ASSESSING THE EFFECTIVENESS OF A PHOTOCATALYTIC PAINT FOR DEPOLLUTION IN A CONTROLLED INDOOR ENVIRONMENT

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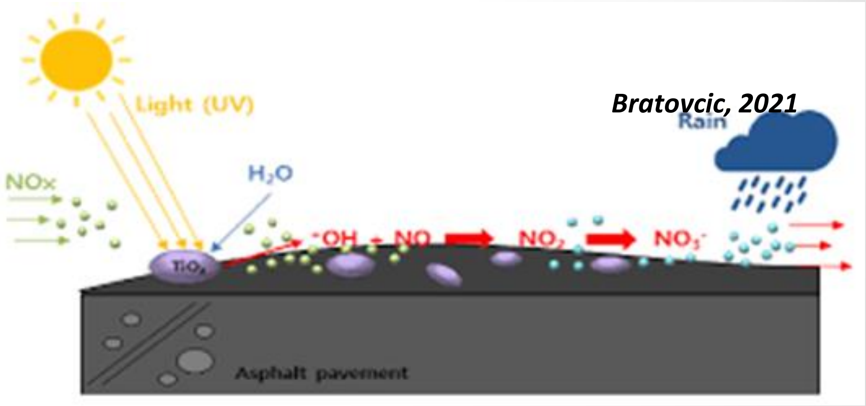
Introduction

Exposure to indoor air pollution is important, as people spend ~80% of their time indoors.

- Photocatalytic paints may help improving indoor air quality in a cost-efficient way.
- The objective of the LIFE VISIONS project was to demonstrate the effectiveness of an innovative TiO_2 photocatalytic paint product aiming to:
  - degrade NO_x and VOCs in indoor evnironments
  - reduce energy consumption as a result of lower ventilation needs

As a follow-up a spin-off company was formed.

Bratovcic, 2021



NO_x decomposition by TiO_2 (*Lee and Baek, 2021*)

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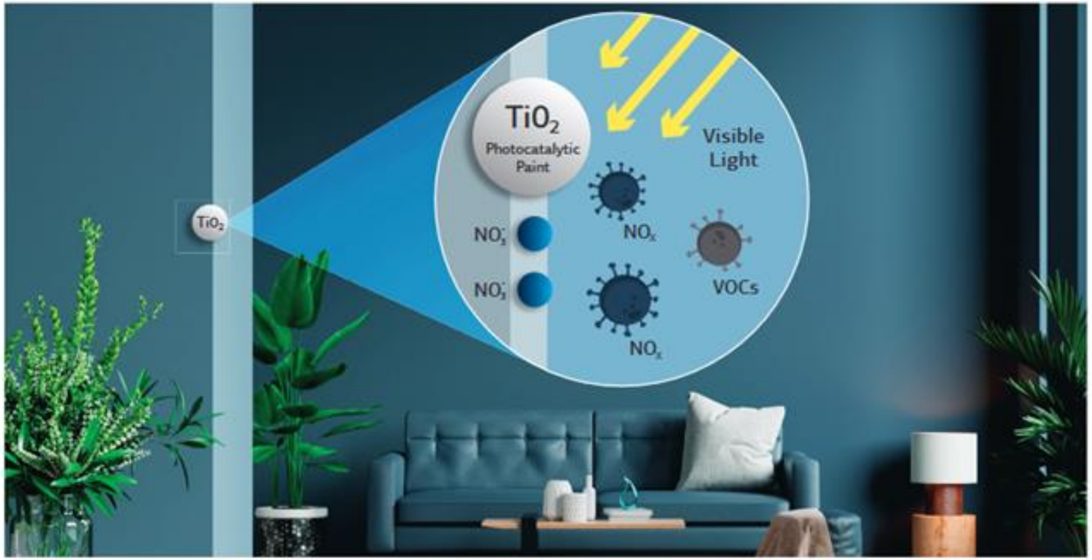
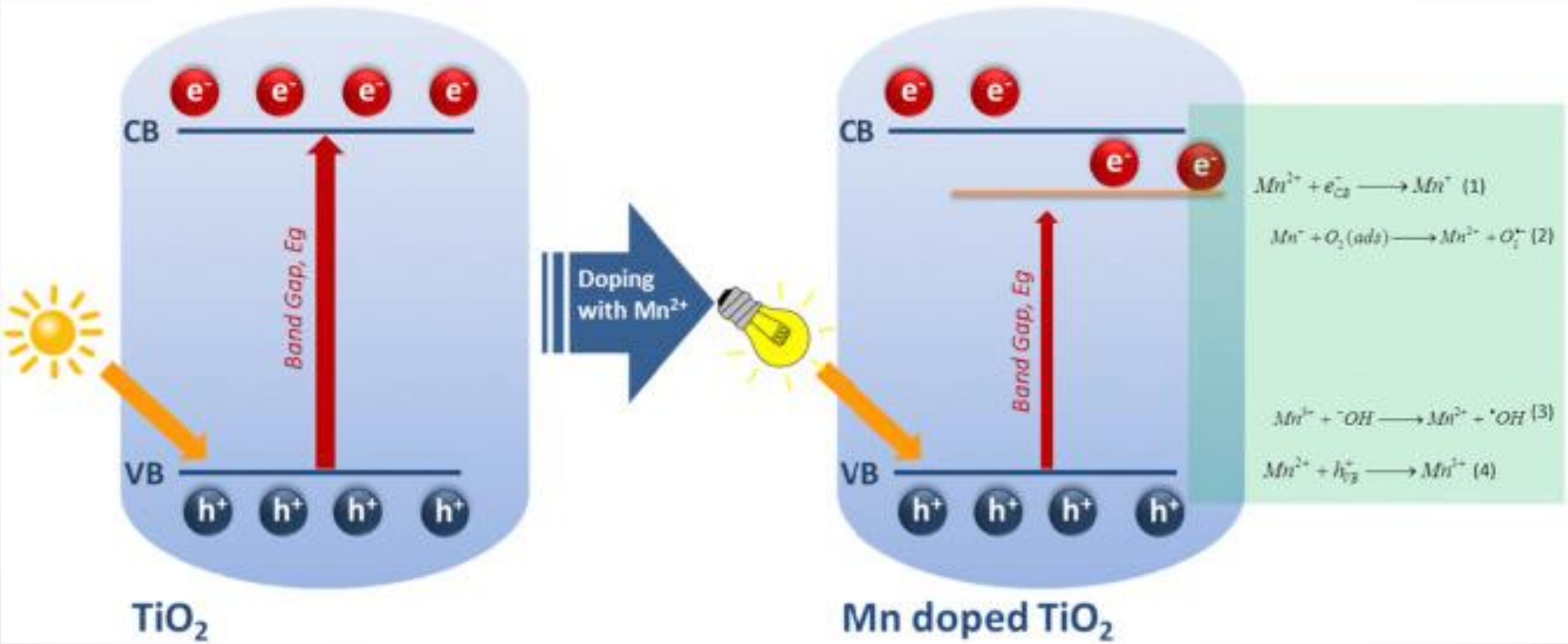
LIFE VISIONS

