# Performance evaluation of air-purifying photocatalytic commercial devices: laboratory and pilot scale tests


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***SafePHOTOCAT project collaborators :***

- *IPREM, project coordinator*
- *Academic laboratories : IPREM, C2MA ARMINES*
- *Technical research center : NOBATEK*

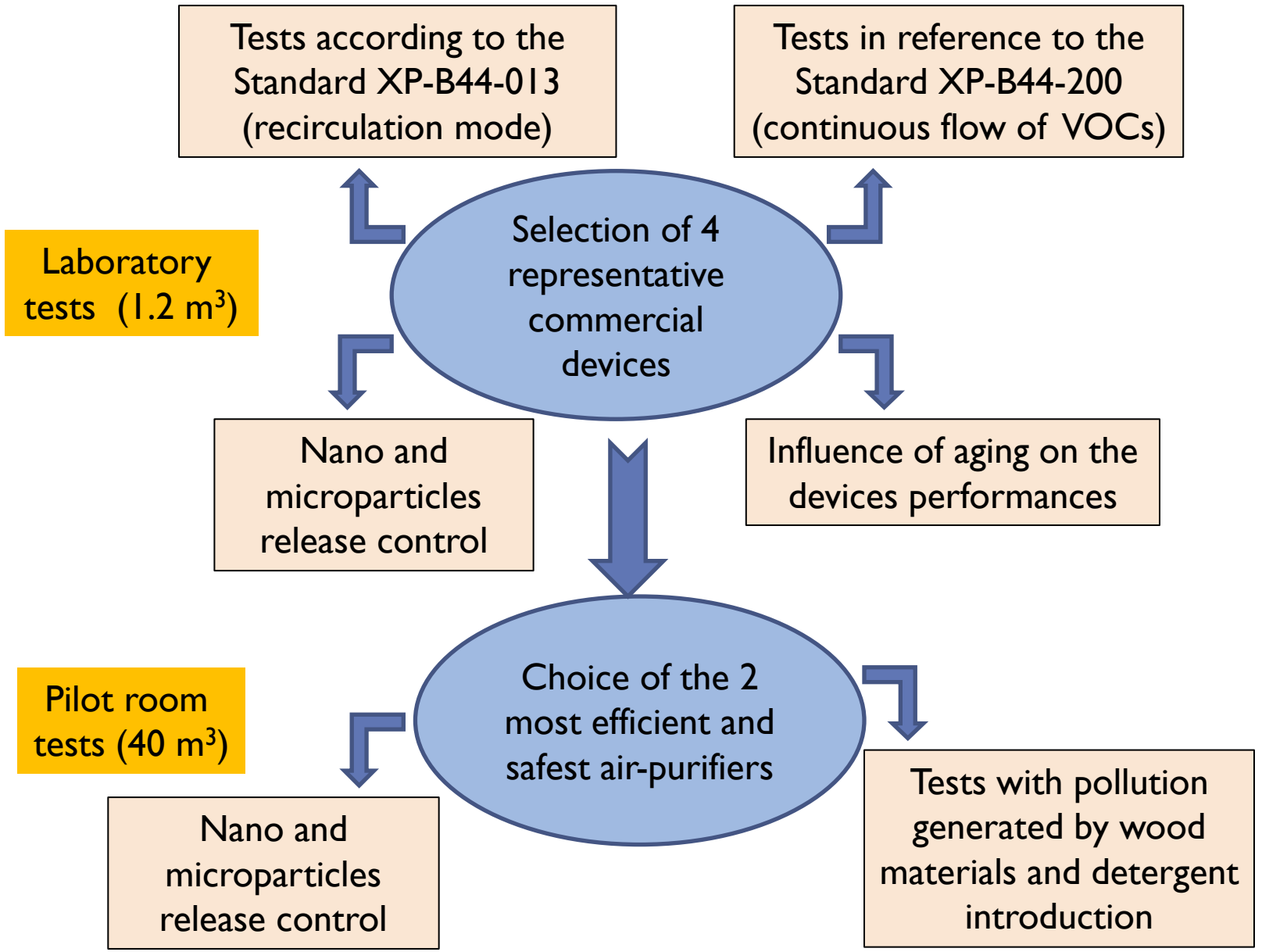
# Context of the study

- A lot of air-purifying devices with photocatalytic functions are now available in the French/European Market
- Are these devices really efficient and safe ?

- How are these systems tested ?
- Information are not very clear in the advertisements
- In some cases, reference to tests carried out in various laboratories, but not **standardized**

Need for normalized tests for photocatalytic air purifiers
Need for data in real conditions of use

# Aim of the study

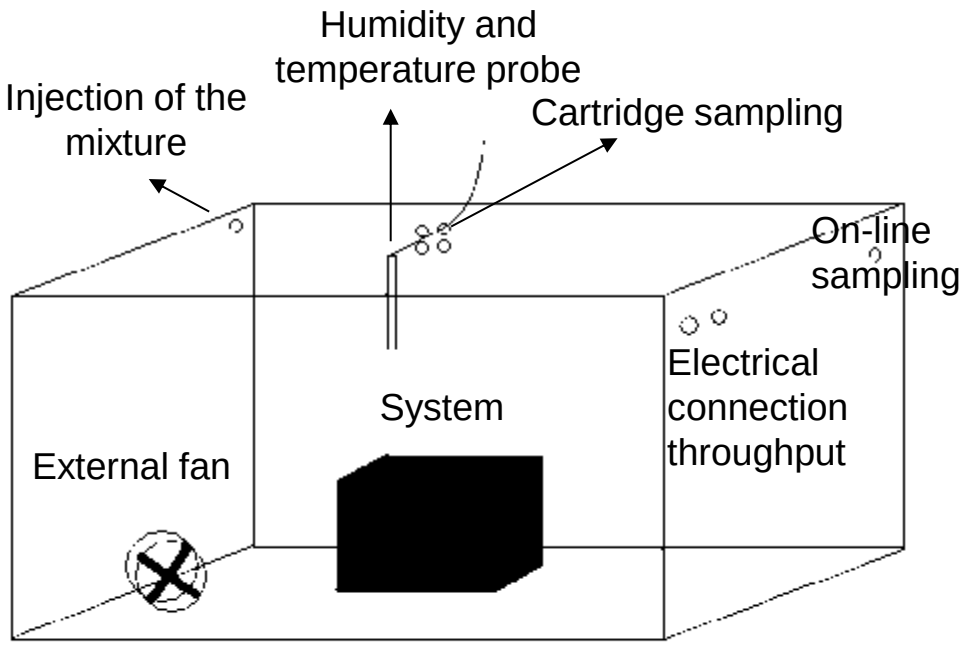


# Principle of the standard closed chamber test (AFNOR XP B44-013 – French standard)

This protocol applies solely **to photocatalytic systems alone or to combined systems that include a photocatalytic function.**

## Conditions

- Pollutants : acetaldehyde, acetone, n-heptane, toluene (formaldehyde in project for CEN)
- Indoor air at two concentrations
  1 : 250 ppbv/pollutants
  (check for by-products)
  2 : 1000 ppbv/pollutant
  (check for $CO_2$)
- Industrial issue : concentration depends on the application.
- Starting humidity and temperature : 50 ± 5 % RH and 22 ± 2 ° C (may be varied)
- Total sampling volume : < 5% of the total chamber volume (50 L/m³)




Closed chamber : **V >1 m³**
System : flow max **1000 m³/h**
**Vsystem/Vchamber ≤ 0.25**
(< 0.1 in project for CEN)

