Dipartimento di Ingegneria
Civile e Meccanica
Università di Cassino e del Lazio Meridionale

Emissione di particelle ultrafini indotta da vernici e film fotocatalitici indoor a base di TiO_2: misure sperimentali e simulazione dell'esposizione in uffici

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Introduction

AIRBORNE PARTICLE EMISSIONS FROM PHOTOCATALYTIC COATINGS AND PAINTS

THE PROBLEM

People spend **~90% of time indoors** → indoor exposure dominates pollutant intake.

A PROMISING TECHNOLOGY

TiO_2-based photocatalytic coatings & paints are increasingly sold to consumers as a two-in-one fix:

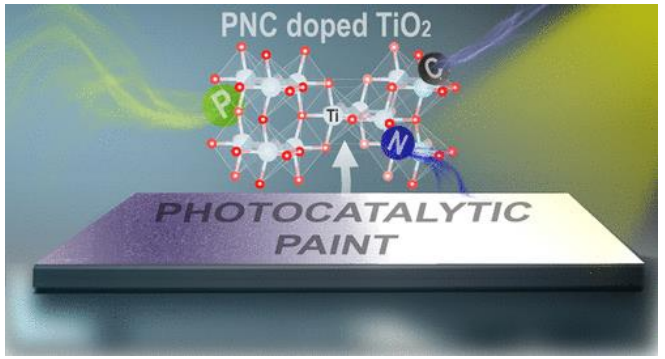
- **degrade VOCs**
- **inactivate microbes** by light generated reactive oxygen species (ROS).

OVERLOOKED CONCERN

Incomplete oxidation → low-volatility by-products → nucleation → secondary aerosol (UFPs).

RESEARCH QUESTION

Can the same oxidation that removes VOCs generate secondary ultrafine particles indoors?



Introduction

THE PHOTOCATALYTIC MECHANISM

Light + TiO_2

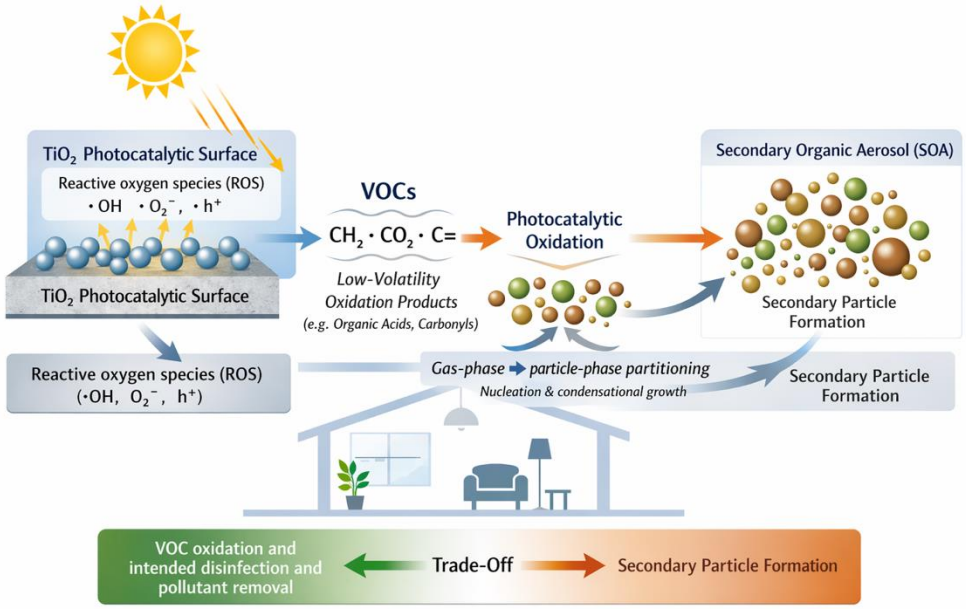
Photon excites the catalyst:
$TiO_2 + hv \rightarrow e^- + h^+$