- The project's main scope was to develop an innovative photo-catalytic paint, which may help improving indoor air quality.
- The best performing product was tested in demo houses in Crete and in a real-life case study in the Hellenic Naval Academy in Athens.



Innovation of the VISIONS photo-paint

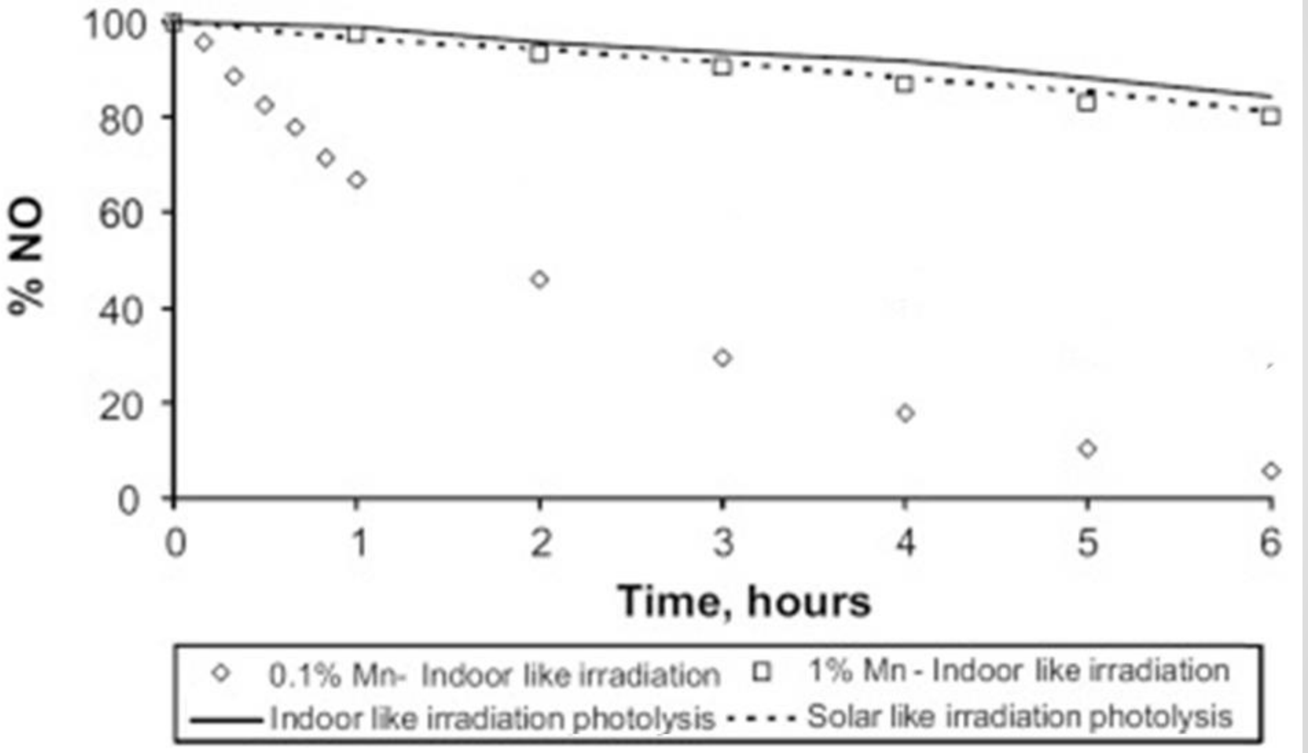
In LIFE VISIONS, the application of metal-doped anatase TiO_2 photo-catalyst powder was tested for the oxidation of NO_x under indoor-like illumination conditions. The metal-doped TiO_2 nanoparticle photocatalytic powder was optimized as it is activated both in visible and UV light.