# Principle of the standard chamber test (AFNOR XP B44-200 – French standard)

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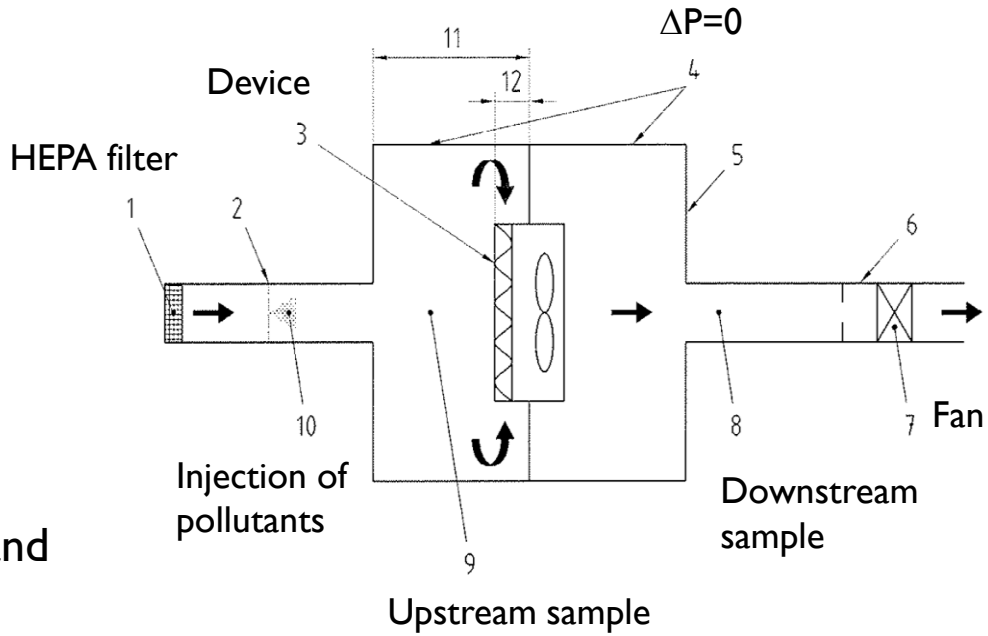
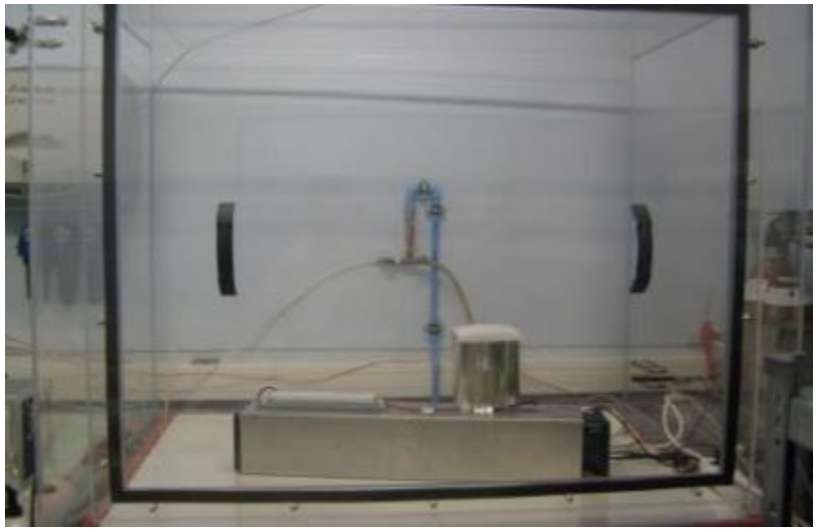
## Conditions

- Pollutants : acetaldehyde, acetone, n-heptane, toluene (generated continuously)
- Concentrations : 250 to 500 ppbv/pollutants (check for by-products : $O_3$, HCHO, CO, NO, $NO_2$)
- Humidity and temperature : 50 ± 5 % RH and 22 ± 2 ° C
- Filtration of introduced air : HEPA filter (NF EN 1822-1 and CA filter)

This protocol applies **to all kind of autonomous air purifiers**. Measurement of device efficiency with various contaminants :
Gas : mixture of VOCs → only contaminants in relation with our project.



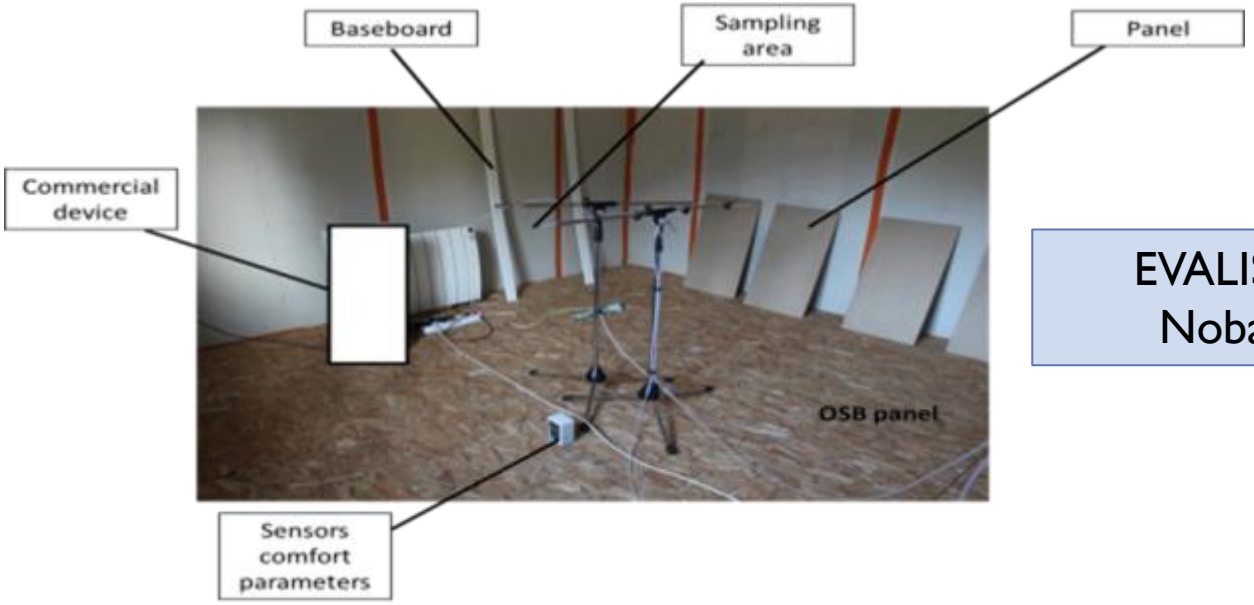
# Chamber test IPREM and pilot room NOBATEK



IPREM : 1.17 $m^3$

Chambers validation :

- No VOCs release : <5 ppbv on 24 h
- Good airtightness : <10% COV leak on 24 h




EVALIS chamber in Nobatek : 40 $m^3$

# Analytical equipment used

| PARAMETERS | ANALYTICAL EQUIPEMENT |
|---|---|
| **Primary VOC** (acetaldehyde, acetone, n-heptane, toluene) | **GC-PID /on line** (LD = 2 to 17 ppbv) |
| **CO-$CO_2$** : VOC mineralisation | **GC-methanizer-FID / on line** (LD=1ppmv) |
| **Secondary species and VOC in the pilot room** | **Formaldehyde :** **adsorption on cartridges +HPLC-UV** (LD=4ppbv) **adsorption on SPME fibers+GC-MS or GC-FID** (LD<4ppbv) **VOC:** adsorption on cartridges +ATD-GC-MS (LD=1ppbv) **Ozone :** adsorption on cartridges +HPLC-UV (LD O3<0.5 µg/$m^3$) |
| **Nano and microparticles** | **ELPI (Electric Low Pressure Impactor) : 13 stages : particles diameter from 7 nm to 10 µm** (detection threshold: 0.5 part. $cm^{-3}$ for 380 nm class, 7 part. $cm^{-3}$ for 100 nm class) |

# Standardized tests (AFNOR XP B44-013) with the 4 selected commercial devices

| Device | Irradiation source | Photocatalysis only | Control test without VOC | | Photocatalytic test with 4 VOC (24 hours maximum) | | |
|---|---|---|---|---|---|---|---|
| | | | VOC release | $CO_2$ produced | VOC removal | Mineralization | End by-product |
| **D1** | **UVA** | **Yes** | **No** | **Yes** | **> 99%** | **complete** | **No** |
| **D2** | **UVC** | **No** (ionization, filtration/activated carbon) | **Yes** | **No** | **<20%** | **<5%** | **HCHO** |
| **D3** | **UVC** | **No** (filtration/ activated carbon) | **No** | **Yes** | **> 99%** | not determined | **No** |
| **D4** | **unspecified** | **No** (ionization, filtration) | **Yes** | **No** | **48 to 99%** | **<5%** | **HCHO** |

The devices could be ranked in two classes:

- **class 1 for efficient devices** : high VOCs elimination, extended mineralization, no by-product
- **class 2 for inefficient and unsafe ones** : by-product release even in the absence of VOCs, low VOCs removal and mineralization

Costarramone N., Kartheuser B., Pécheyran C., Pigot T., Lacombe S., *Catal. Today,* 252, 35-40 (2015)

