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The University of Manchester

Analysis of the innovative material AIRCORAL+

FINAL REPORT

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Report AIRCORAL+ Confidential

The present document faithfully reports the measurements performed by The University of Manchester – the School of Chemical Engineering and Analytical Science – Professor Krishna Persaud and his team. The information and data that it purports to represent are ideally complete and neutral.

Professor Krishna Persaud

November 2017, K C Persaud

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`Glossary

Abbreviation / Acronym	Description/meaning
VOC	Volatile Organic Compounds
GMT	Greenwich Mean Time
PM1	Particulate matter 1 micron
PM2.5	Particulate matter 2.5 micron
PM10	Particulate matter 10 micron
PID	Photoionisation detector
WITH	Air quality measurements done with direct influence of AIRCORAL+
WITHOUT	Air quality measurements done without any direct influence of AIRCORAL+
BUZZI	BUZZI & BUZZI

Introduction

This report forms a summary of the results obtained from a detailed study carried out on "Analysis of the innovative material AIRCORAL+" for BUZZI & BUZZI made by the independent authority, **The University of Manchester –** the **School of Chemical Engineering and Analytical Science – Professor Krishna Persaud** and his team.

The analyses were conducted along the following plan during 2017.

TASK 1 - Prototypes installation at 6 real scenarios (BUZZI & BUZZI; University of Manchester);

The best location options were analysed, both as real and controlled scenario installations giving the possibility to test and validate the innovative AIRCORAL+ material in different real air conditions by the Professor Krishna Persaud.

1) **Residence Palace (Brussels, Belgium) – during the '*The European Sustainable Energy Week*' www.eusew.eu, initiative of the European Commission**
2) **Hospital San Giacomo (in the Brescia suburb, Northern Italy)**
3) **Restaurant 'Alessandro Borghese - Il Lusso della Semplicità' (center of Milan, Northern Italy)**
4) **Kindergarten - Scuola dell'infanzia Statale "Gianni Rodari" (in the Milan suburb, Northern Italy)**
5) **High School - Liceo Scientifico "Giordano Bruno" (in the Milan suburb, Northern Italy)**
6) **The University of Manchester - School of Chemical Engineering and Analytical Science (Manchester, UK)**: the lamps were also installed at the University, in a specific simulation chamber to further assess the produced benefits under controlled conditions.

TASK 2 - Environmental benefits assessment of AIRCORAL+ lamps installations (University of Manchester)

The effects on the main air pollutants due to the eco-activity of the innovative AIRCORAL+ material, were measured, before and after the installations of the AIRCORAL+ (body)lamps: different kind of measurements were foreseen as follows, **according to recognized international standard methods** (ref. the next dedicated chapter).

a) Online measurements:

• gaseous pollutants were checked by using an array of gas sensors of different technologies capable of on-line measurements

• mass concentrations of particle fractions PM10, PM2.5 and PM1 were measured

b) Passive or active sampling/analysis for VOCs;

c) Sampling/elemental analysis of health relevant fractions of suspended particles (alveolar particles, PM1);

d) Analysis of major and trace elements.

This was done using Inductive Conductive Plasma-Optical Emission Spectroscopy (ICP-OES).

e) Bacterial load measurements

Determination of microbial load for airborne microorganisms. Focus was placed on two common pathogens – staphylococcus and pseudomonas.

Materials and Methods

Particle Size Measurements

The accepted international standard definitions of particle mass loadings in the air are PM2.5 and PM10, as not all standards groups have defined PM1 yet. These definitions relate to the mass and size of particles that would be inhaled by a typical adult. So, for example, PM2.5 is defined as 'particles which pass through a size-selective inlet with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter'. The 50% cut-off indicates that a proportion of particles larger than 2.5 µm will be included in PM2.5, the proportion decreasing with increasing particle size, in this case out to approximately 10 µm particles. The measure of airborne particulate matter PM10 is effectively defined for European regulatory purposes by the European Committee for Standardisation (CEN) standard EN 12341 which supersedes CEN standard for PM2.5, EN 14907:2005, (which includes tighter control of the handling of sampled filters to reduce losses of semi-volatile material).

The Alphasense Optical Particle Detector OPC-N2 portable instrument was used for the measurements of the effect of BUZZI light fittings on the distribution of ambient particles in the ambient environment. This calculates the respective PM values according to the method defined by **European Standard EN481**. Conversion from the 'optical size' of each particle as recorded by the OPC-N2 and the mass of that particle requires knowledge of both particle density and its Refractive Index (RI) at the wavelength of the illuminating laser beam, 658 nm. The default values are those defined by European Standard EN481 for PM1, PM2.5 and PM10 with an additional multiplier being used such that the OPC-N2 matches better to standard reference instruments when used in the field and to correct for some of the missing mass below the OPC detection limit of 0.38 µm.

Sampling of airborne microorganisms

The Sartorius MD8 air sampler was adopted during the measurements of BUZZI light fittings. It operates by filtration where a known volume of air is drawn through a gelatine membrane filter. The filter is subsequently incubated on an agar plate and any colonies formed are counted. The filter membrane is composed of gelatine foam designed to prevent vegetative micro-organisms being inactivated by desiccation when air is drawn through the filter. Microbiological assay of the collected sample can either be carried out by placing the gelatine filter directly on nutrient agar before incubation, or by dissolving the gelatine filter in buffer and determining the microbial content of the suspension by suitable assay technique. The portable AirPort MD8, is designed to detect smallest viruses and microorganisms in the air by using unique Gelatine Membrane Filters (GMF) and BACTairTM agar plates.

Passive sampling of Airborne Microorganisms

1441070050 Blank Strip Kit, Agar Strips 941605 HYCON® were used for trapping airborne organisms. These were subsequently cultured on agar plates to determine the microbial growth.

Dust Sampling for Elemental Analysis

A Casella General Dust Monitoring Kit with an APEX sampling pump and 0.45 µm pore size cellulose acetate filters were used to sample air according to **EN1232 and EN12341 standards**. Elemental Analysis was carried out using an inductively coupled plasma optical emission spectrometry ICP-OES instrument (Plasmaquant PQ9000 Series). **ICP standards** (Agilent 6610030600) were used to calibrate

the instrument for the following metals: Ag, Al, As, Ba, Be, Cd, Co, Cr, Cu, Mn, Ni, Pb, Se, Ti, Th, U, V, Zn.

Table 1 shows the limits established by the EU for trace elements in particulate matter.

Elements	Limit Value	Averaging Period	Date to be met	EU Directive
Pb	0.5 µm m^{-3}	Year	Since 2005	EU Directive 2008/50/EC
PM10	40 µg m^{-3}	Year	Since 2005	EU Directive 2008/50/EC
PM10	50 µg m^{-3}	Day (90%ile)	Since 2005	EU Directive 2008/50/EC
PM2.5	25 µg m^{-3}	Year	2015	EU Directive 2008/50/EC
PM2.5	20 µg m^{-3}	Year	2020	EU Directive 2008/50/EC

Elements	Target Value	Averaging Period	Date to be met	EU Directive
As	6 ng m^{-3}	Year	2013	EU Directive 2004/107/EC
Ni	20 ng m^{-3}	Year	2013	EU Directive 2004/107/EC
Cd	5 ng m^{-3}	Year	2013	EU Directive 2004/107/EC

Table 1 EU limit and goal concentrations for Pb, As, Cd and Ni in PM10 (From J. Boman et al. / Spectrochimica Acta Part B 65 (2010) 478–482 479)

Typically, **air was sampled for 4 hours at 2 litres/min.** The filter was placed in a glass vial and 1 ml of 68% Nitric Acid was added. This was heated to 100 ^{o}C to digest the filter. 200 µl was diluted into 10ml of 2% Nitric acid, and this was analysed using the ICP-OES instrument.