V. Binas *et al.*, Journal of Materiomics *3* (2017) 3-16

VISIONS photo-paint – NO degradation

- Comparison of photo-lytic and photocatalytic decomposition of NO with metal doped TiO_2 catalysts under indoor- and solar-like illumination.
- The most effective degradation rate was obtained with the 0.1% doping photo-catalytic coatings under visible light irradiation.



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Modelling methodology in LIFE VISIONS

- In addition to measurements, modelling tools were applied in order to assess the overall environmental, health and economic benefit of the innovative photo-paint compared to conventional paints already in the market.
- A Computational Fluid Dynamics (CFD) model was applied to analyze the flow and the concentration patterns of air pollutants in indoor environment.
- The assessment of environmental impacts was performed on the basis of Life Cycle Assessment (LCA) covering the entire life-cycle (cradle-to-grave approach) of the two alternative paint products.
- Cost Benefit Analysis (CBA) was conducted as a final stage in the evaluation of the photo-paint, where the health benefits resulting from the reduced indoor air pollutant levels are also translated into monetary terms.

Depollution CFD modelling

- The commercial CFD code ANSYS CFX was utilized in RANS mode.
- The standard *k*-*ε* two-equations turbulence closure model was chosen, in conjunction with the standard wall functions for the near wall treatment.
- An algorithm which utilizes lab-scale measurements for the degradation of the pollutants under consideration upon contact with covered walls and surfaces was employed:
  - The deposition calculations were based on the deposition flux at the treated surfaces, F_d

    $$F_d = U_{dep} \cdot C_{walls}\,, \quad \text{where } U_{dep} \text{ is the deposition velocity}$$

  - Pollutant removal was taken into account by including a momentum sink term in the momentum equation.

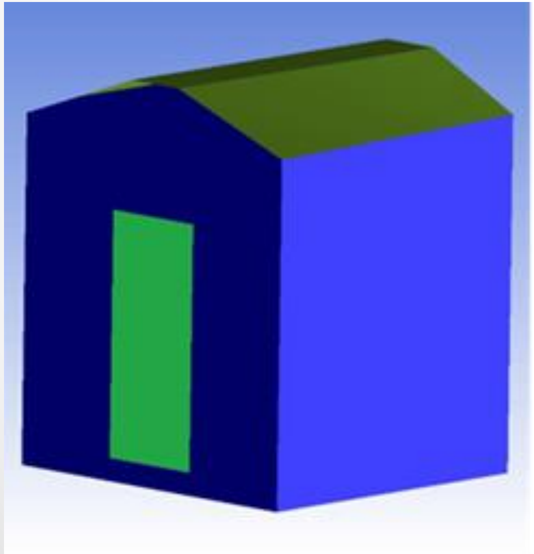
Demonstration of the photo-paint: Demo houses

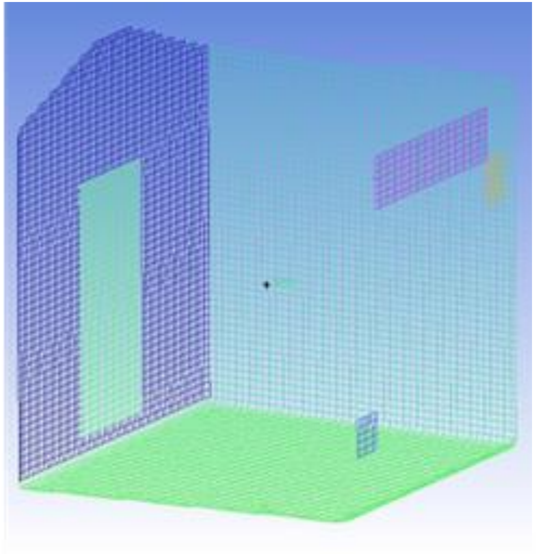
- Two identical demo houses were constructed in the premises of the Foundation for Research and Technology – Hellas (FORTH, Crete).
- The inner walls were covered either with photocatalytic paint (green house) or with an inactive paint (conventional house).
- Measurements were conducted for NO_x and toluene under visible light and UV lamp.
- The houses were initially filled with NO_x up to 500 ppb. A small fan on the floor was then used to increase the mixing.