# Example of photocatalytic device D1

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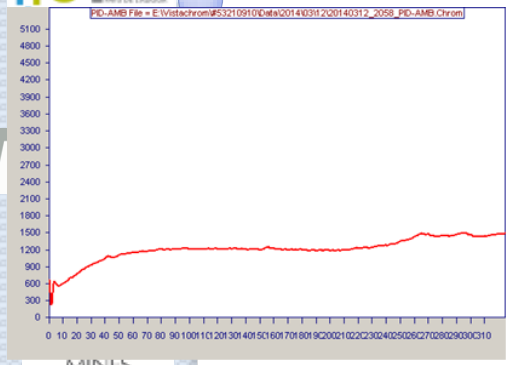
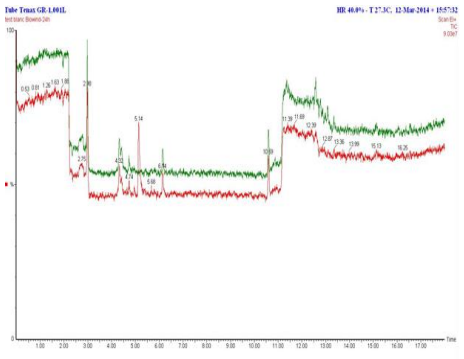
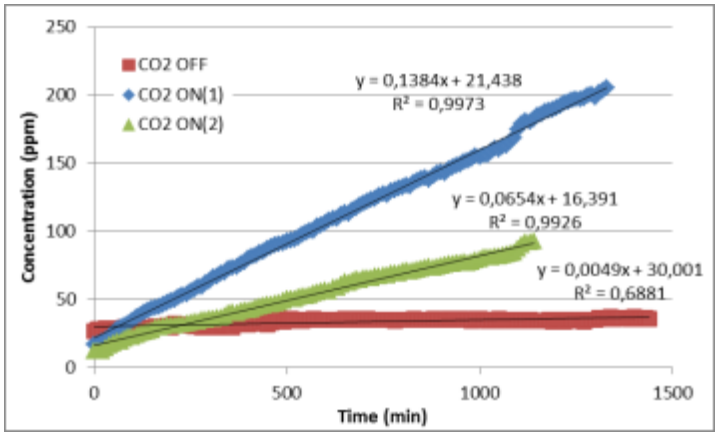
## Without VOC added

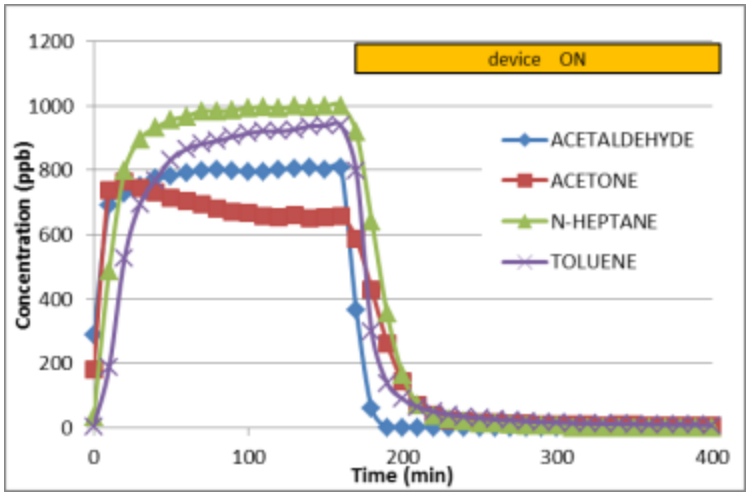


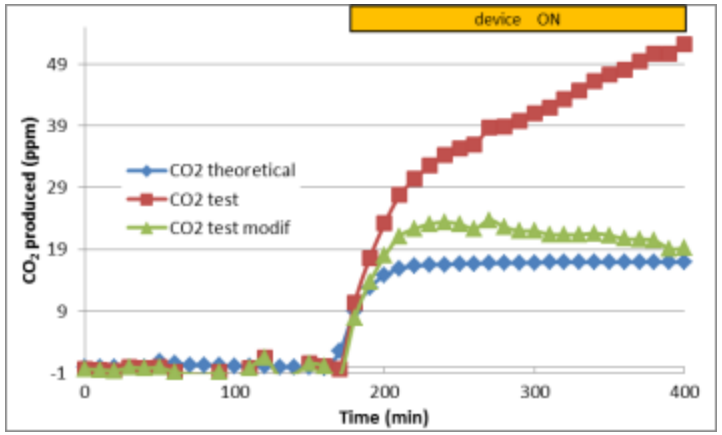





No VOC release by the device, but $CO_2$ produced by the device (decrease with time): interfere with $CO_2$ from mineralisation

## With 4 VOC ≈1 ppm

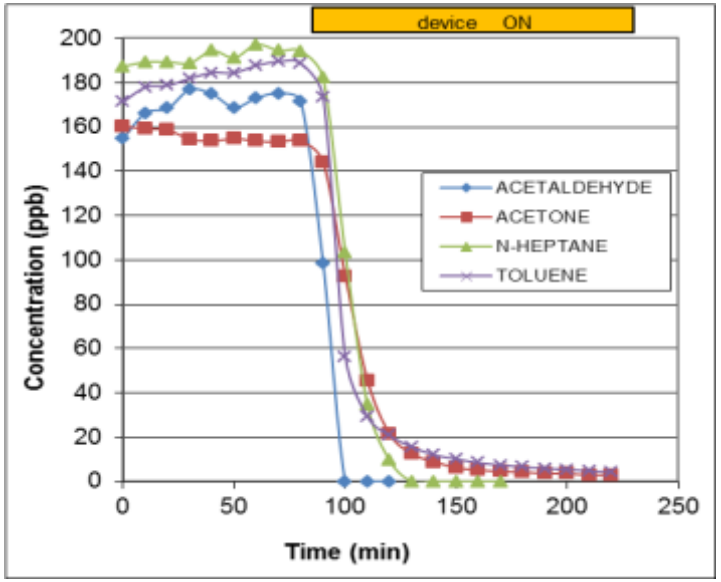



Complete 4 VOC elimination with device ON – Total mineralisation

# Example of photocatalytic device D1

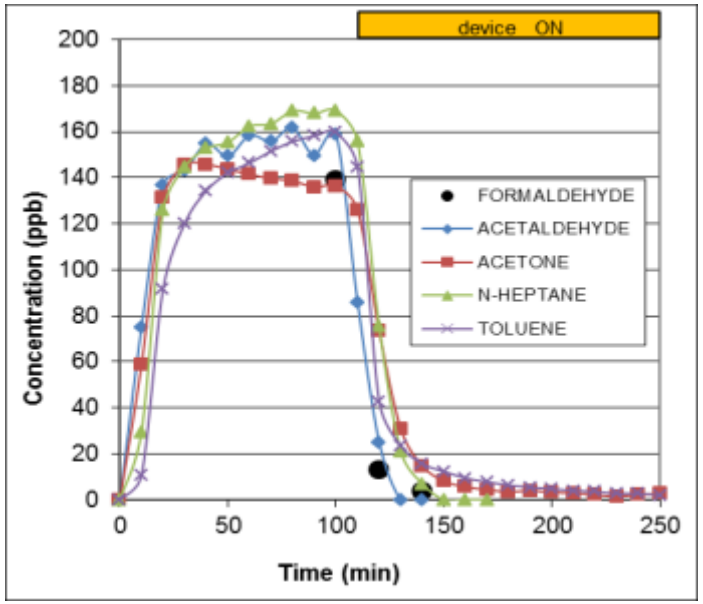
## 4 VOC ≈ 250 ppb




| Sampling time (after start) | Formaldehyde test 1 | Formaldehyde test 2 |
|---|---|---|
| T 5-20 min | ---------- | 14 ppb |
| T 15-30 min | 8 ppb | ---------- |
| T 30-45 min | ---------- | 5 ppb |
| T 45 min-1h | <DL | ---------- |

Formaldehyde : only transient by-product detected in low amount

## 5 VOC ≈ 250 ppb




Complete elimination of 5 VOCs including HCHO with device ON

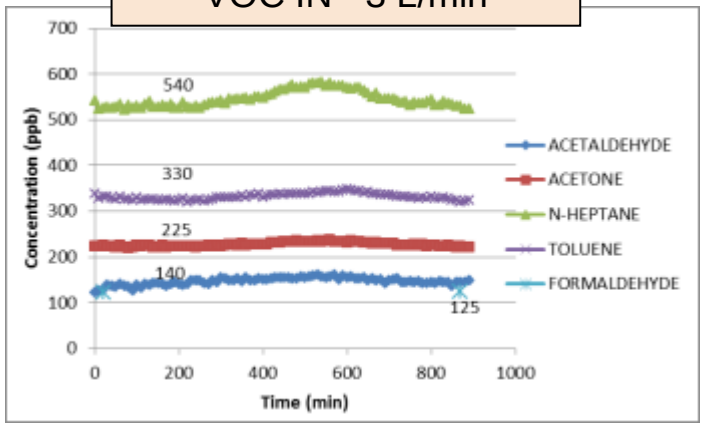
# Tests according to the AFNOR XP-B44-200 standard

| Device | Control test without VOC | | Test with 4 VOCs added continuously (24 hours maximum) | | |
|---|---|---|---|---|---|
| | $NO_x$ produced | $O_3$ generated | VOC removal | Mineralization | By-products |
| **D1** | Yes | **No** | **> 99%** | **Yes** | $NO_x$ |
| **D3** | **No** | **No** | **> 99%** | **Yes** | **None** |
| **D4** | Yes | **No** | residual acetone and toluene (≈20 ppb) | No | Formaldehyde $NO_x$ |