Kirby Bauer Bacterial Susceptibility Testing

The Kirby-Bauer test for antibiotic susceptibility, called 'the disc diffusion test', is a standard that was first developed in the 1950s, it was refined and by W. Kirby and A.Bauer, then standardized by the World Health Organization in 1961. This test is used to determine the resistance or sensitivity of aerobes or facultative anaerobes to specific chemicals, which then is used by the clinician for treatment of patients with bacterial infections. The presence or absence of an inhibitory area around the disc identifies the bacterial sensitivity to the drug.

The bacterium is swabbed on the agar and the antibiotic discs are placed on top. The antibiotic diffuses from the disc into the agar in decreasing amounts the further it is away from the disc. If the organism is killed or inhibited by the concentration of the antibiotic, there will be NO growth in the immediate area around the disc: this is called the zone of inhibition. The zone sizes are looked up on a

standardized chart to give a result of sensitive, resistant, or intermediate. The Mueller-Hinton medium being used for the Kirby-Bauer test is very high in protein.

The following organisms were used for Kirby Bauer susceptibility testing for AIRCORAL+ light fittings.

- QC Organism Staphylococcus Aureus ATCC25923 for Kirby Bauer susceptibility testing
- QC Organism Pseudomonas Aerogines ATCC10145

Gas Sensing

An array of sensors consisting of different technologies was deployed. This incorporated O_2 (electrochemical), CH_3SH (electrochemical), H_2S (electrochemical), volatile organic hydrocarbons (photo ionisation detector PID), CO_2 (infrared detector), CH_4 (infrared), CO (electrochemical), NH_3 (ammonia).

These sensors are capable of detection of ppm to ppb levels, and the percentage changes in concentration levels were recorded.

Compliance to International Standards

We do believe measurements must follow international standards and procedures to be reliable and to effectively demonstrate the real achievements.

Here following we summaries all the internationally recognized standards we followed and complied with for each type of measurements taken as described in the present analytical report.

All measurements described in the present report fully comply with the mentioned standards.

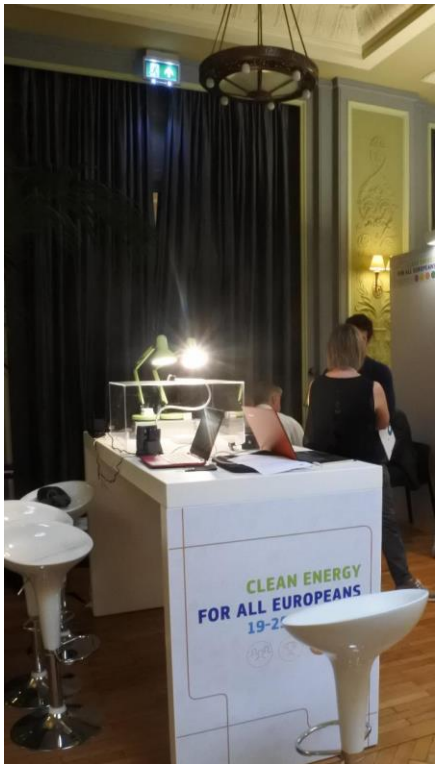
Measurement type	Standards compliance
PM Measurements	EN481 and EN 12341
Dust Samples Trace Measurements	EN1232 and EN12341
Gas Sensing	ISO 22197-1:2007
Microbial Measurements	ISO27447:2009

Scenario 1. Residence Palace Brussels

Deployment of sensing systems at the Residence Palace hotel in Brussels during "*The European Sustainable Energy Week*". This was carried out on 21st and 22nd June 2017.

It is worth underling that the setting at the "*The European Sustainable Energy Week*" was also very useful – upon specific request by the EC - to showcase the innovativeness and sound features of the AIRCORAL+ to a wide audience during a specifically dedicated event to the environmental sustainability.

In the Exhibition hall of the Palace, on our desk we placed a plexiglass box, used to provide a controlled environment for the measurements of the effect of tiles made of AIRCORAL+ illuminated by lamps. Air sampling was taken out of the influence of the AIRCORAL+ light fittings when the hall was populated by tens of persons: this represent the control of the measurements.



The temperature inside the hall was kept constantly at about 22°C by an air conditioning system and the pressure was between 1012 and 1016 mbar.

The plexiglass box was placed on the desk in the conference hall, with an AIRCORAL+ tile inside. On the left front is the particle counter measuring PM1, PM2.5 and PM10 particles. Between these two, on the bench is another agar strip for sampling air outside the plexiglass box.

Effect on PM Concentrations

Trial Setting and Configuration

An illuminated plexiglass box was used to produce a controlled environment – to avoid air sample changes and external influences - for the tests and particle measurements (PM1, PM 2.5 and PM 10): air sample was acquired outside the box in the Hall room in a real time monitoring configuration at a rate of 2 litres/minute, to determine first the air quality without the AIRCORAL+ material and then with the material, by introducing inside the plexiglass box a AIRCORAL+ tile.

Data were collected over a two days period. The air sampling and measurements lasted continuously for approximately 10 hours, each day.

Results

The Figures 1 and 2 show results obtained from real time monitoring of the environment for PM 1, PM 2.5 and PM10 particles for the 2 days measurements.

- There was large increase in the PM particle concentrations when the hall was populated.
- When the sample air was placed in the plexiglass box **WITH the AIRCORAL+ material, the monitored PM particles fell to very low levels**. **Figures 3 and 4** show the mean differences found in PM1, PM2.5 and PM10 particles over the monitoring period. The results clearly indicate **reduction of PM concentrations of all sizes from 40% to 72% depending on the size of the PM particles**.