ROS formation

Holes & electrons generate
$OH•$, O_2^-, H_2O_2

VOC oxidation

Reactive species oxidize gas-phase VOCs



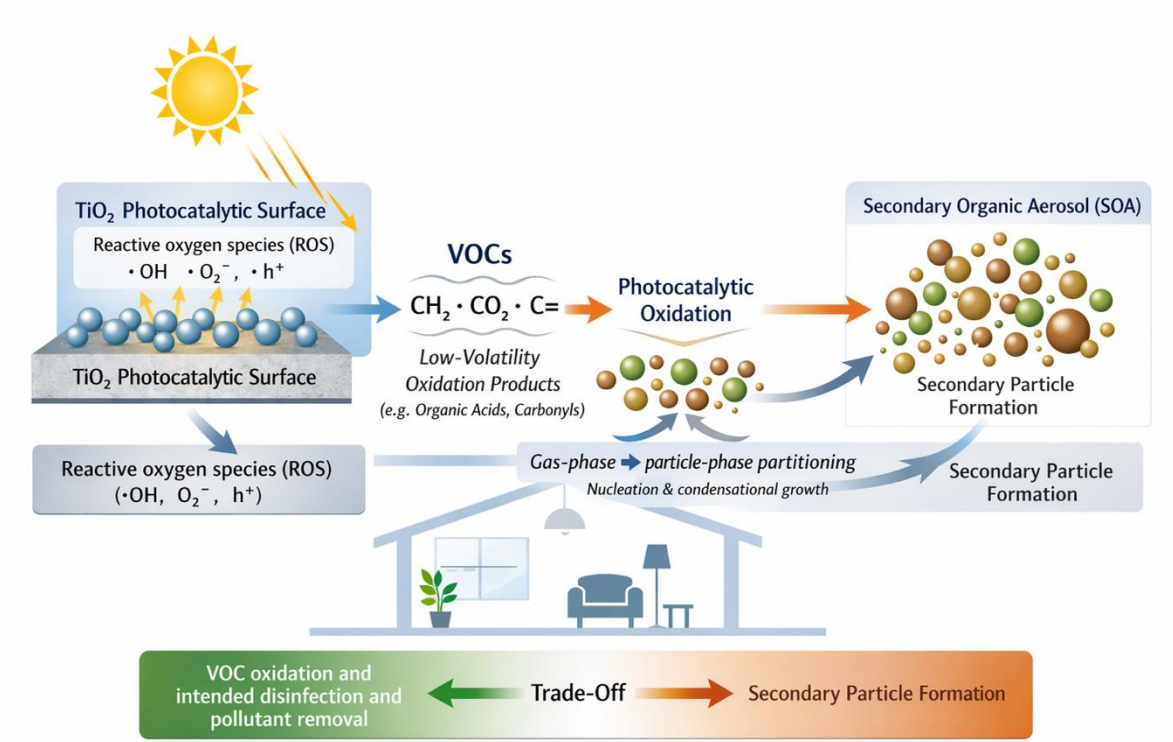
Full mineralization is rarely achieved indoors

Partial-oxidation pathways dominate, producing aldehydes, ketones, alcohols and organic acids. **Some PCO systems may even release more harmful by-products than the pollutants they remove** *(Mamaghani et al., 2018; Mo et al., 2009; Smaiyl et al. 2026).*

Knowledge gap: *by-products may be SOA precursors — yet UFP formation from coatings & paints had not been quantified.*

Aims of the study

- Investigate whether **TiO_2-based transparent photocatalytic coatings and photocatalytic paints**, when activated by **indoor lighting**, can drive **VOC oxidation** pathways that may lead to **SOA formation** and thereby **increase UFP concentrations**.