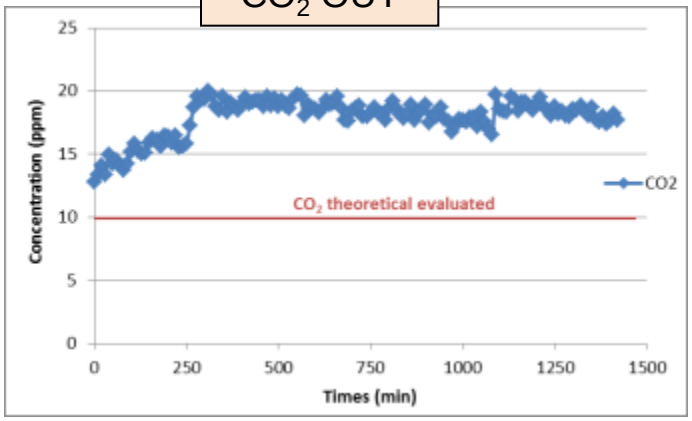
2 devices/3 are efficient for mineralization
Only device D3 releases neither VOC nor $NO_x$

# Test according to the AFNOR XP-B44-200 standard : exemple of device D1

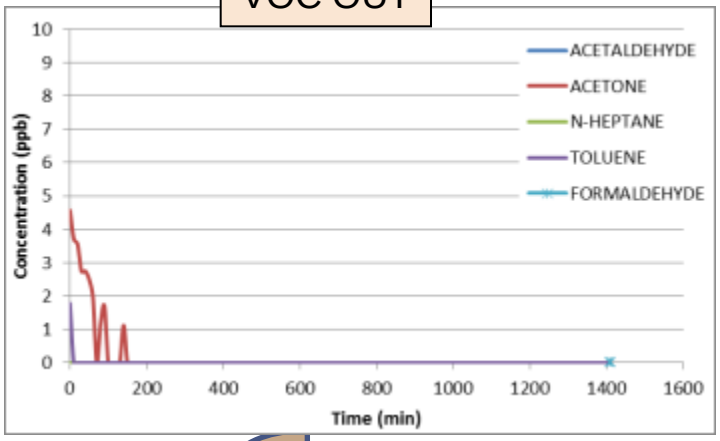
VOC IN - 3 L/min



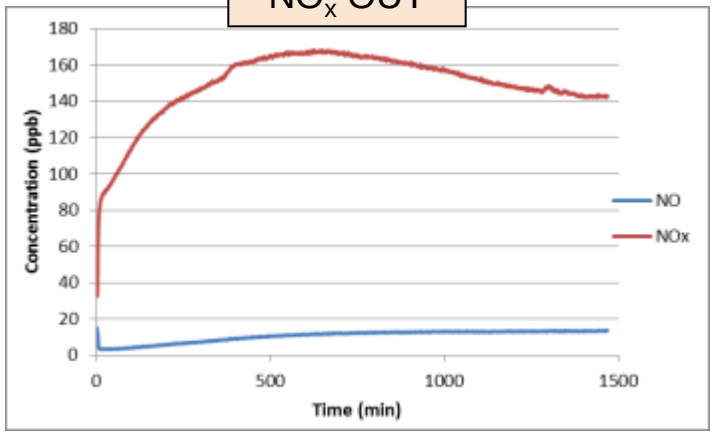

$CO_2$ OUT




VOC OUT



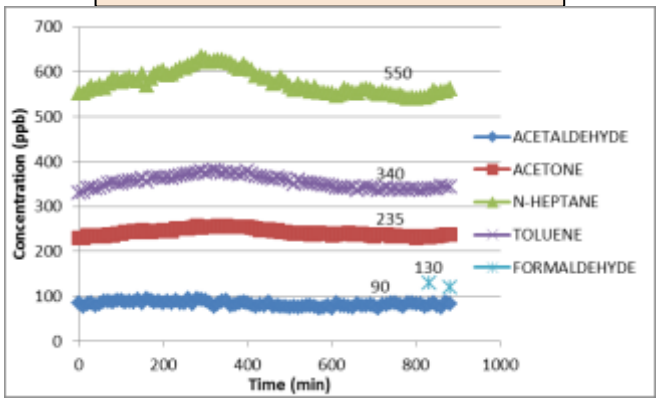

$NO_x$ OUT



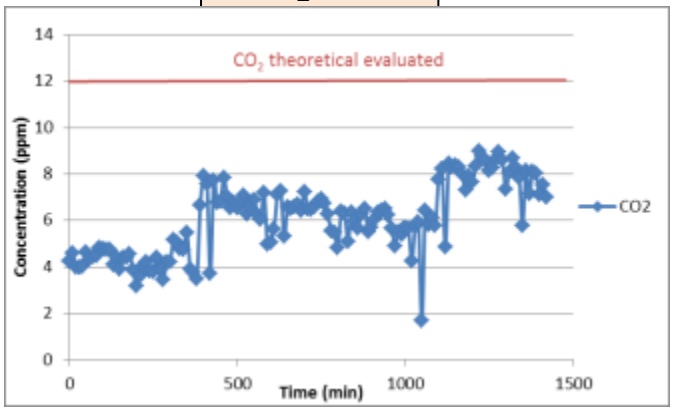

No residual VOC
Good VOC mineralization
BUT : $NO_x$ release by the device (due to the particles filter)