Front and back view of the two demonstration houses in the premises of FORTH

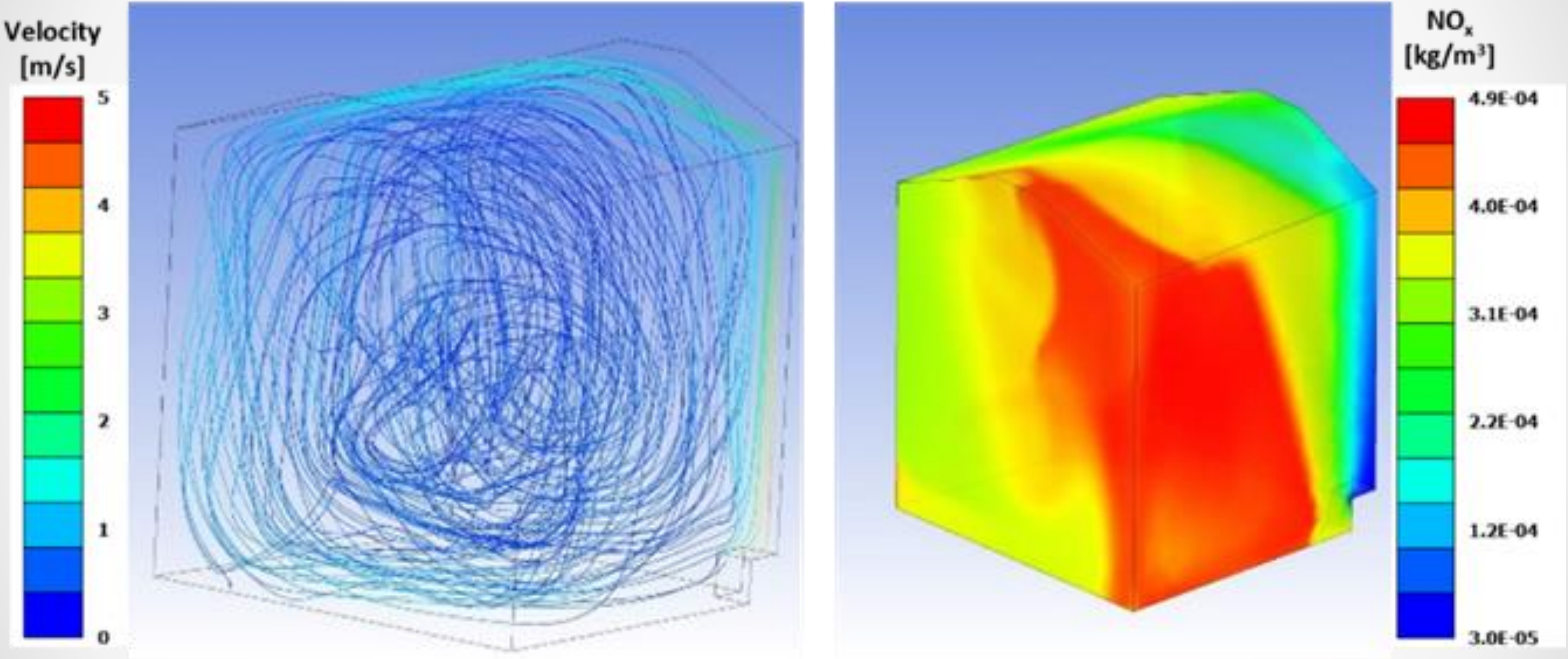
CAD model and grid mesh – Demo houses

- A CAD model and a grid mesh for the demo houses were generated.
- Based on the results of a grid sensitivity study, the optimum mesh comprised of a total 1×10^6 hexahedral cells.
- The effect of the fan on the mixing was approximated as a vertical jet.