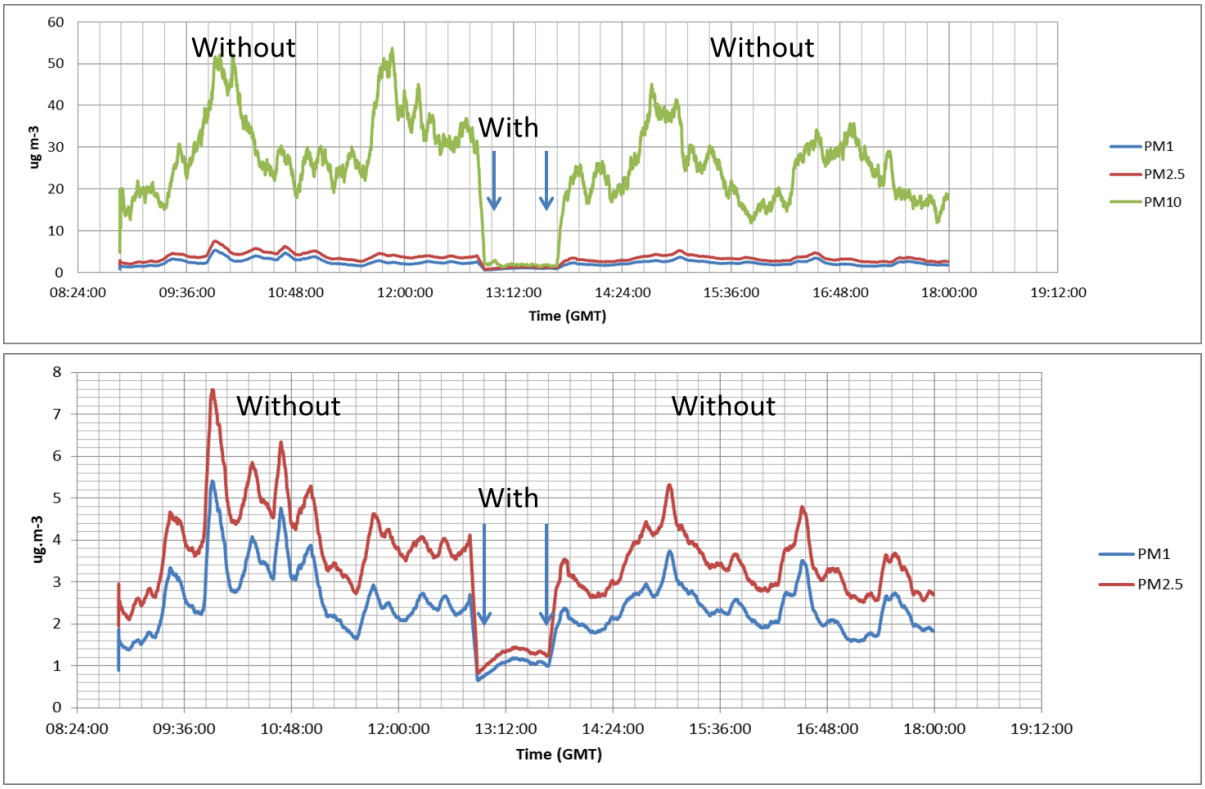


Figure 1 **Day 1 Measurements**. Top graph shows the real-time PM concentrations measured WITHOUT the effect of the AIRCORAL+ material followed by environment WITH the AIRCORAL+ material in the plexiglass box. **A dramatic decrease in PM particles is observed**. The lower graph shows the PM1 and PM2.5 particle concentrations on an expanded scale.

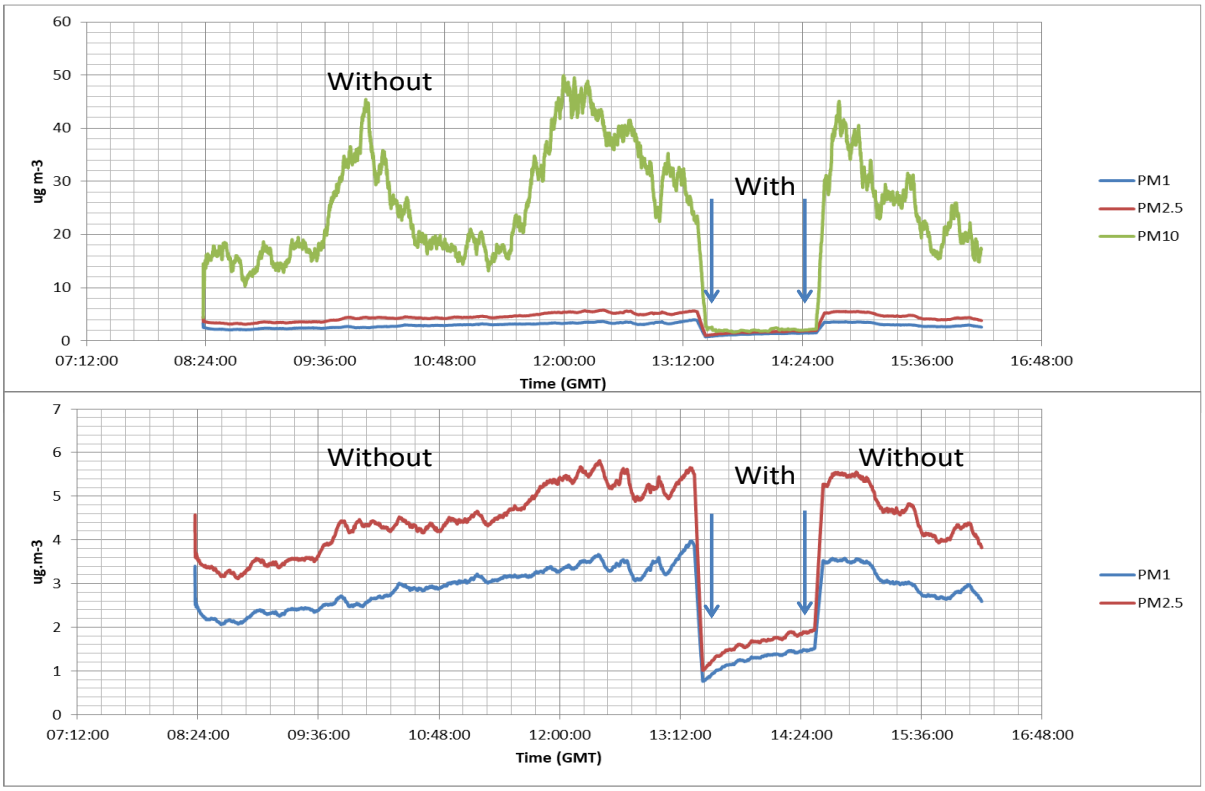
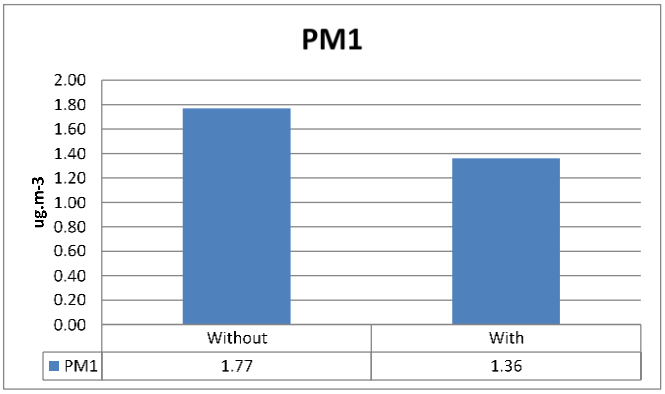
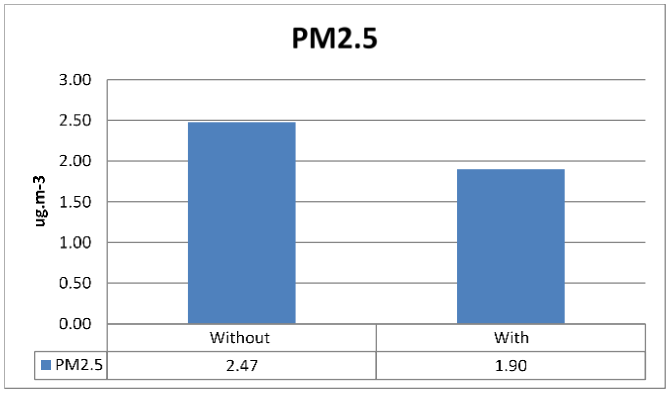


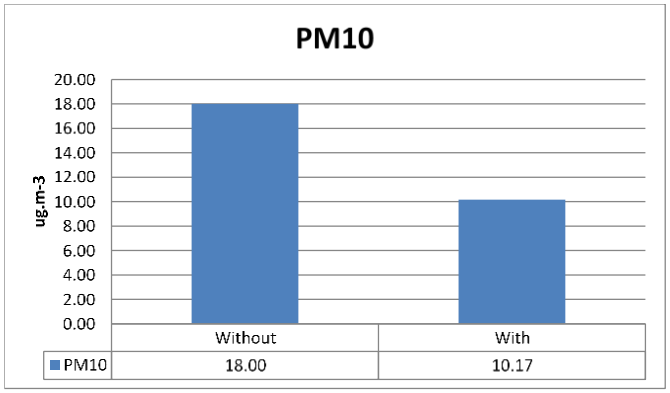
Figure 2 **Day 2 Measurements**. Top graph shows the real-time PM concentrations measured WITHOUT the effect of the AIRCORAL+ material followed by measurements from the environment WITH the AIRCORAL+ material in the plexiglass box. **A dramatic decrease in PM particles is observed**. The lower graph shows the PM1 and PM2.5 particle concentrations on an expanded scale.