# Test according to the AFNOR XP-B44-200 standard : exemple of device D4

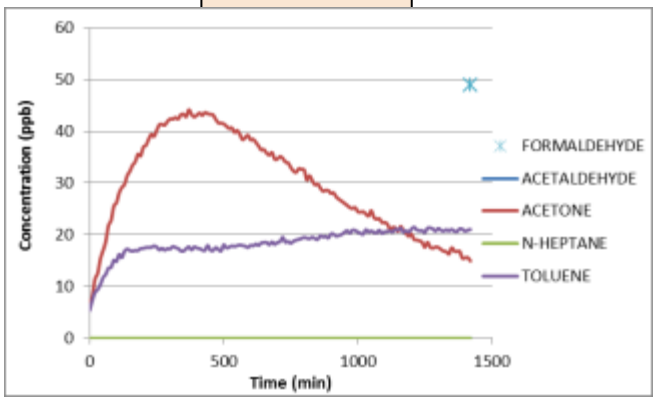
VOC IN - 3 L/min



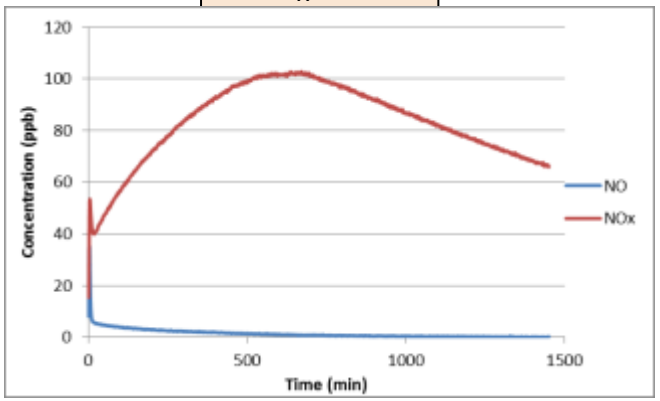

$CO_2$ OUT




VOC OUT




$NO_x$ OUT




Residual VOC : few ppbv
No VOC mineralization
$NO_x$ release by the device

# Results about system aging - device D1

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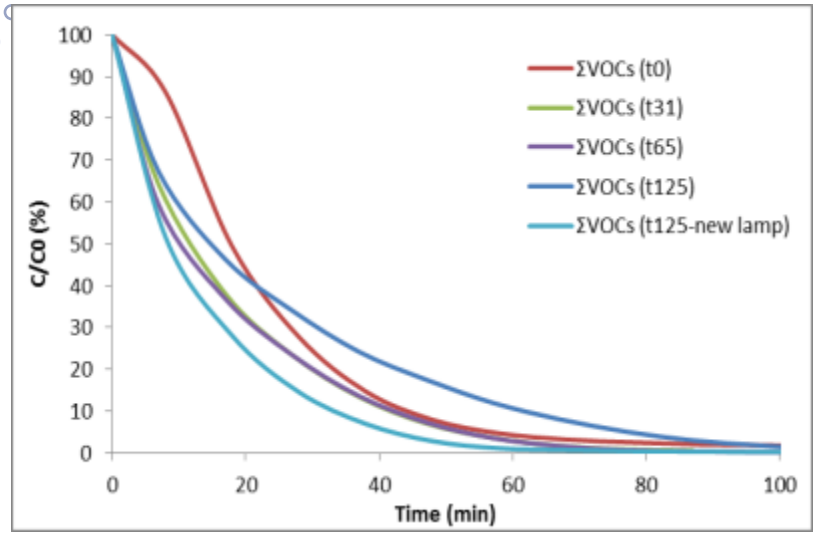
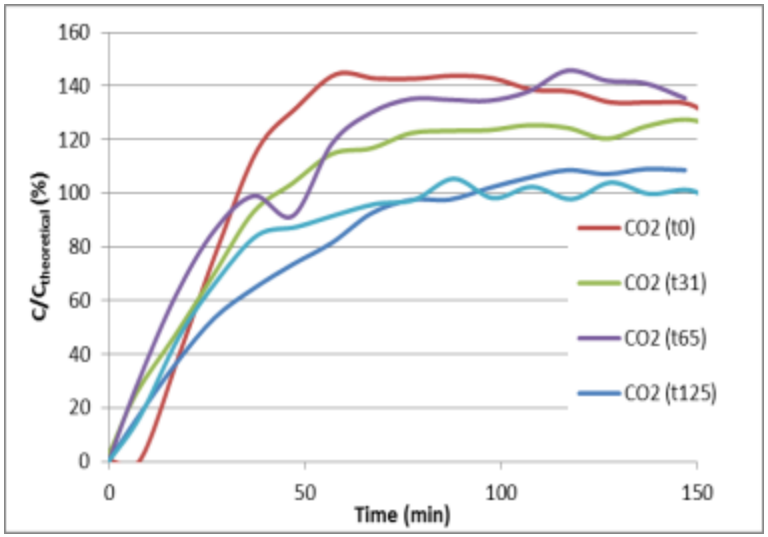
## VOC DECREASE (1 ppmV)




## Mineralisation




## CADR

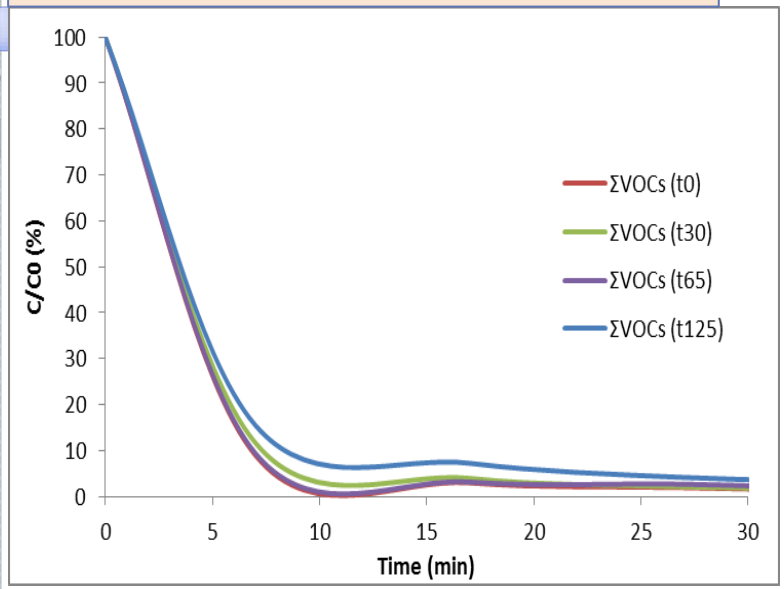
| CADR | Acetaldehyde | Acetone | n-heptane | Toluene | Σ COV |
|---|---|---|---|---|---|
| T 4 months (new lamp) | 10.30±0.94 | 2.85±0.16 | 4.26±0.17 | 13.18±0.58 | 5.42±0.36 |
| T 4 months | 5.18±0.28 | 1.44±0.04 | 1.85±0.03 | 8.29±0.01 | 2.64±0.04 |
| T 2 months | 9.49 | 2.51 | 2.76 | 11.81 | 3.88 |
| T 1 month | 10.03±0.70 | 2.84±0.15 | 2.89±0.27 | 8.31±0.26 | 4.14±0.25 |
| T0 (new device) | 9.10±0.90 | 2.79±0.25 | 2.71±0.18 | 4.39±0.10 | 3.65±0.16 |

## Irradiance

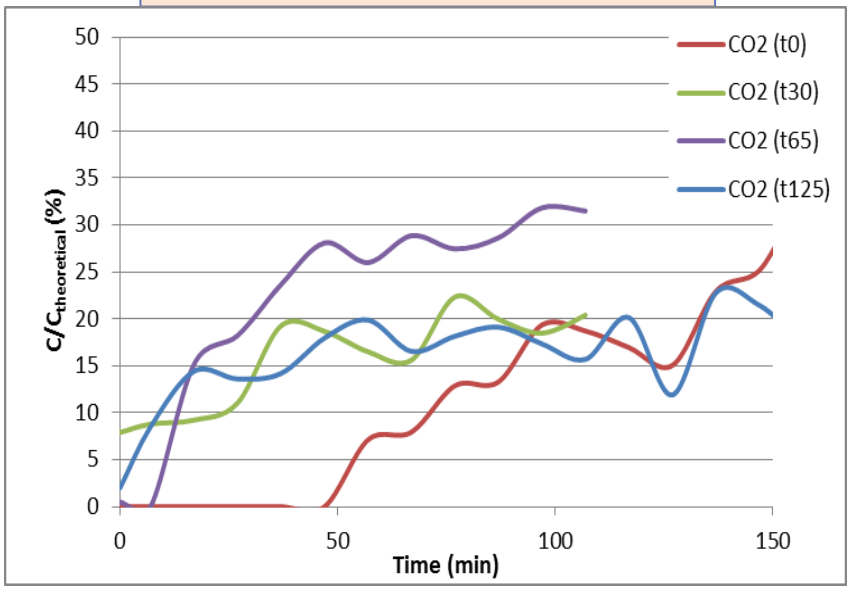
| Wavelength range | 300-550 nm Lamp 1- up | 300-550 nm Lamp 2 - down |
|---|---|---|
| New device | 5.7 mW $cm^{-2}$ | 5.8 mW $cm^{-2}$ |
| 4 months old device | 2.2 mW $cm^{-2}$ | 2.3 mW $cm^{-2}$ |

# Results about system aging - device D3

## VOC DECREASE (1 ppmV)




## Mineralisation




## CADR

| CADR | Acetaldehyde | Acetone | n-heptane | Toluene | Σ COV |
|---|---|---|---|---|---|
| T 4 months | 10.5±0,4 | 11.6±2.1 | 23.4±0.4 | 18.3±1.9 | 15.6±1.4 |
| T 2 months | 10.9±1.8 | 17.2±1.2 | 28.6±2.2 | 25.6±0.5 | 22.3±1.4 |
| T 1 month | 11.8±0.6 | 23.7±4.0 | 31.4±3.7 | 29.7±2.9 | 26.8±3.4 |
| T0 (new device) | 12.8 | 23.2 | 29.4 | 24.5 | 34.4 |

## Irradiance

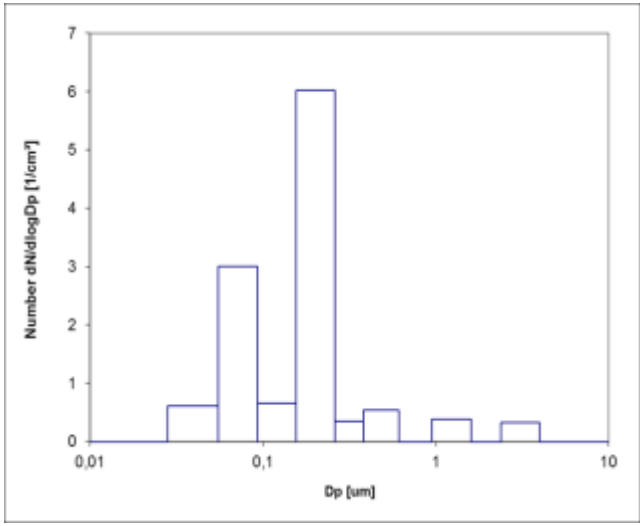
| Wavelength range | 200-300 nm | 200-800 nm |
|---|---|---|
| New device | 7.7 mW/cm² | 10.8 mW/cm² |
| 4 months old device | 9.4 mW/cm² | 11.5 mW/cm² |

