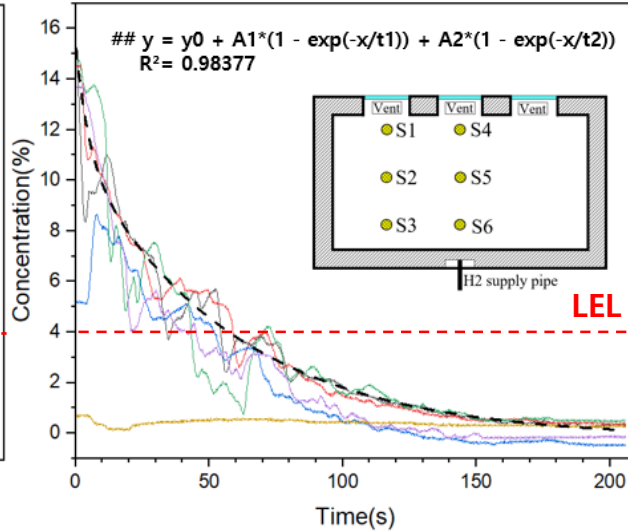


## Hydrogen concentration change over time for a vent area corresponding to 36% of the floor size

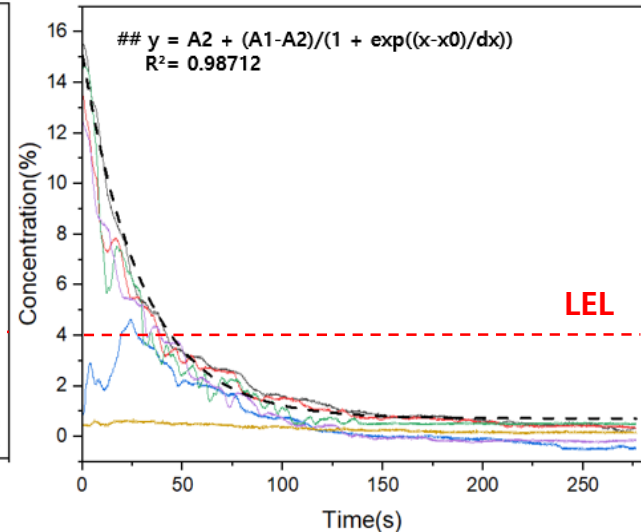
— S1 — S2 — S3 — S4 — S5 — S6 - - - Fitting Curve up to 4%