Materials and Methods

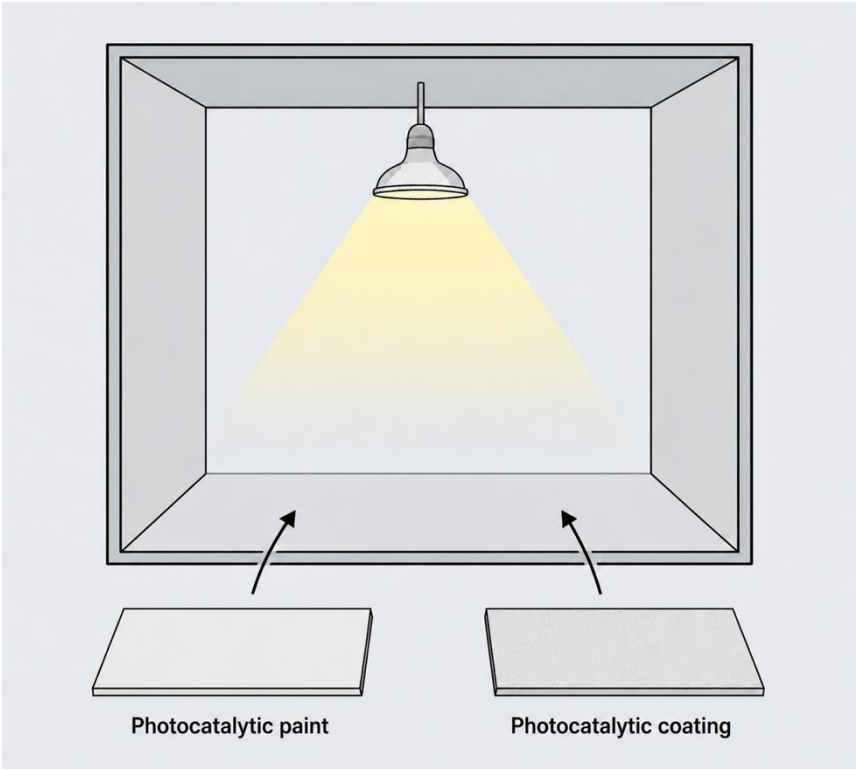
EXPERIMENTAL SETUP & SAMPLING SITE

- **CPC 3775 (TSI Inc.)** — Condensation Particle Counter for particle number concentration; 1 s sampling time, 1.5 L min^{-1} aerosol flow rate.

- **FMPS 3091 (TSI Inc.)** — Fast Mobility Particle Sizer for particle size distribution; 1 s sampling time, 5.6–560 nm mobility diameter range.

- **PID 10.6 eV with OmniTrak™ Smart Station** — photoionization detector for total VOCs (TVOC); 0–20000 ppb range, 1 ppb resolution, aggregate wireless signal.

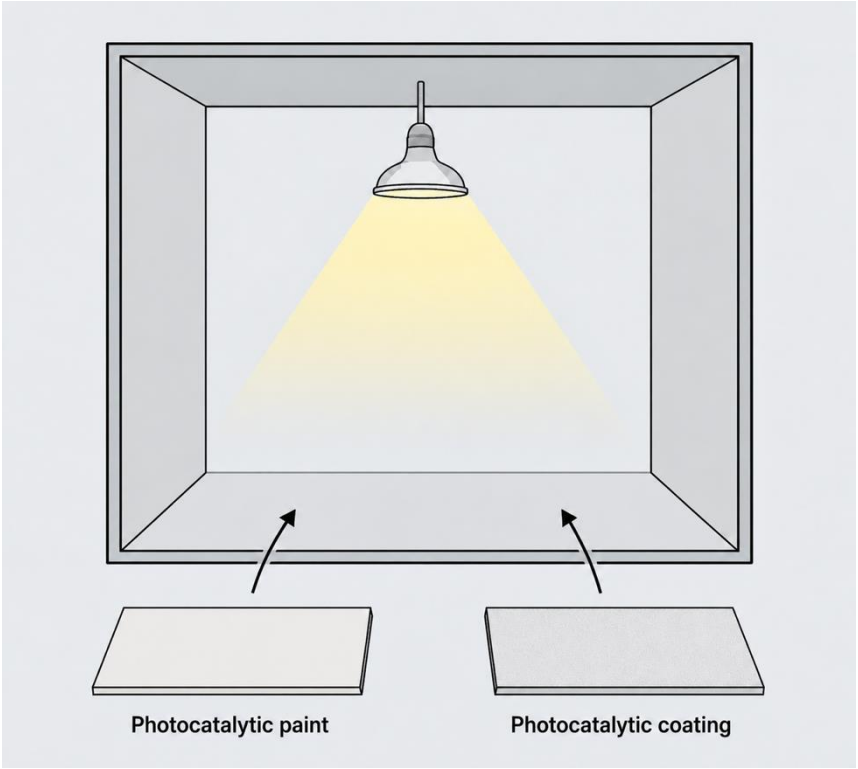
- **Lux meter ESR003 (LSI-Lastem) + BABUC/m datalogger** — illuminance measurement inside the chamber.