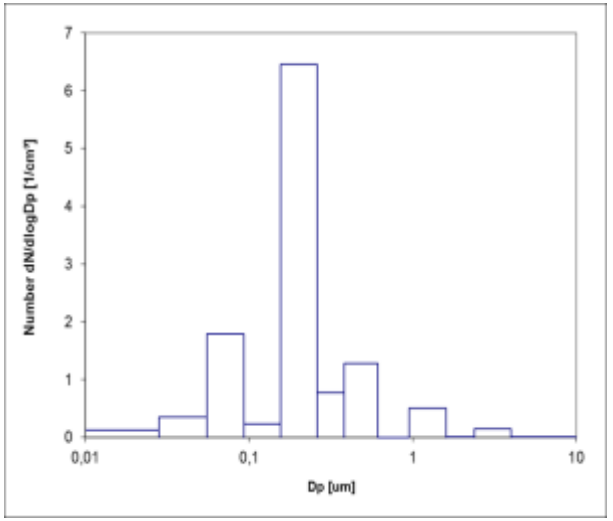
No possible quantification of mineralisation : Activated Carbon filter
Low variation of efficiency between 0 and 4 months

# First results of nanoparticles release

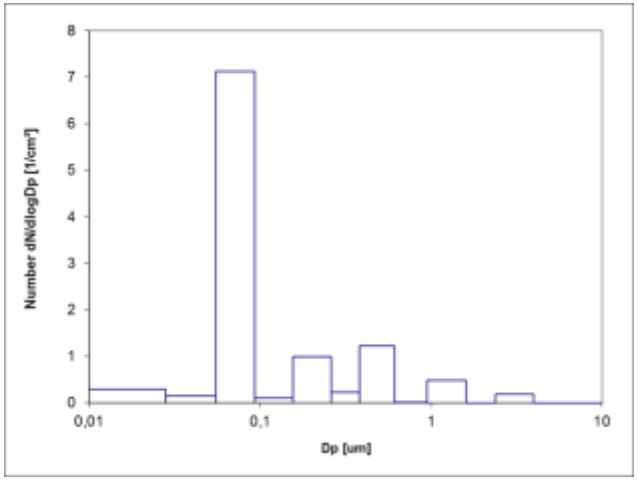
| Distribution average range of the background of the chamber flushed with clean air | Distribution average range with system ON during 3h30 (D1) and 4h30 (D3) |
|---|---|

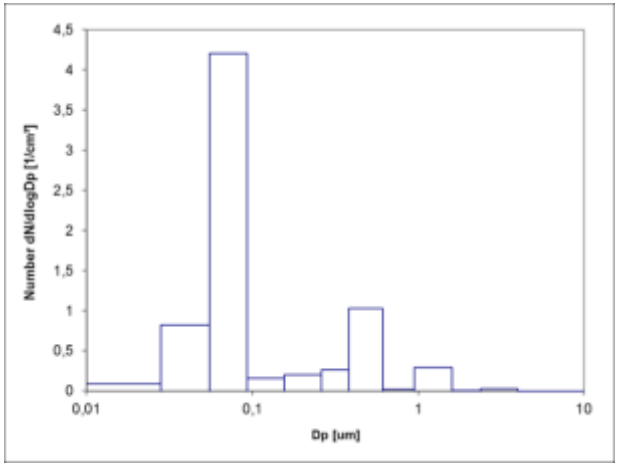
Test D1




Test D3




No nanoparticles release by either the 4 new or old devices D1/D2/D3/D4

# PILOT SCALE TESTS (EVALIS) STUDY WITH DEVICE D3

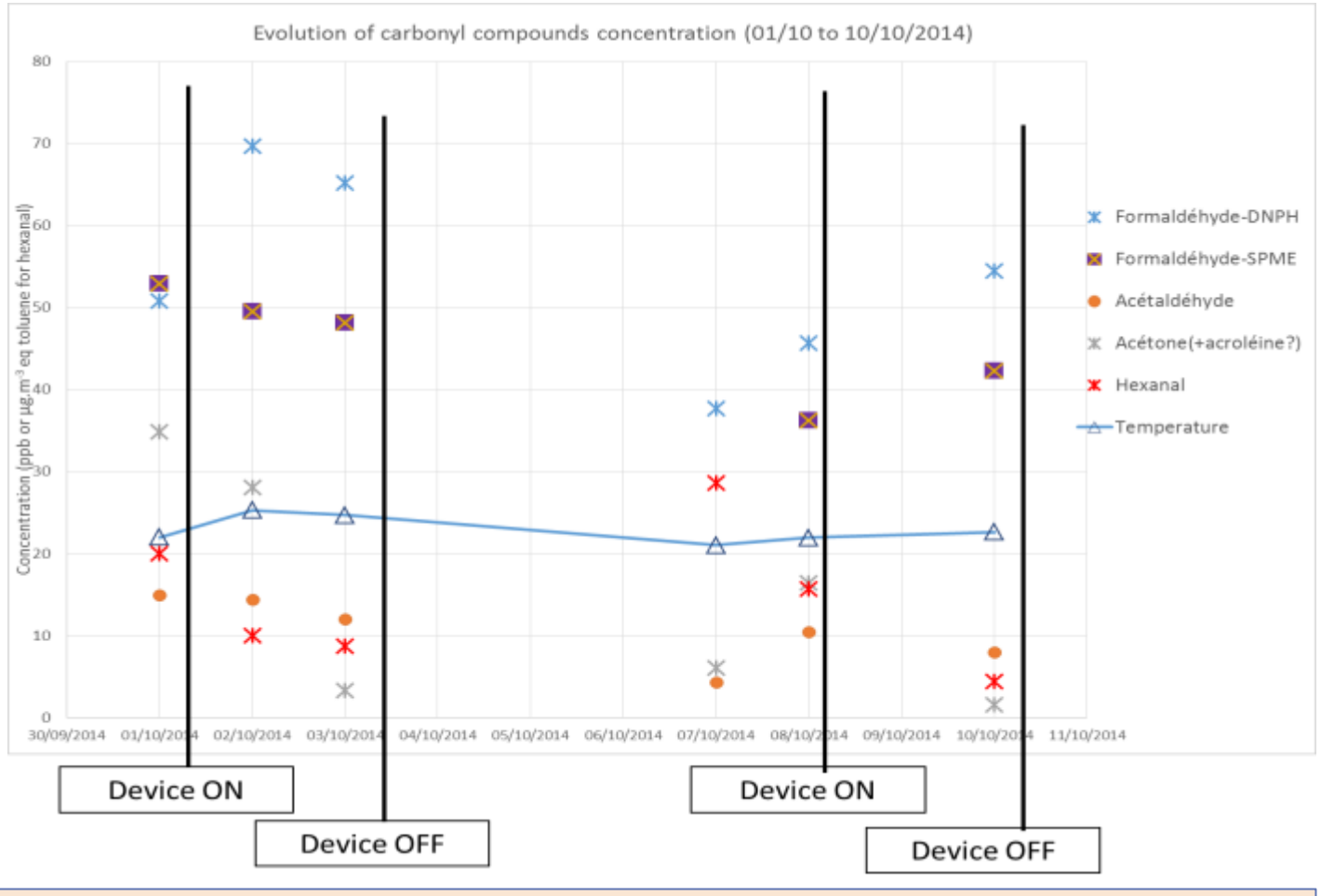
## Tests conditions and organisation

| | |
|---|---|
| **Temperature** | **21 °C ± 5°C** |
| **Air exchange** | 0.02 vol/h ± 0.01 vol/h |
| **Air pollution simulation** | Panels and baseboards introduction |

| N° phase | Description | Date – number of days |
|---|---|---|
| **Phase 1** | The room is empty, this is the reference. | 18/09-20/09/2014 – 2 d |
| **Phase 2** | Device introduction in the room. The device is OFF. | 22/09-24/09/2014 – 2 d |
| **Phase 3** | Device ON | 24/09-26/09/2014 – 2 d |
| **Phase 4** | **Device OFF, Panel and baseboard introduction** | 29/09-01/10/2014 – 3 d |
| **Phase 5** | **Device ON** | 01/10-03/10/2014 – 2 d<br>08/10-10/10/2014 – 2 d<br>21/10-21/11/2014 – 31 d |
| **Phase 6** | **Supplementary pollution added (detergent)** | 12/11-21/11/2014 – 9 d |

# PILOT SCALE TESTS (EVALIS) - STUDY WITH DEVICE D3

**Formaldehyde and others carbonyl compounds with pollution introduced, device ON/OFF**




Results PHASES 4-5-6

With device ON : noticeable effect on carbonyl compounds except formaldehyde continuously released in high amount from the wooden material