Case 3

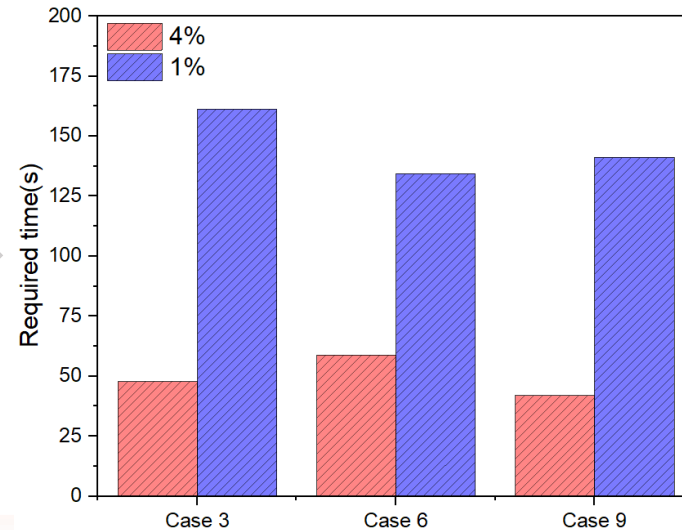


Case 6



Case 9

	36%		
	Case3	Case6	Case9
4%	47.8	58.8	42
1%	161.2	134.4	141.2

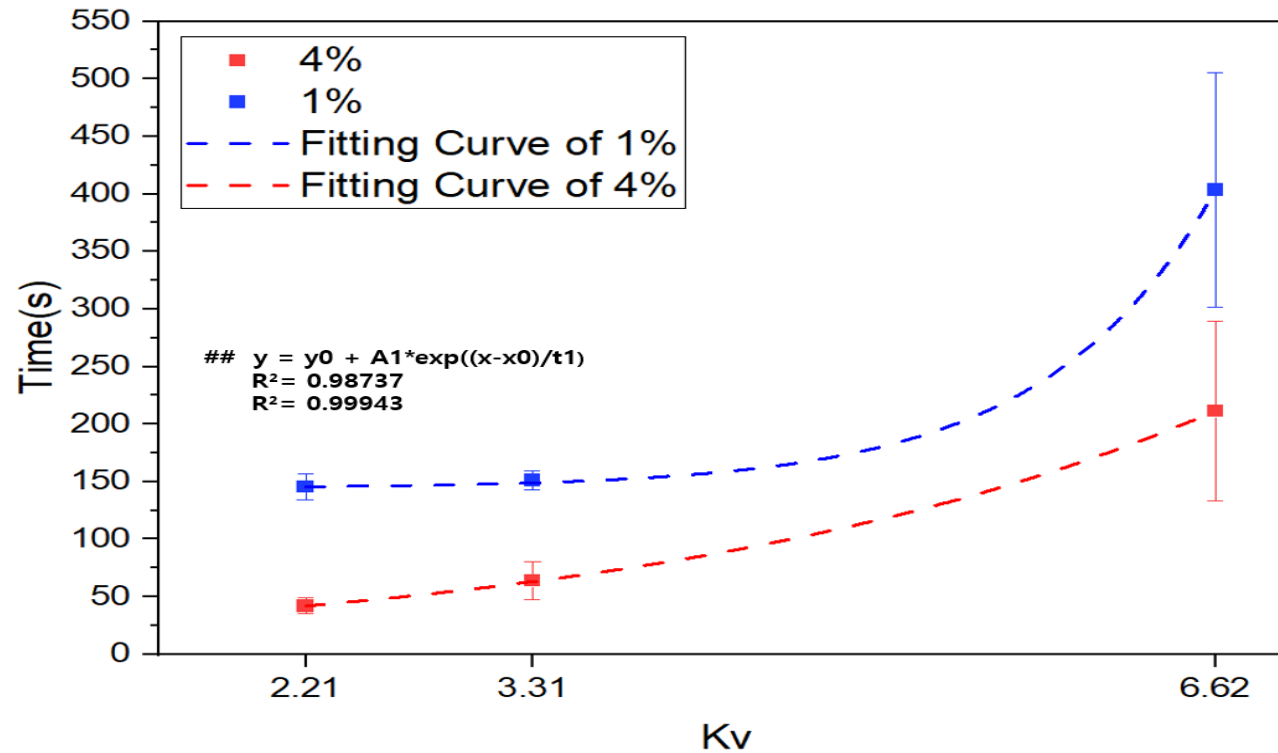






## Venting coefficient

$$K_v = V^{2/3} / A_v \quad V = \text{Internal volume(m}^3\text{)}, A_v = \text{Vent area(m}^2\text{)}$$



Time to target concentration based on venting coefficient ( $K_v$ )



## Conclusion

Results obtained by performing natural ventilation by opening the roof vent after accumulating the concentration of hydrogen in the enclosed space through this study,

- 1** Depending on the **size of the leakage hole** through which hydrogen leaks, the time to reach the concentration that could explode was **clearly different**, and the **larger the size of the leakage hole, the faster it reaches**.
- 2** Stratification in the enclosed space varied depending on the **size of the leakage hole and the leakage pressure**, and it is judged that **explosion safety measures are needed** considering this.
- 3** In the case of ventilation time, **the smaller the area of the vent**, the higher the dependence on the external environment, making it **difficult to predict** the normal ventilation time, and it **also takes a long time**.
- 4** As the area of the ventilation hole increased, the ventilation time and deviation decreased, and the ventilation time of the **medium and largest** ventilation holes showed a **similar range**.



# THANK YOU

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