(a)



(b)



(c)

Figure 3 - Day 1 Measurements. Average difference of PM1, PM2.5 and PM10 concentrations WITHOUT and WITH exposure to the AIRCORAL+ material in a plexiglass box.

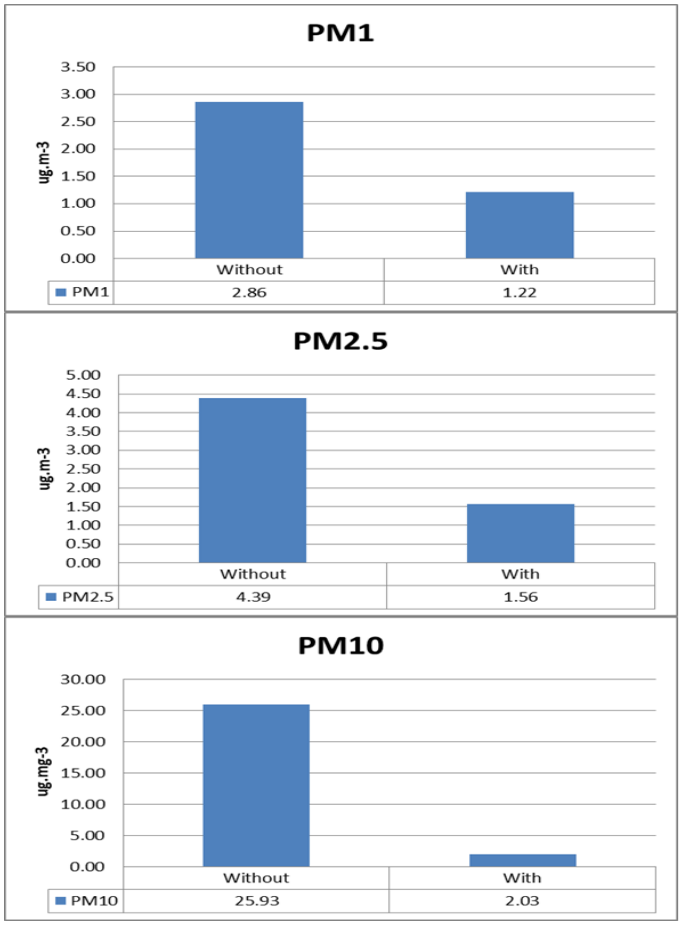


Figure 4 - **Day 2 Measurements**. Average difference of PM1, PM2.5 and PM10 concentrations WITHOUT and WITH exposure to the AIRCORAL+ material in a plexiglass box.

EFFECT ON PM CONCENTRATION BY AIRCORAL+ → SUMMARY OF RESULTS

Summary Results PM Measurements – average data over the 2 days measurements

Scenario	PM	WITHOUT AIRCORAL+ µg/m3	WITH AIRCORAL+ µg/m3	Variation in PMs observed µg/m3	% variation
Field trial Brussels (Average over 2 days)	**PM1**	2.3	1.3	**-1.0**	**-40%**
Field trial Brussels (Average over 2 days)	**PM2.5**	3.4	1.9	**-1.7**	**-50%**
Field trial Brussels (Average over 2 days)	**PM10**	22	6	**-16**	**-72%**

Trace Metal Analysis of Dust Samples

No trace metal analysis was carried out on this site.

Gas Sensing

No gas sensing measurements were carried out on this site.

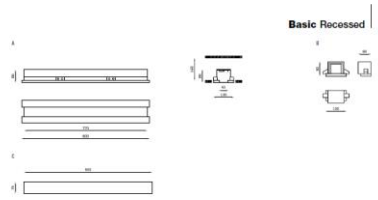
Microbiology

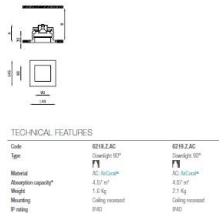
No microbiology measurements were carried out on this site.

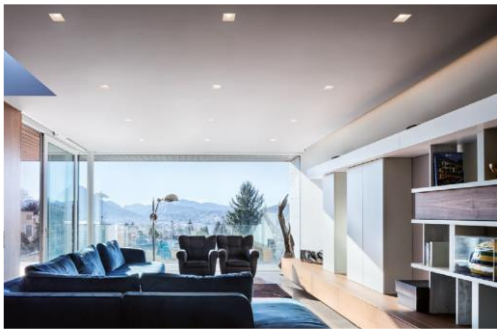
Scenario 2. San Giacomo Hospital

Deployment of sensing systems at the San Giacomo Hospital in Brescia (IT) suburb.

The tests were carried out in the main waiting room of 15 square metres at the Hospital with 4 lamps made by AIRCORAL+ of models *Nothing* and *Nefi* (as in the following figures from the catalogue).







- Images from the catalogue of the wall lamps used in this setting -

There the temperature was 20°C controlled by an air conditioning system and the air pressure was about 1018 mbar. The main room where the experiment was carried out was also well illuminated by sunlight in the morning, and shaded in the afternoon.

Effect on PM Concentrations

Trial Setting and Configuration

PM monitoring was carried out in real time over the day for approx. 5 hours. Several persons during the hours stayed and passed by the room. The measurements started by acquiring the air sample in the room where the AIRCORAL+ lamps were installed (see chart below where it indicates WITH, until approx. 13.00) then the air sample was acquired in another adjacent waiting room, without any lamp influence.

Results

Figure 5 shows the real-time PM10 data recorded. It is evident the PM10 lower level in the time range WITH the AIRCORAL+ while the PM10 increase within the air sample without the material. Due to technical problems in air sampling acquisition by the device, data of PM1 and PM2.5 are not available.

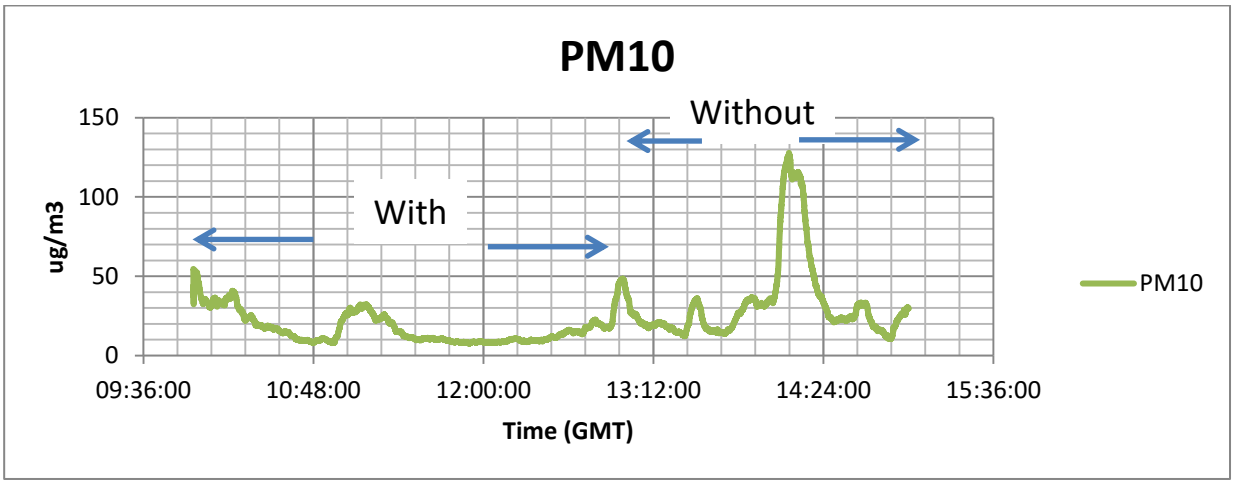


Figure 5 Realtime monitoring of PM10 concentrations – With/without AIRCORAL+

In the following figure 6, the average change in concentration of PM10 concentrations is recorded.