Materials and Methods

EXPERIMENTAL SETUP & SAMPLING SITE

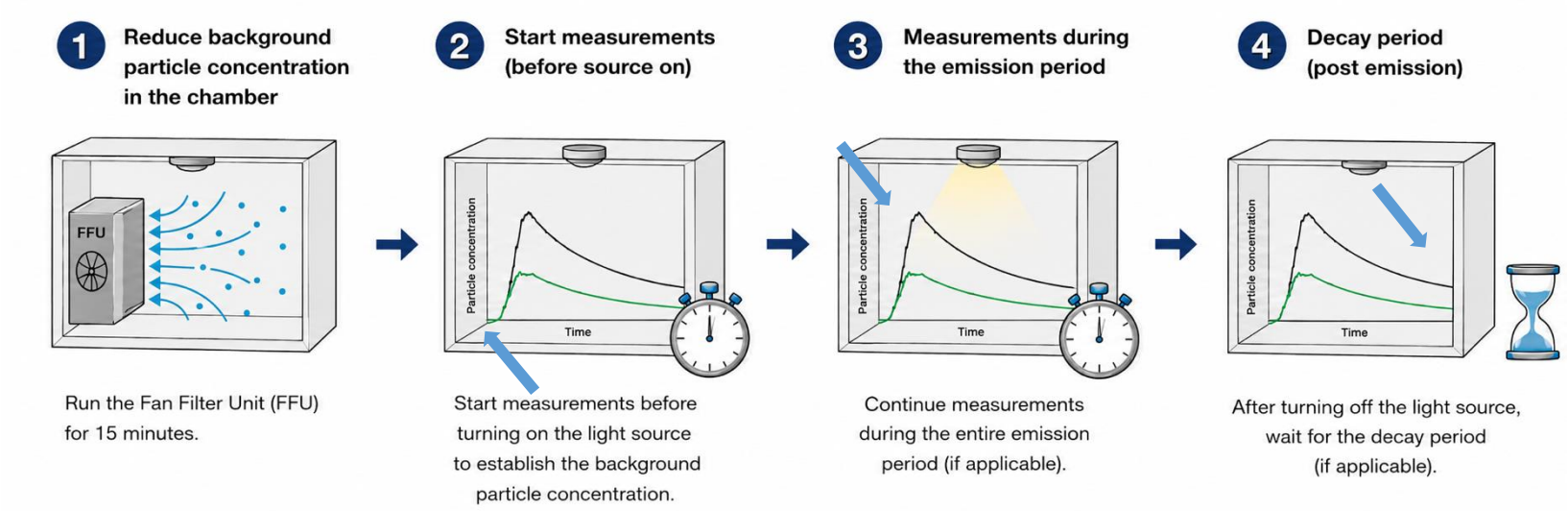
- Tested materials: **photocatalytic paint** and **photocatalytic coating**
- Experimental campaign conducted under typical indoor lighting and VOC concentration conditions.
- Particle number concentrations and distributions, illuminance, and total VOC (TVOC) concentrations were measured;
- Experimental analyses performed in 0.90 m × 1.90 m × 1.84 m naturally ventilated chamber (AER=0.5 h^{-1});
- The photocatalytic paint was applied to a plasterboard panel measuring 0.5 m^2 (the paint was diluted with 15% (v/v) water and applied at a coverage rate of 1 L per 14 m^2 of surface);
- The transparent photocatalytic coating was applied to the chamber floor (total surface area of 0.79 m^2);
- To evaluate the effect of **lighting conditions**, tests were conducted under different lighting conditions (**1200 lux, 300 lux, and darkness**);
- Lighting was provided by a Sanolux HRC 300–280 (Radium) lamp positioned 1 m above the samples. The lamp used is designed to approximate the solar spectrum.



Materials and Methods

EXPERIMENTAL PROCEDURE

- First, the background particle concentration inside the chamber was reduced by running a fan filter unit (FFU) for 15 minutes. Then, particle measurements started before the light source was switched on to establish background particle concentrations. Thus, all measurements consisted of a few minutes of background, followed by measurements during the emission period (if any), after which the decay period began.