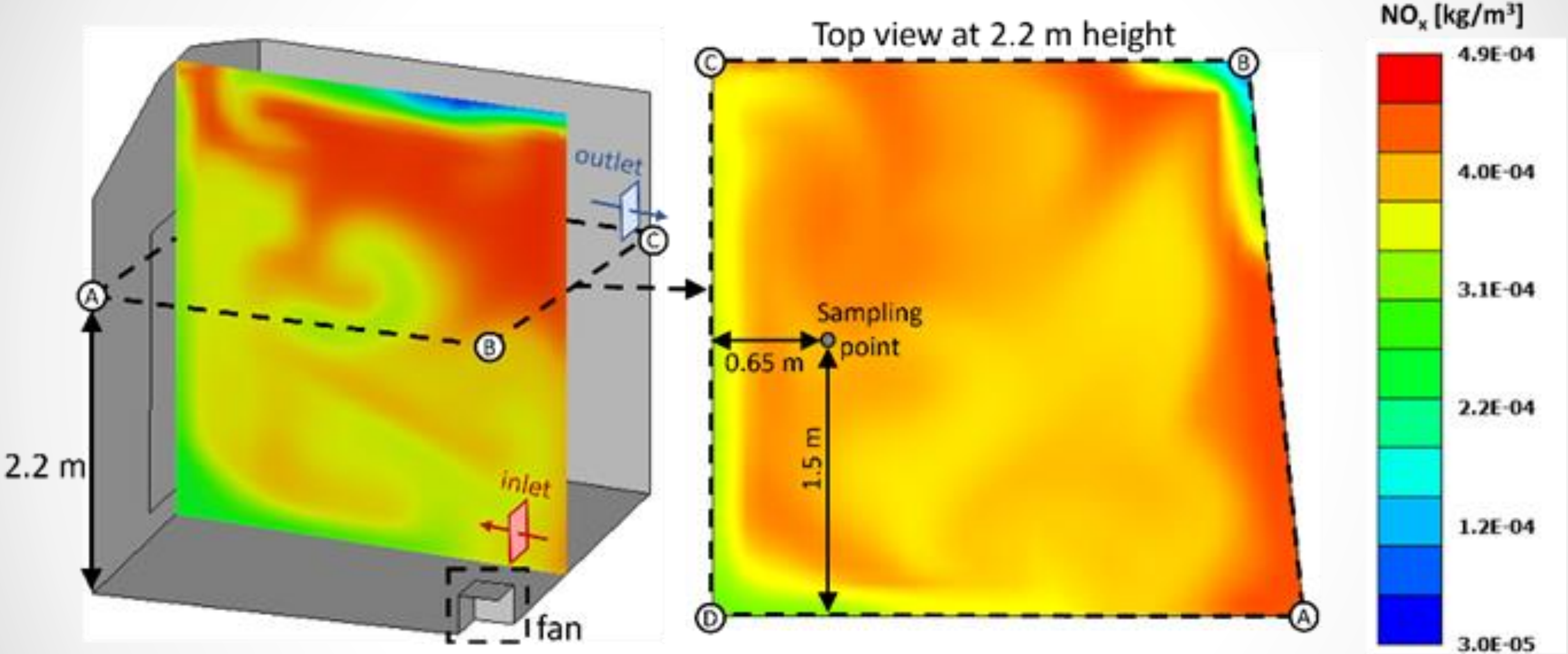


CFD results - Demo houses (1)



Fan induced mixing (left) and NO_x concentration distribution at the walls (right)

CFD results - Demo houses (2)



NO_x concentration distribution in a vertical level at the middle of the houses (left) and NO_x concentration distribution in a horizontal level at middle height of the houses (right)

CFD results - Demo houses (3)

Pollutant	Radiation scenario	Removal (%)		U_{dep} ($cm\ s^{-1}$)
		Measured	Modelling	
NO_x	Natural light	61.7	70	0.028
	Natural + artificial light	70.1	85	0.034

- Depending on the radiation scenario, both measurements and modelling results indicate a very high removal of NO_x, between 60% and 85%.
- The removal rate is enhanced by the fan-induced intense mixing, forcing air masses towards the treated walls.
- This also explains accumulation of NO_x concentrations near the walls and corners.

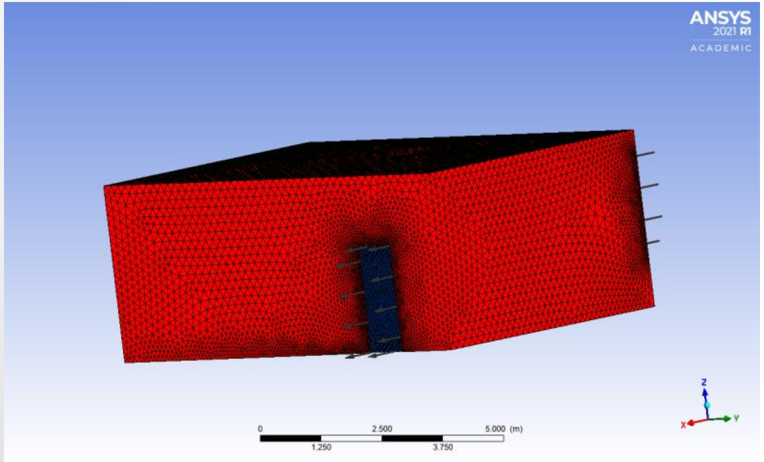
Real-life application, Hellenic Naval Academy

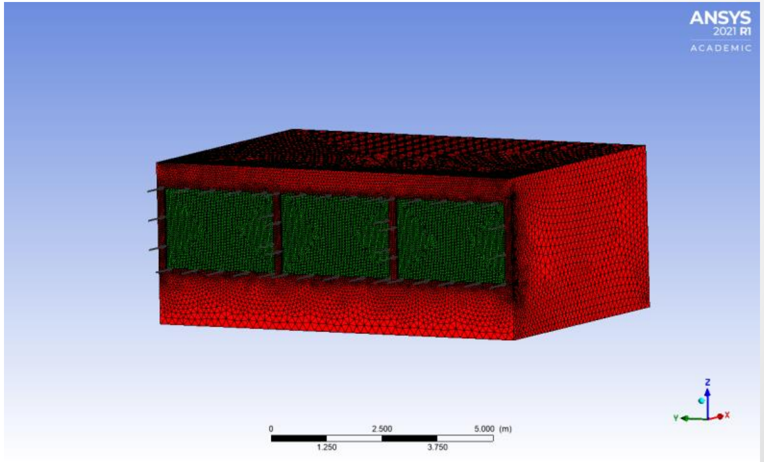
- Two identical teaching rooms in the HNA were monitored using passive organic (BTX) and inorganic (NO_x) samplers, temperature and humidity recorders.
- Conventional room: two coats of the baseline paint, Green room: 2^{nd} coat (only) was done with the photocatalytic product.