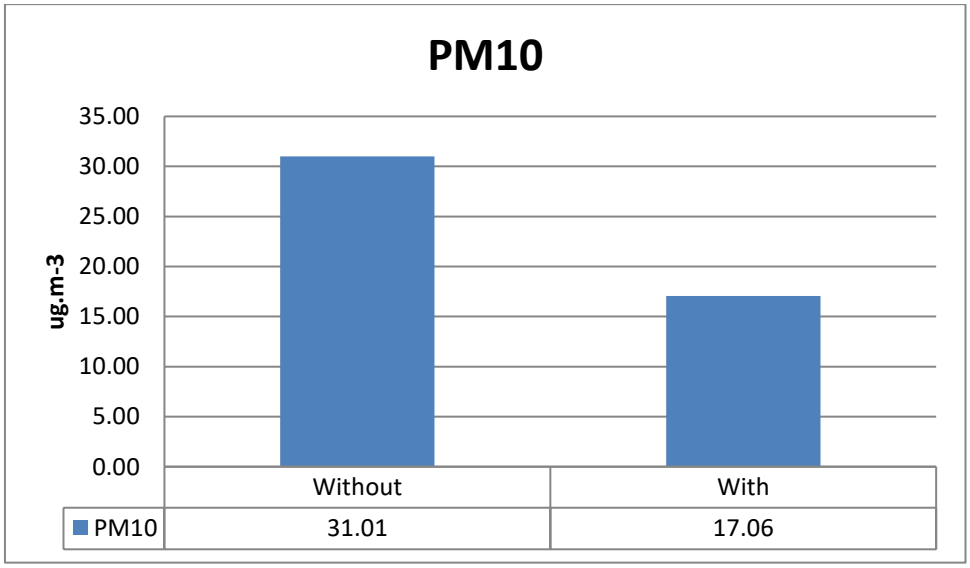


Figure 6 Average change in PM10 concentrations recorded from data.

EFFECT ON PM CONCENTRATION BY AIRCORAL + → SUMMARY OF RESULTS

Summary Results PM Measurements – average data

Scenario	PM	WITHOUT AIRCORAL+ µg.m-3	WITH AIRCORAL+ µg.m-3	Variation in PMs observed µg.m-3	% variation
Field trial Hospital in Brescia	**PM10**	31.01	17.06	**-13.95**	**-45.0%**

Trace Metal Analysis of Dust Samples

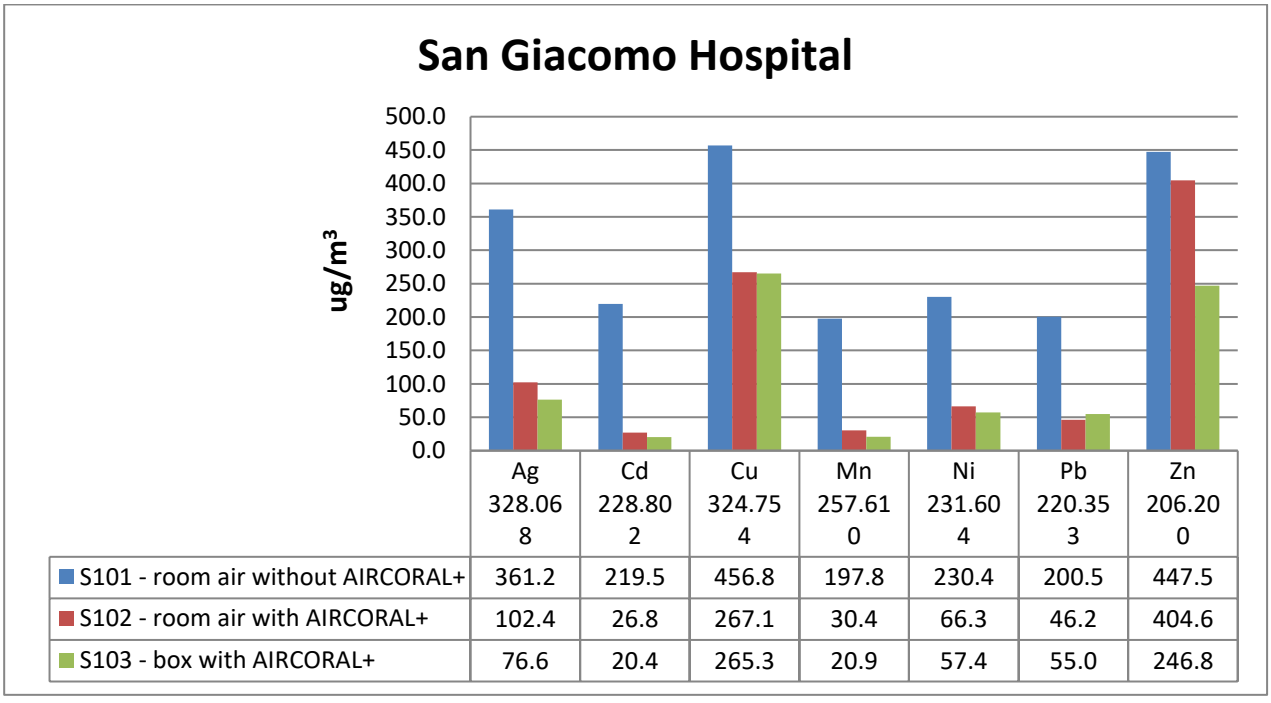
Trial Setting and Configuration

The following air samples were taken:

- An initial sample of dust (**S101**) from the air in an adjacent room out of the lamps influence was taken for 1.5 hours trapping 180 litres of air on to the sampling filter.
- Then another sample (**S102**) was taken in the waiting room for 2 hours (240 litres air) under the influence of AIRCORAL+ lamps.
- Finally, another sample was also taken for another 2 hours within an enclosed Plexiglass box with AIRCORAL+ tiles (**S103**).

Results

Figure 7 shows that there was a substantial metal traces decrease in the quantity of trace elements measured. Table 2 shows the percentage reduction in metal elements observed.



	Ag 328.068	Cd 228.802	Cu 324.754	Mn 257.610	Ni 231.604	Pb 220.353	Zn 206.200
S101 - room air without AIRCORAL+	361.2	219.5	456.8	197.8	230.4	200.5	447.5
S102 - room air with AIRCORAL+	102.4	26.8	267.1	30.4	66.3	46.2	404.6
S103 - box with AIRCORAL+	76.6	20.4	265.3	20.9	57.4	55.0	246.8

Figure 7 **S101** – Sample taken initially in test room, WITUOUT AIRCORAL+ influence. **S102** – Sample taken after 2 hours of illumination with BUZZI tiles. **S103** – sample taken from inside Plexiglass box with AIRCORAL+ tiles. There was significant reduction in concentrations of silver, cadmium, copper, manganese, nickel, lead and zinc thanks to the effects of the AIRCORA+ material lamps.

More specifically, it must be noticed that metal traces decrease is relevant in both the 2 conditions considered WITH AIRCORAL+:

comparing results from the sample S101 (blue bars in the chart above) and the sample S102 (red bars), means comparing the air quality in the room without the AIRCORAL+ effect with the air under the effect of the AIRCORAL+ made lamps in the waiting room. **The decrease is substantial**.