- Emission rate from mass balance (then divided by the area of photocatalytic material)

$$ER = V \cdot \left[\frac{C_{in,peak} - C_{in,0}}{\Delta t} + (AER + k) \cdot C_{in} - AER \cdot C_{in,0}\right] / A$$

(part. min^{-1} m^{-2})

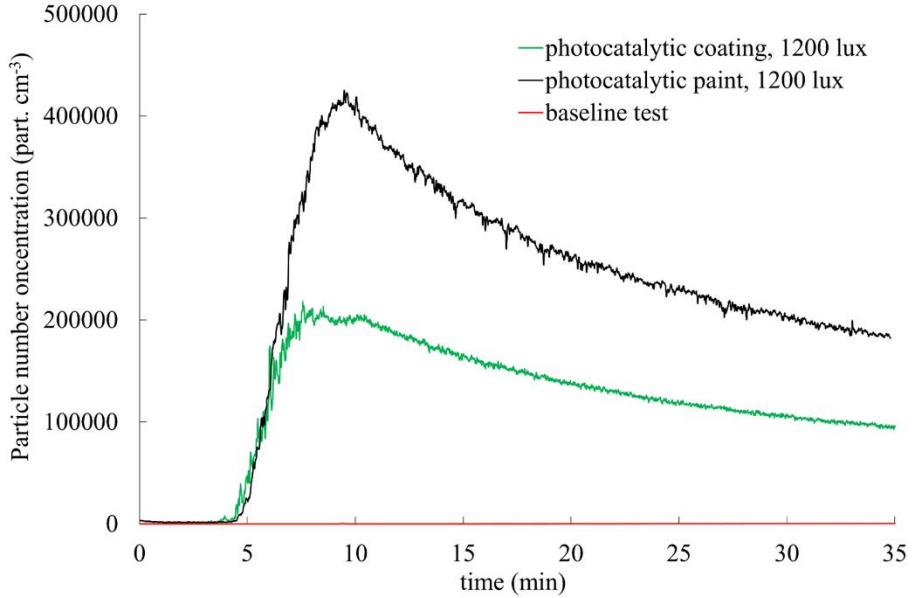
Results

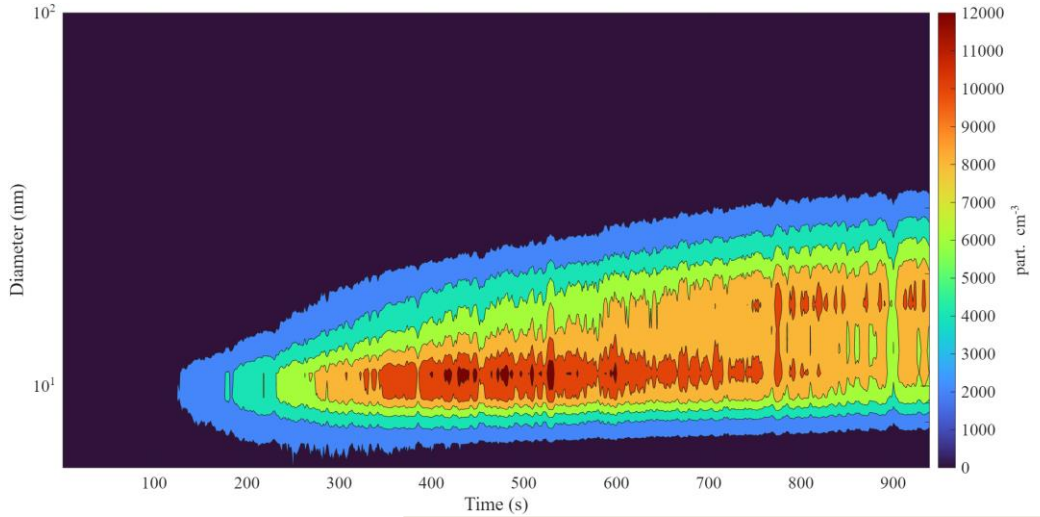
CONCENTRATION TRENDS & PARTICLE NUMBER DISTRIBUTIONS

- **Concentration trends** demonstrate that the particles emitted during the tests carried out with photocatalytic paints and coatings, and a simultaneous presence of illuminance, are related to those emission sources, and no other unknown particle-emitting phenomena are present.

- During the tests, a decrease in TVOC concentration was also recognized (from 250 ± 98 to 210 ± 45 ppb) due to photocatalytic coating and paint under light exposure.

- **Particle number distributions**: as soon as particle generation begins, the total concentration increases, and the distribution presents a main mode at approximately 10 nm (i.e., ultrafine particle range).