- No mechanical ventilation in the rooms

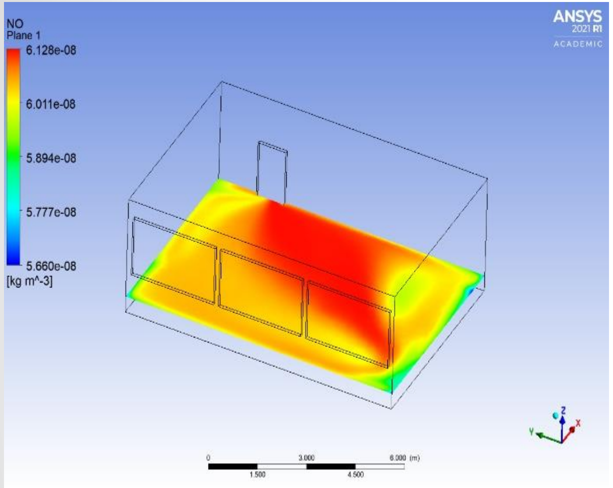
CAD model and grid mesh – HNA

- An unstructured computational mesh was generated comprising 758449 tetrahedral cells based on HNA CAD model.
- The air was assumed to flow in through the windows and out through the door
- Outdoor pollutants were assumed to enter following the wind direction

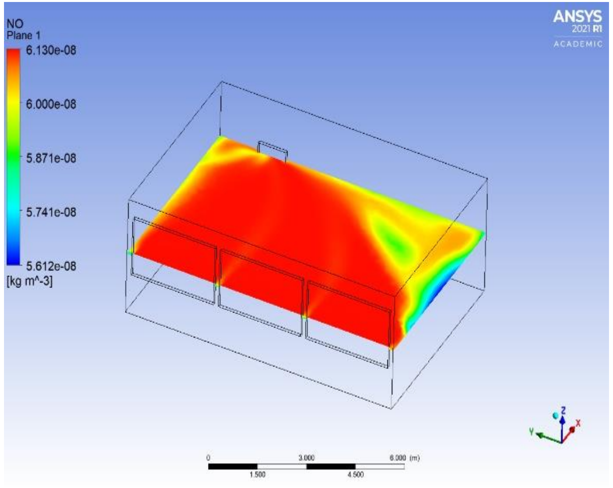




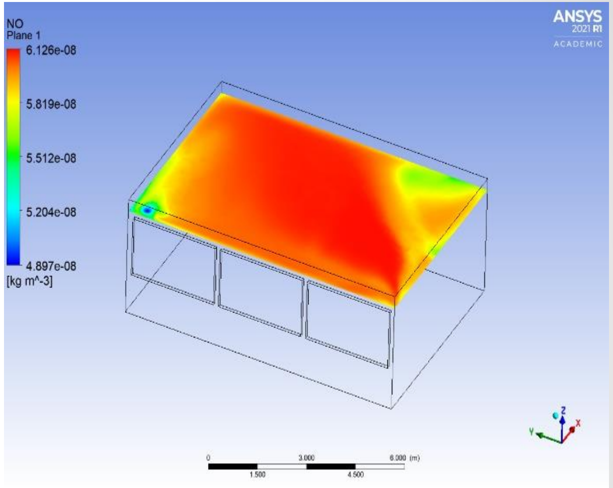
CFD results – HNA (1)



z = 0.5 m



z = 1.9 m



z = 3.3 m

NO concentrations on a x–y section for z=0.5 m, z=1.9 m, and z=3.3 m

CFD results – HNA (2)

	NO concentration ($\mu g/m^3$)	Percentage reduction (%)
Maximum reduction	42.0	31.5
Layer for $z = 0.5\ m$	56.6	7.7
Layer for $z = 1.9\ m$	56.1	8.5
Layer for $z = 3.3\ m$	49.0	20.1

- NO concentration throughout the entire room with photocatalytic paint tends to align with the outdoor concentration levels ($c = 61.3\,\mu g/m^3$) coinciding with those in the conventionally painted room.
- Highest NO concentration decreases are observed near the photocatalytically painted walls.

LCA methodology

Goal & Scope

- Environmental impacts comparison:
  - Conventional paint vs Innovative photocatalytic paint
- Cradle-to-Gate & Cradle-to-Grave approach
- Support Decision Support System (DSS) for stakeholders

Inventory

- Data were collected from VITEX, FORTH, HNA, Process Equipment Design Laboratory (PEDL) and literature
- Choice of software (openLCA) and database (Product Environmental Footprints - PEF)

Impact Assessment

- Choice of impact assessment method (PEF) to conduct all related calculations and analysis