We also can notice that the measurements of trace elements within the plexiglass box (S103 – green bars) show a very limited variation compared to those about the 'open air' in the desk area (S102 – red bars). **We can derive that the AIRCORAL+ material seems to be very effective even without an enclosed and delimited setting (as it happens in the plexiglass box, with tight proximity of the air to the lamps) but it also shows huge reductions in a relatively 'open air' settings as in a large room.**

EFFECT ON DUST PARTICLES CONCENTRATION BY AIRCORAL + → SUMMARY OF RESULTS

The following table shows the metal traces average reductions according to the air samples of the previous experiments. **The % are calculated against the air sample WITHOUT any AIRCORAL+ influence**.

Table 2 - Reduction in trace elements observed after exposure to AIRCORAL materials

	Metal traces variation in the air room after 2 hours of illumination WITH AIRCORAL+		Metal traces variation after 2 hours within the plexiglass box with AIRCORAL+	
	%	ug/m3	%	ug/m3
Ag	**-71.6%**	-258.8	**-78.7%**	-284.5
Cd	**-87.7%**	-192.7	**-90.7%**	-199.1
Cu	**-41.5%**	-189.7	**-41.9%**	-191.5
Mn	**-84.6%**	-167.4	**-89.4%**	-177.0
Ni	**-71.2%**	-164.1	**-75.0%**	-173.0
Pb	**-76.9%**	-154.4	**-72.5%**	-145.5
Zn	**-9.5%**	-42.9	**-44.8%**	-200.7

Gas Sensing

An array of gas sensors were deployed in the waiting room of the Hospital, to monitor:

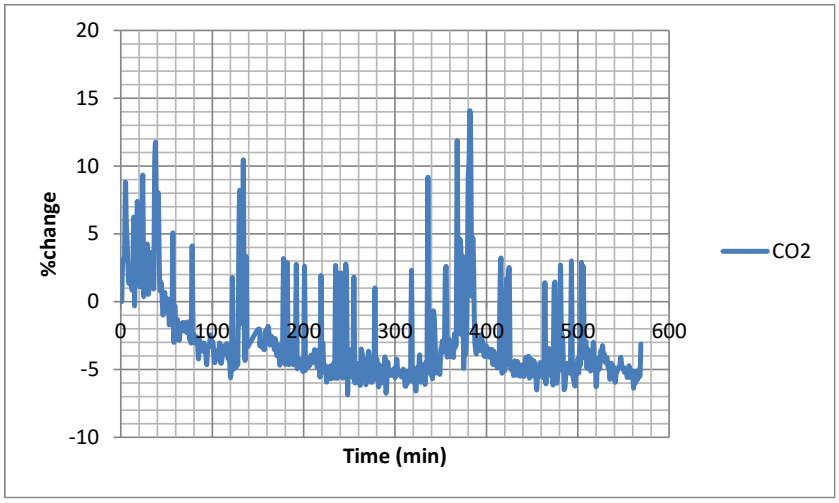
- oxygen,
- methyl sulphide,
- hydrogen sulphide,
- volatile organic hydrocarbons,
- carbon dioxide,
- methane,
- carbon monoxide
- ammonia.

The aim was to determine if any change of the environment occurred as a result of the AIRCORAL+ catalytic and anti-bacterial material lamps being deployed.

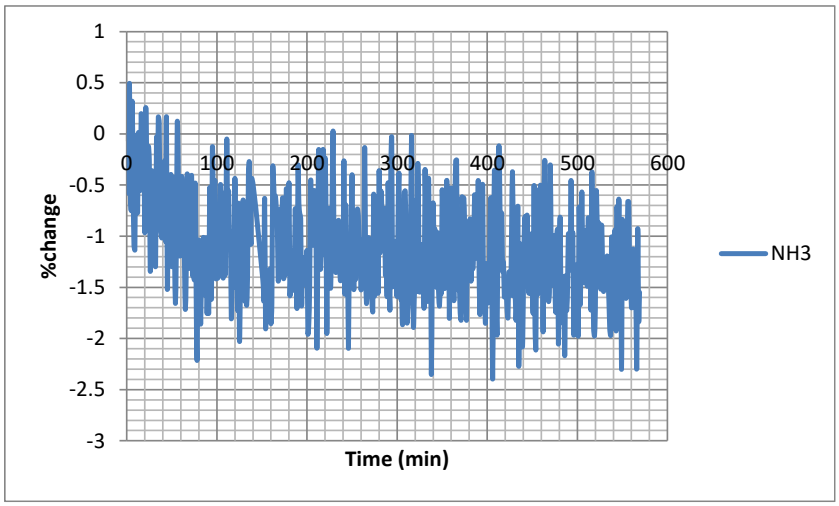
This instrument recorded data at 1 minute intervals during the day.

The results can be commented as follow:

- with **oxygen** there was no particular change during the day.
- As for **methyl sulphide and hydrogen sulphide, carbon monoxide** and **volatile hydrocarbons** (monitored by the photoionisation detector (PID)), their initial concentrations present in the environment were very small to measure any significant (positive or negative) trends.
- **Carbon dioxide** concentrations correlated with room occupancy – the peaks seen (as in the following chart) correspond to human activity. However there appeared to be an average decrease in carbon dioxide during the day.



- **Ammonia concentrations** decreased over the first two hours – as shown by the following chart - and then continued to decrease slightly over time.



Microbiology

Trial Setting and Configuration

A Sartorius air sampler was used to pull 150 litres of air across the filters from the plexiglass box with the AIRCORAL+ material, and the same was done outside the box to sample air from the environment in the adjacent room (without any AIRCORAL+ material influence).

The agar strips were then incubated in brain-heart media and tryptic-soy media to allow optimal growth of a range of different airborne bacteria.

Results

Figure 8 shows the control samples taken from the plexiglass container containing AIRCORAL+ tiles, the left grown in brain-heart media and the right in tryptic-soy media.

No microbial growth was found. The data obtained are very interesting. The effect of AIRCORAL+ material has had an effect of inhibiting bacterial growth (ref. fig. 8 and 9).

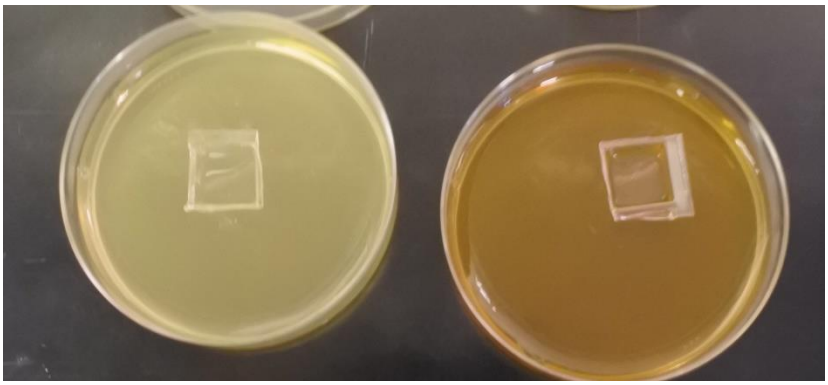


Figure 8 Samples taken from plexiglass box **WITH AIRCORAL+ tiles**. Left -> samples grown in brain-heart media. Right -> samples grown in tryptic-soy media. No microbial growth was found.