Results

EMISSION RATES AND EXPOSURE IN A REAL-WORLD SCENARIO

- **Emission rates (part. min^{-1} m^{-2}):**

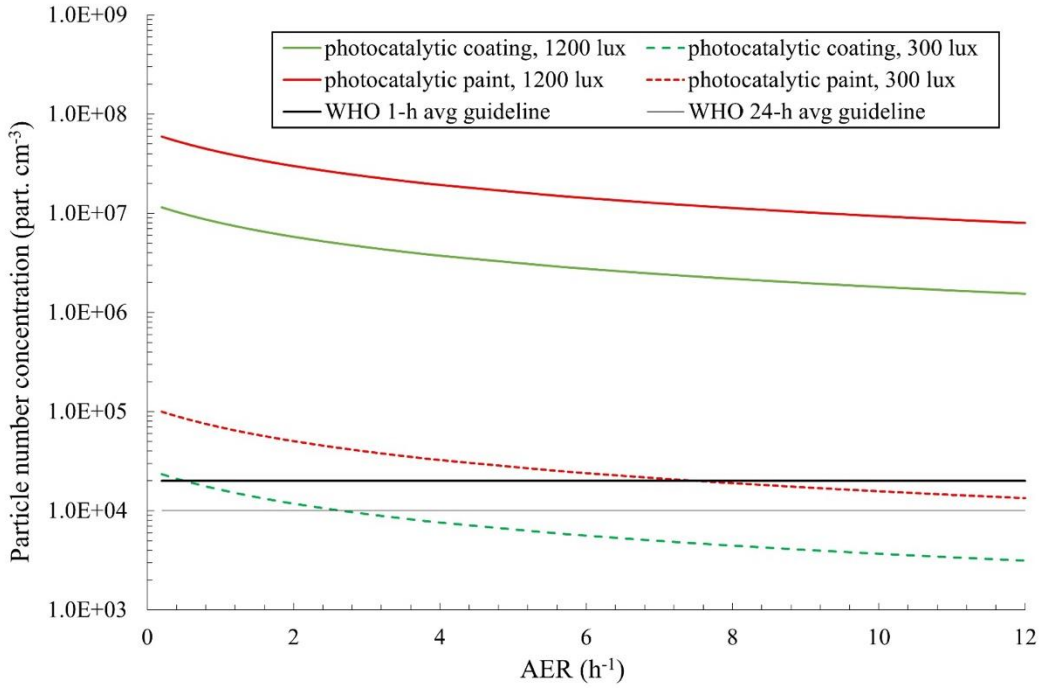
photocatalytic coating			photocatalytic paint		
High illuminance	Medium illuminance	Darkness	High illuminance	Medium illuminance	Darkness
2.2×10^{11} (1.3×10^{11}-3.9×10^{11})	4.5×10^{8} (2.9×10^{8}-7.1×10^{8})	<LOD	2.8×10^{11} (6.9×10^{10}-4.0×10^{11})	4.7×10^{8} (4.2×10^{8}-5.1×10^{8})	<LOD

- **Exposure to particles in a real-world scenario:**

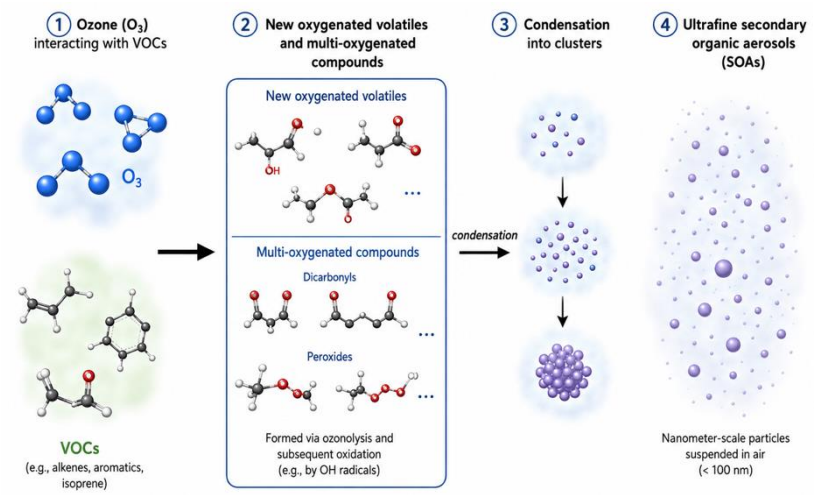
- Estimate of the overexposure to particle number concentration in a typical office scenario during a working day (8 h) through a mass balance equation