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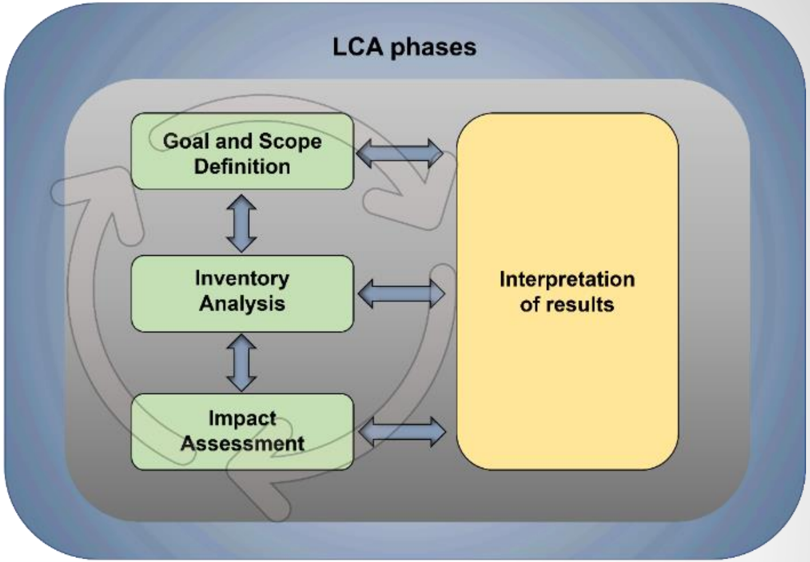
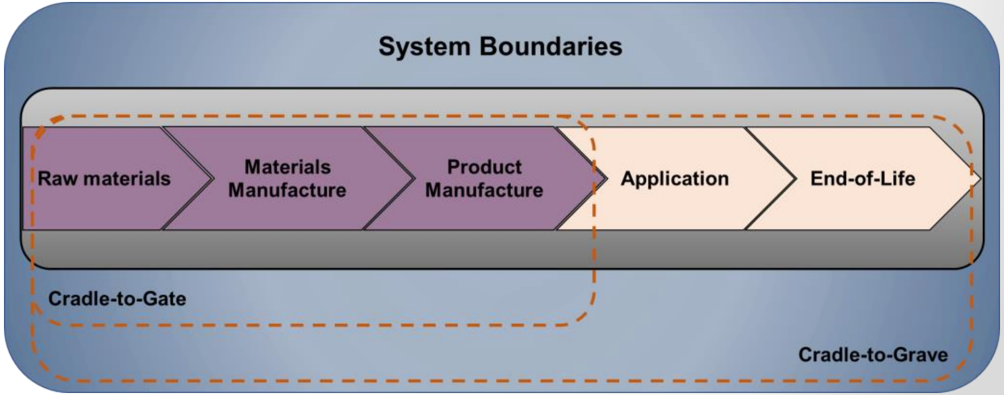
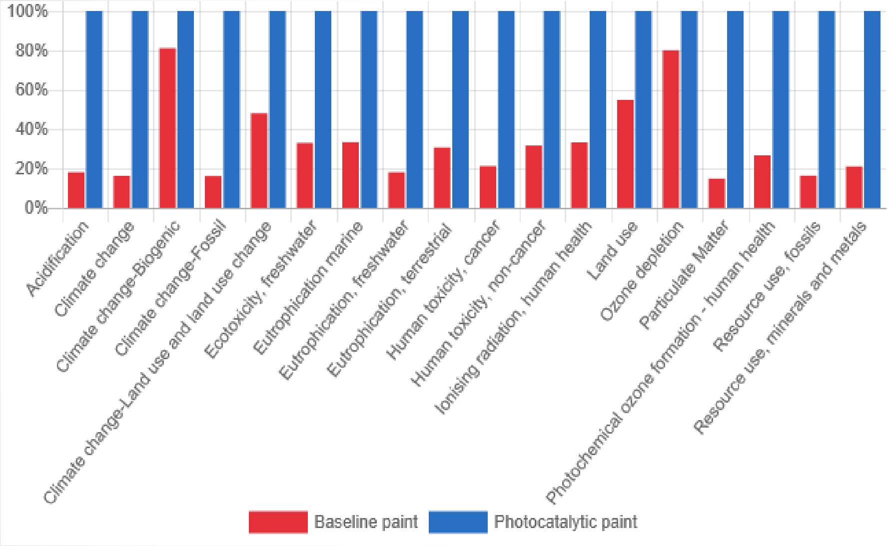
Results Interpretation