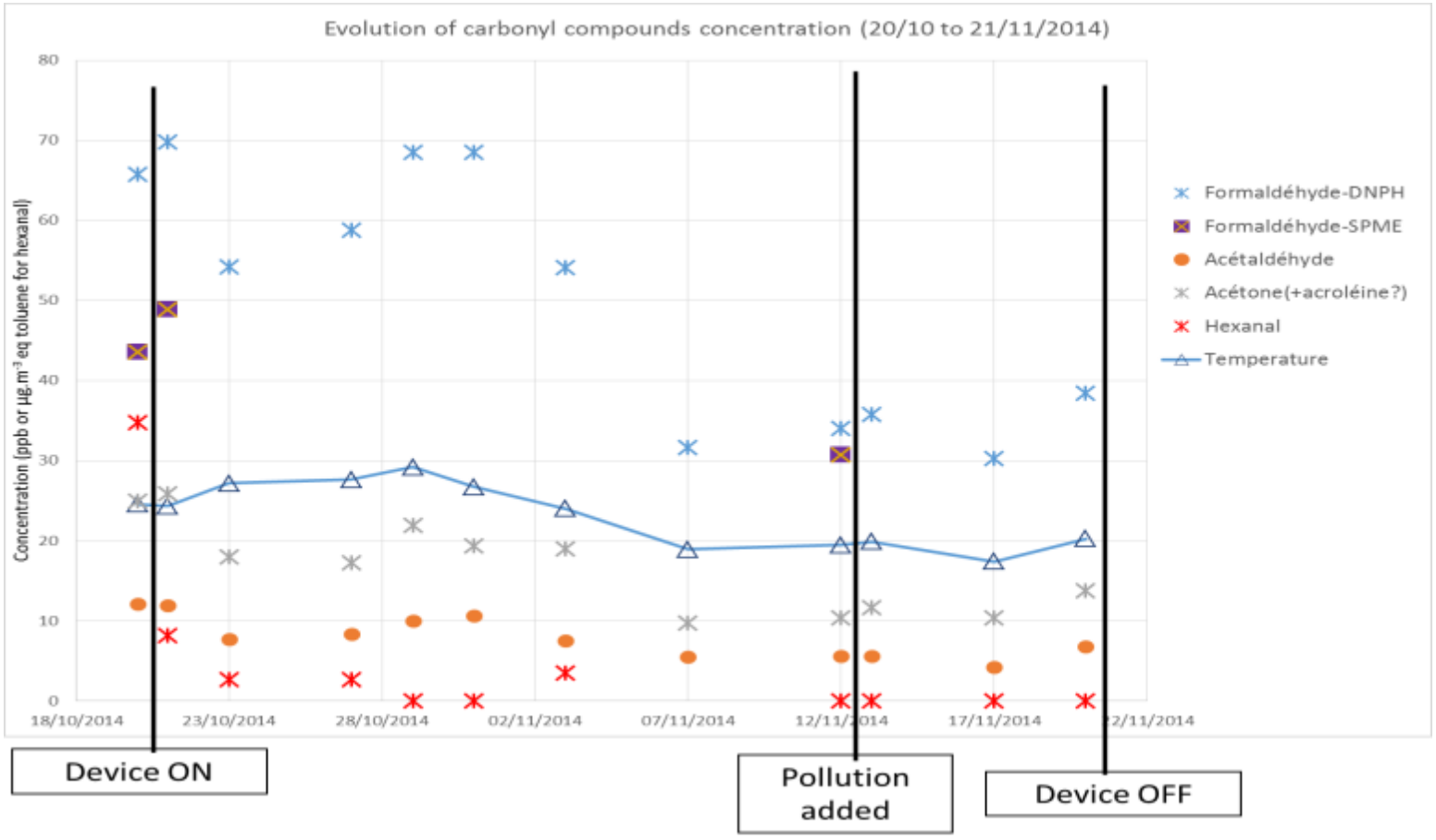
# PILOT SCALE TESTS (EVALIS) STUDY WITH DEVICE D3

IPREM

Nobatek

Results PHASES 4-5-6

**Formaldehyde and others carbonyl compounds with pollution introduced, device ON during 1 month**

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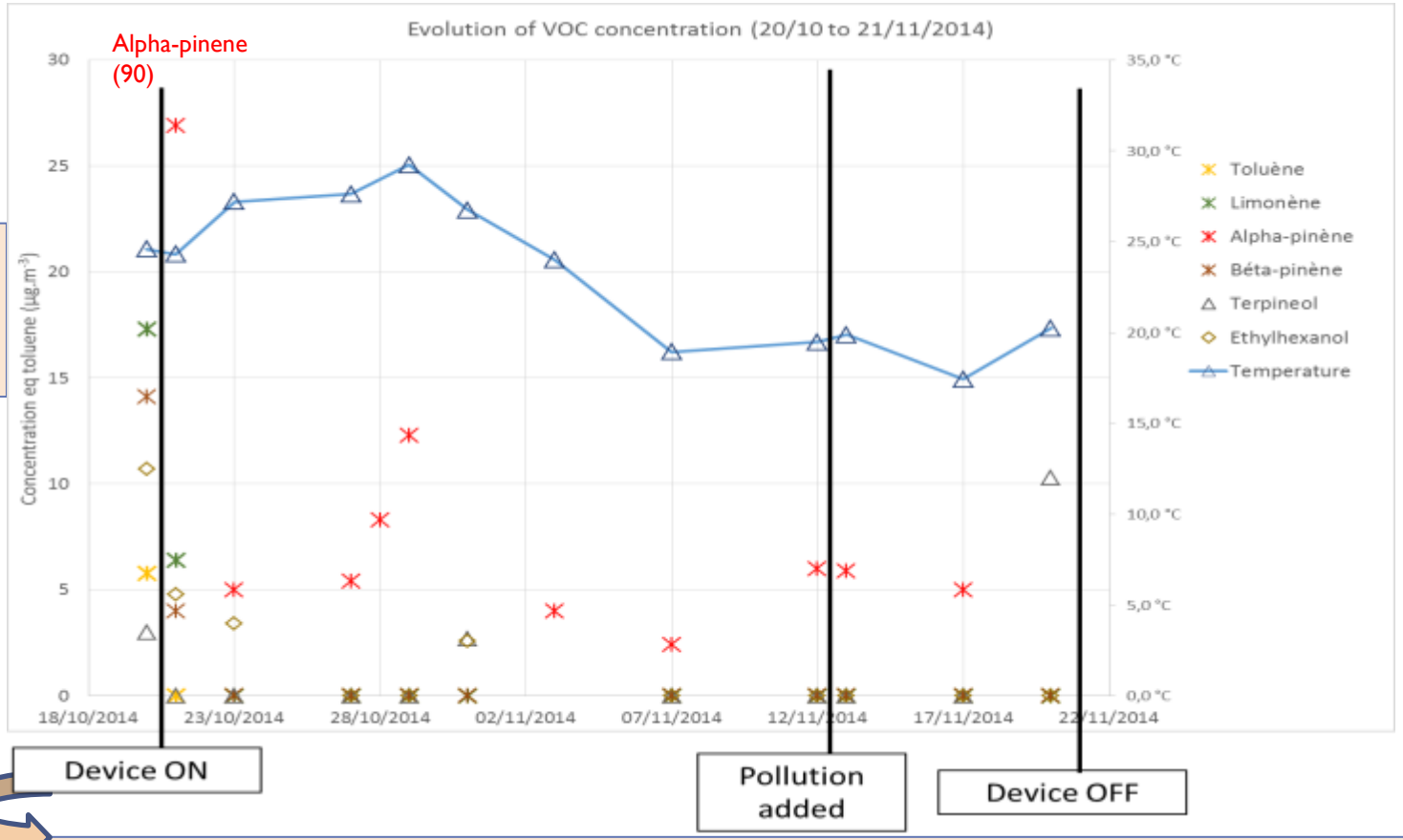
Stabilisation of the concentrations after 3 days but formaldehyde concentration remains high.
The equilibrium is affected by temperature.