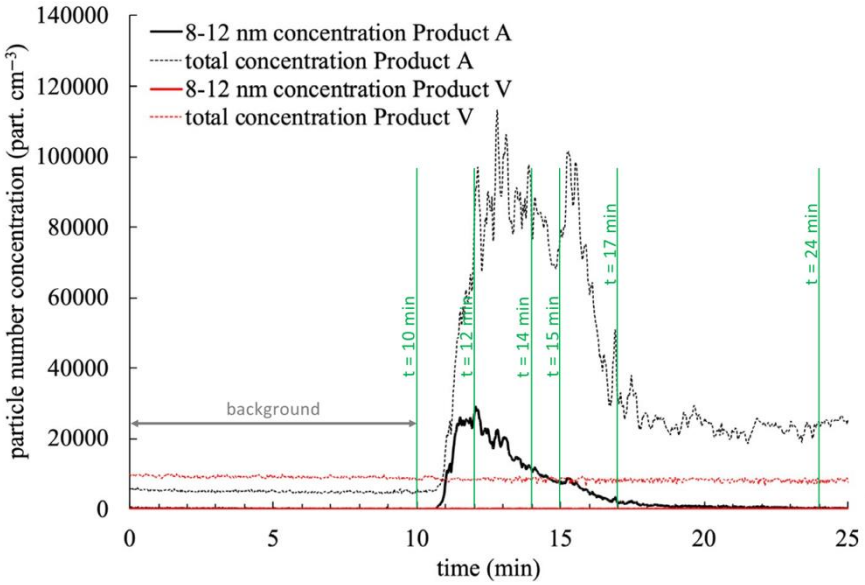
- typical office environment (95 m^3, painted surface 77 m^2, total area of the windows 19 m^2; data reported by Asif e Zeeshan, 2023).

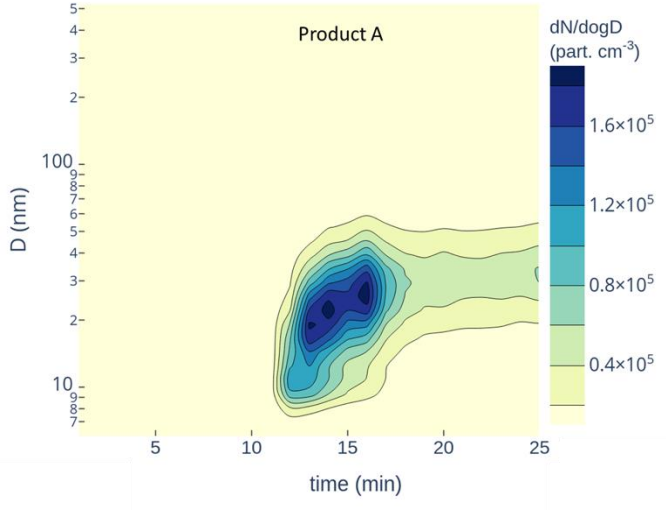
- In environments with a significant daylight contribution, the use of photocatalytic materials may lead to substantial increases in ultrafine particle concentrations, potentially exceeding recommended exposure levels, especially under low ventilation conditions.



Insights







- Increase of the **8-12 nm size range concentration** clearly evidenced a new particle formation due to the co-presence of favorable boundary conditions leading to nucleation events!

Conclusions

- **First quantitative evidence** that TiO_2-based photocatalytic coatings and paints emit ultrafine particles under indoor lighting, with emission rates up to ~10^{11} part·min^{-1}·m^{-2} at 1200 lux — while emission stays below detection limit in the dark.
- **Strong light dependence**: emission drops by roughly 3 orders of magnitude from 1200 to 300 lux, confirming the process is driven by photocatalytic activation.
- **Secondary aerosol via nucleation**: a stable size mode at ~10 nm points to SOA formation through nucleation (not growth), consistent with partial oxidation of VOCs.
- **A real trade-off**: VOCs decrease (TVOC from ~250 to ~210 ppb) while UFPs rise — the marketed benefit and an unintended secondary source are two faces of the same oxidation chemistry.
- **Exposure implications**: in a typical low-ventilation office, WHO guidelines are exceeded even at moderate illuminance, suggesting these materials should be re-evaluated for use in poorly ventilated, daylight-rich indoor spaces.
- **Future work**: chemical speciation of gas- and particle-phase products, and LED-only lighting tests for realistic illumination scenarios.

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Grazie per l'attenzione!