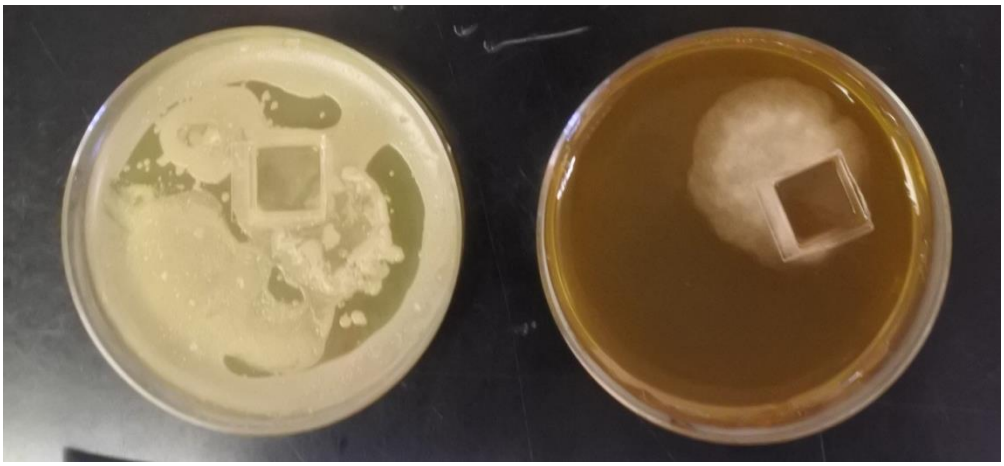
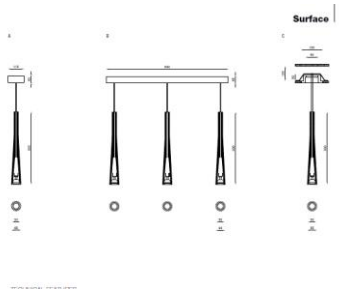


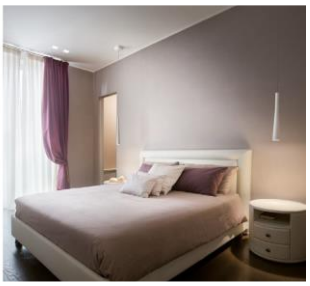
Figure 9 Samples taken from the room environment **WITHOUT any AIRCORAL+ influence.** Left -> grown in brain-heart media. Right -> growth in tryptic-soy media. The samples without AIRCORAL+ influence showed significant airborne bacteria colonies.

Scenario 3. Restaurant

Deployment of sensing systems at the restaurant 'Alessandro Borghese - Il Lusso della Semplicità' in the centre of Milan (IT).

4 BUZZI light fixtures were installed in the area of the restaurant bar, with the lamp model named 'Funnel' as shown in the pictures.





- Images from the catalogue of the lamps used in this setting -

The temperature was 22°C controlled by an air conditioning system and the air pressure was between 1020 and 1025 mbar.

Trial Setting and Configuration

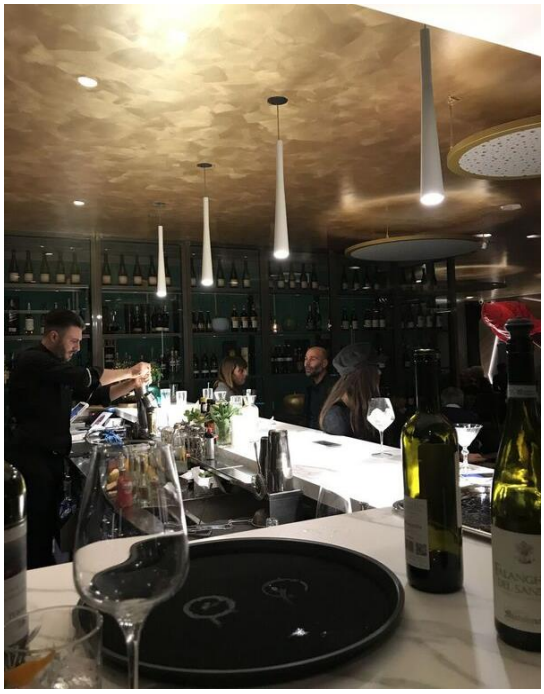
An illuminated plexiglass box was used to produce a controlled environment for the tests and particle measurements (PM1, PM 2.5 and PM 10), airborne bacterial passive sampling, and dust samples for elemental analysis were acquired within and outside the box. 4 light fittings (funnel model) made by AIRCORAL+ were installed over the bar desk. PM concentrations were also measured in an adjacent unlit room (restaurant area) as a control without the influence of the AIRCORAL+ material.

Data were collected over a one day period.

Effect on PM Concentrations

PM concentrations were measured outside and within the Plexiglas box containing AIRCORAL tiles.

All described PM measurements correspond to EN 12341.



Results

Figure 10 shows the real-time measurements of PM concentrations. A dramatic decrease in PM particles is observed for all particle sizes, between the environment WITH AIRCORAL+ and WITHOUT AIRCORAL+. A summary of the change in PM concentrations between the environment in the room and the control environment in the plexiglass box with AIRCORAL+ tiles is shown in Figure 11.

This records the average change of PM concentrations WITHOUT and WITH AIRCORAL+.

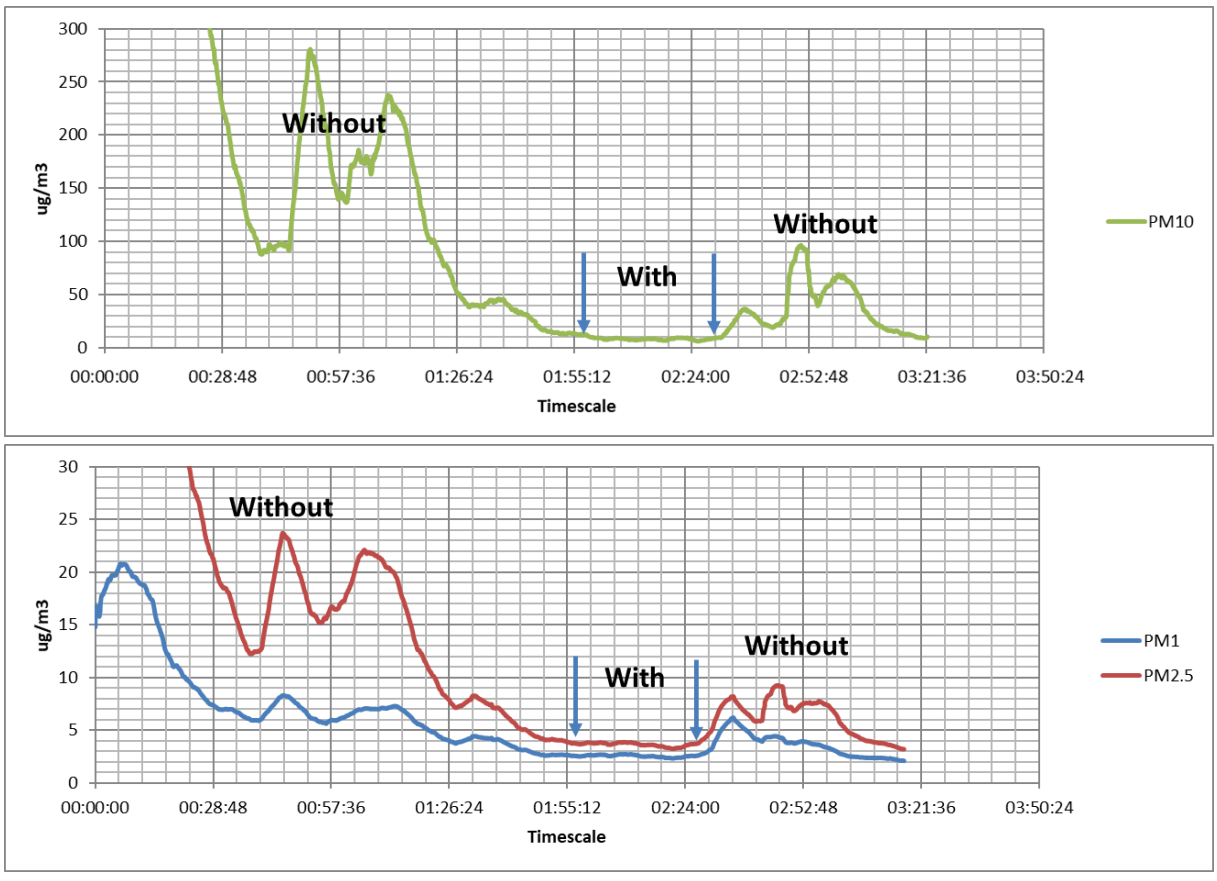


Figure 10 Top graph shows the real-time PM10 concentrations measured from the room ambient (WITHOUT) followed by measurements (WITH) with the AIRCORAL+ material. **A dramatic decrease in PM particles is observed.** The second graph shows the PM1 and PM2.5 particle concentrations on an expanded scale.