# PILOT SCALE TESTS (EVALIS) STUDY WITH DEVICE D3

**Others VOCs (TENAX+ATD-GC-MS) with pollution introduced, device ON during 1 month**

Results PHASES 4-5-6

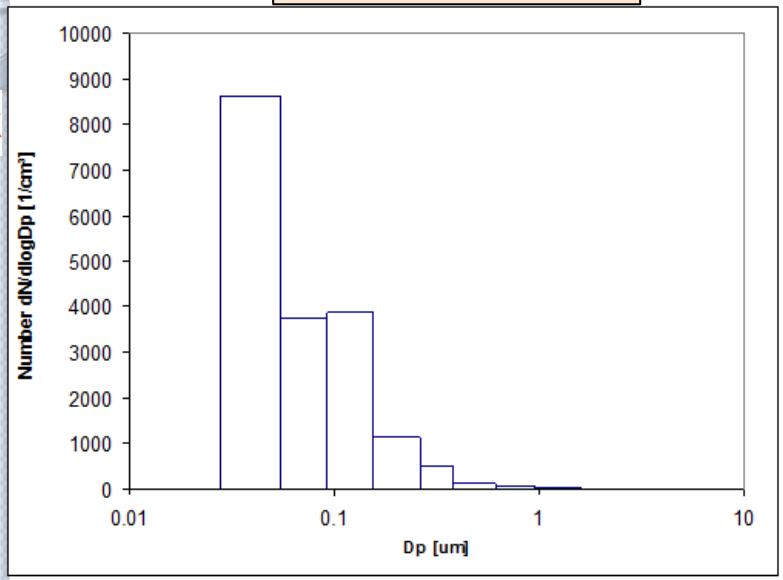



Stabilisation of the concentrations after 3 days with device ON.
$\alpha$-pinene decreases from 90 to 27 µg $m^{-3}$ eq. toluene in only 1 day.
The others pollutants show a high elimination rate too.
The equilibrium is affected by temperature.

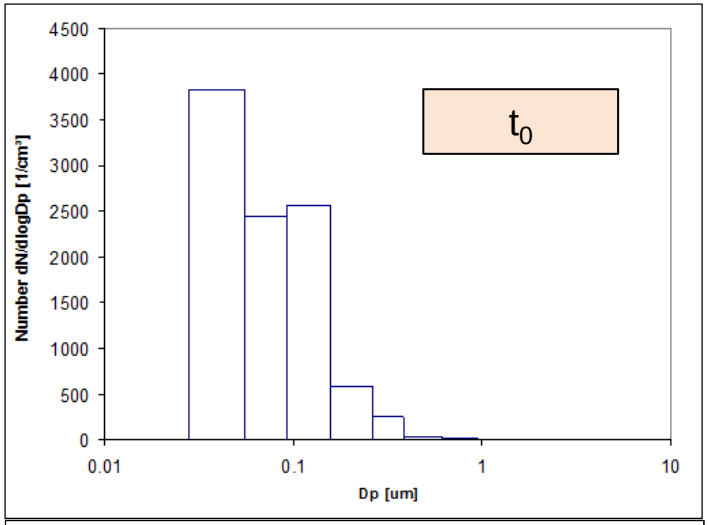
# PILOT SCALE TESTS (EVALIS) - STUDY WITH DEVICE D3

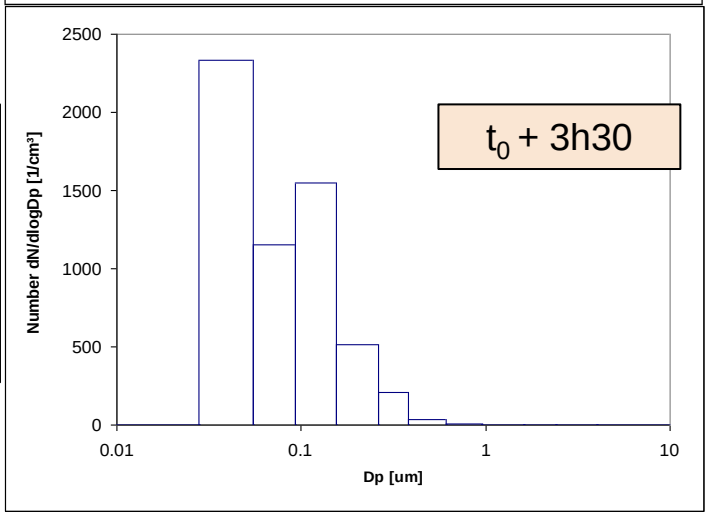
Measures after 6 days with device working continuously (27-10)

Outdoor air EVALIS




Indoor air EVALIS with device ON



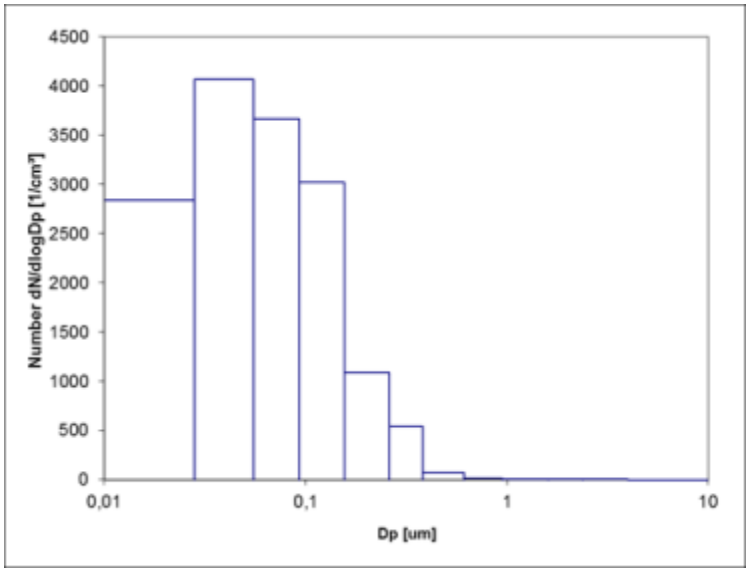




- Nano and microparticles measured outdoor upper than the amount collected indoor.
- Downward trend of the nano and microparticles collected indoor with the device ON between the beginning and the end of experiment.

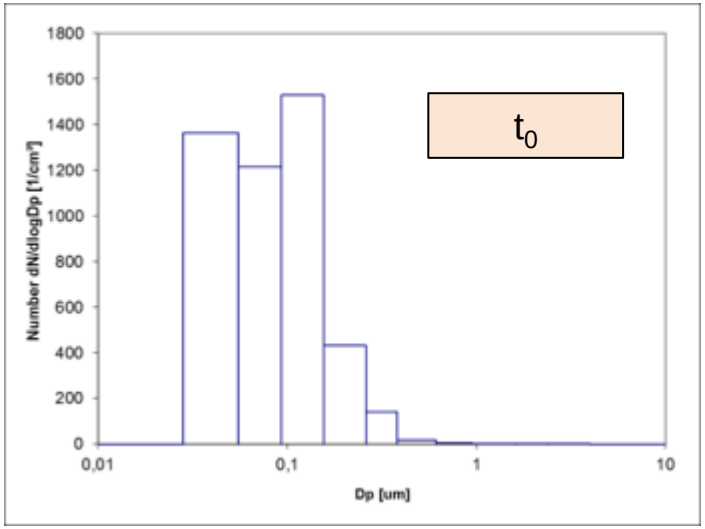
# PILOT SCALE TESTS (EVALIS) STUDY WITH DEVICE D3

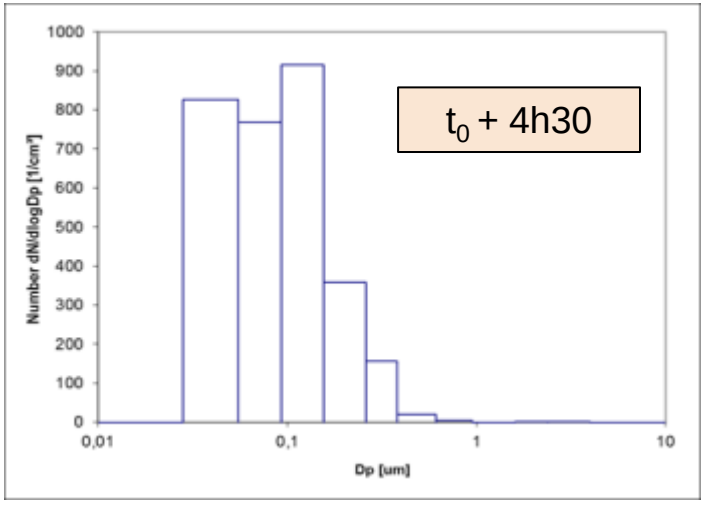
Measurements after 30 days with device working continuously (20-11)

Outdoor air EVALIS




Indoor air EVALIS with device ON




- Nano and microparticles measured outdoor upper than the amount collected indoor.
- Downward trend of the nano and microparticles collected indoor with the device ON between the beginning and the end of experiment.

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# Conclusion

- Possible comparison of photocatalytic commercial and innovative devices and materials at laboratory scale using standardized tests.
- Standardised tests useful to insure that devices found on the market are safe and efficient.
- Certification needed for these commercial products
- Analysis of systems and media aging as well as nanoparticles release useful to know the performance evolution with time
- First tests in real conditions with an efficient device (previously tested in laboratory), show a decrease of VOCs concentrations except formaldehyde. Its concentration is strongly dependant on the temperature.
- No nano and microparticles were released by the device.
- In progress : tests in real conditions with a second efficient device.

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# Thank you for your attention