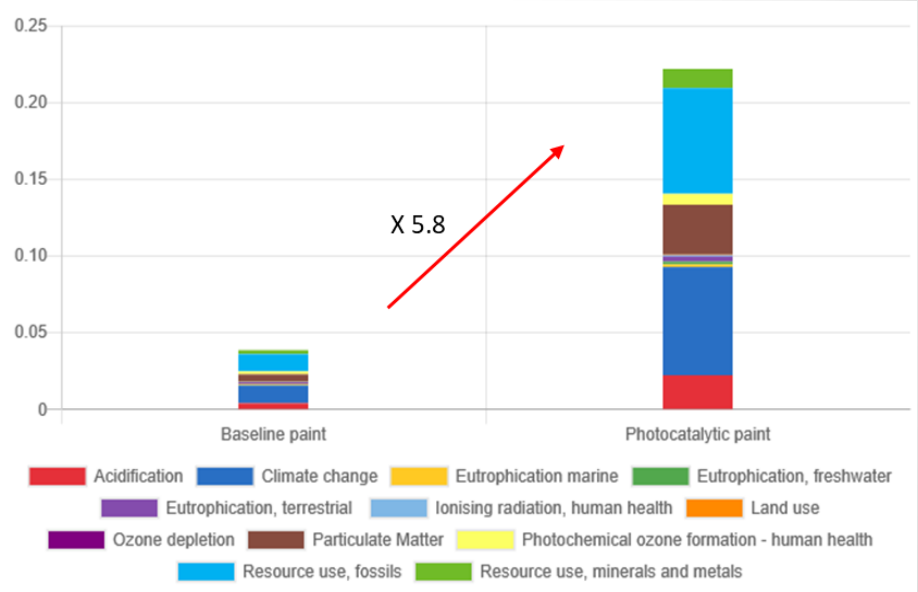


LCA results: Cradle-to-Gate approach

Paint production



Relative bar chart:
Midpoint impacts of producing 1tn of paint

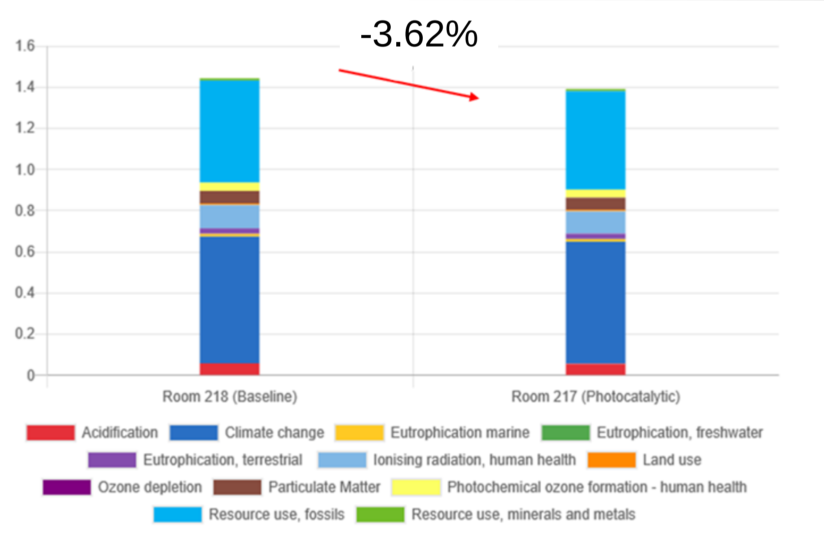


Single score analysis

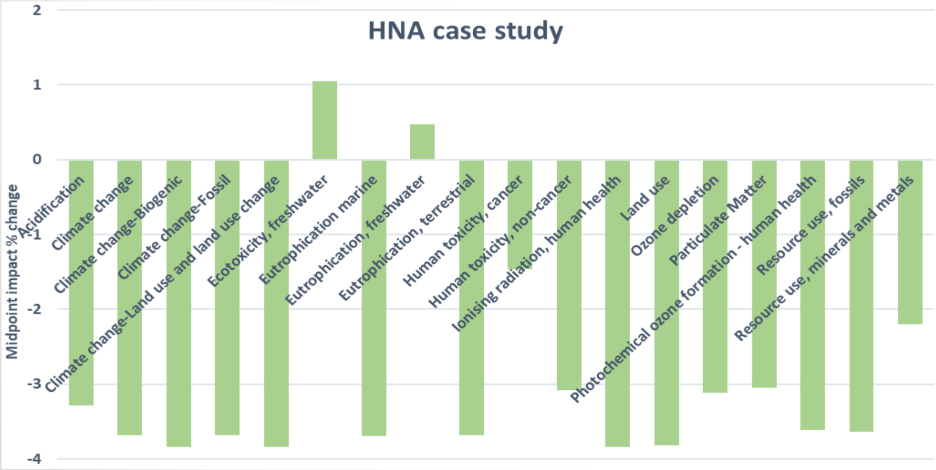
LCA results: Cradle-to-Grave approach

Including paint application

Energy saving rate of 3.85%, based on PEDL's (AUTh) simulations



Single score analysis



Midpoint impacts % relative change

If at least an 0.22% energy saving rate is achieved, the photo-paint proves to be environmentally friendlier

Conclusions

- The LIFE VISIONS project aimed to demonstrate the effectiveness of an innovative photocatalytic paint (photo-paint) in indoor air quality improvement.
- CFD results from the demo houses (FORTH) show a good agreement with measurements and exhibit a high NO_x removal rate between 70% and 85%, as a result of the fan-induced mixing, forcing air masses towards the treated walls.
- The results in the real-life application (HNA) indicate that application of the photo-paint leads to notable concentration level decreases, especially near the painted walls (rates exceeding 30%).
- LCA results show that, despite the high environmental footprint related to the photo-paint production, an energy saving rate of as low as 0.22% during the application is sufficient for achieving an overall environmental performance improvement.

Acknowledgements

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Thank you for your attention!