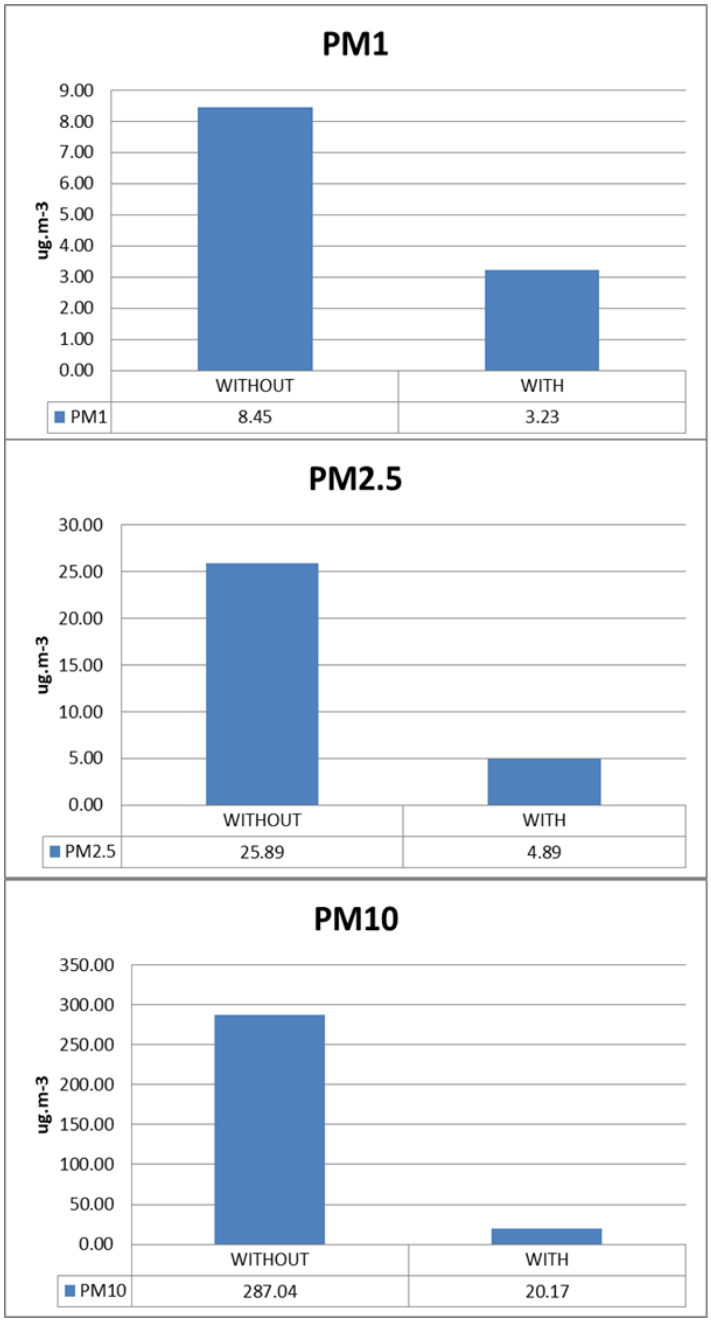


Figure 11 Average change in PM concentrations recorded from data

EFFECT ON PM CONCENTRATION BY AIRCORAL + → SUMMARY OF RESULTS

Summary Results PM Measurements – average data

Scenario	PM	WITHOUT AIRCORAL+ µg/m³	WITH AIRCORAL+ µg/m³	Variation in PMs observed µg/m³	% change
Field Trial Milan Restaurant	**PM1**	8.45	3.23	**-5.22**	**-61.8%**
Field Trial Milan Restaurant	**PM2.5**	25.89	4.89	**-21.00**	**-81.1%**
Field Trial Milan Restaurant	**PM10**	287.04	20.17	**-266.87**	**-93.0%**

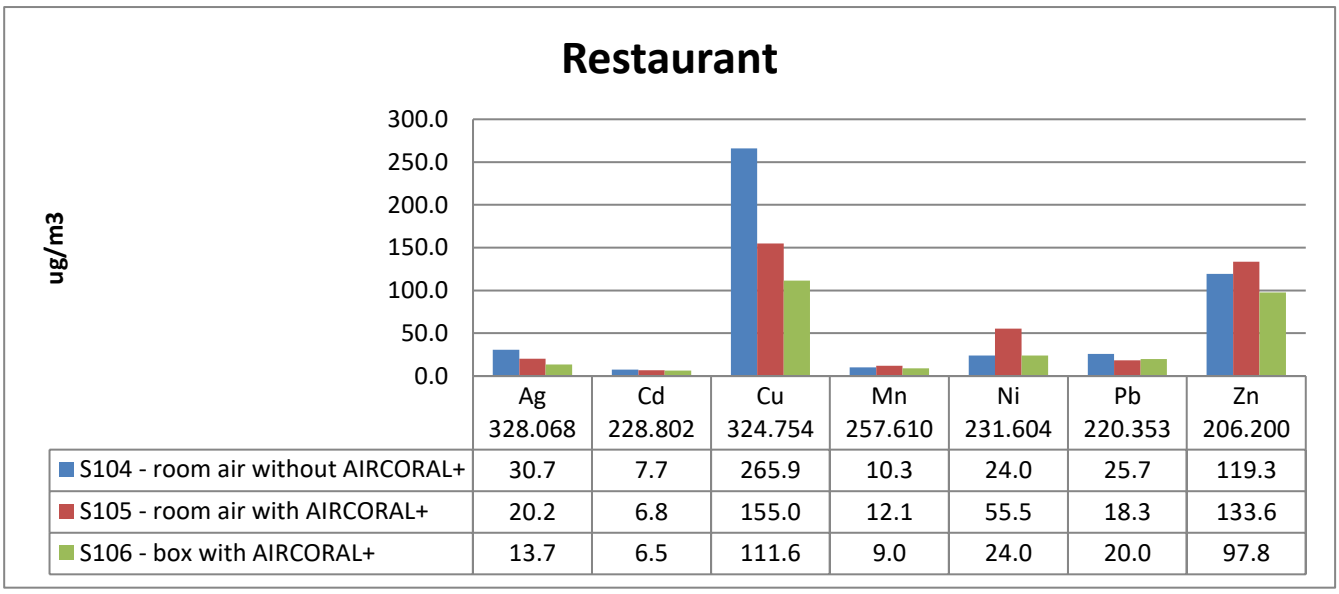
Trace Element Analysis of Dust Samples

Trial Setting and Configuration

Dust samples were trapped initially for two hours S104 taken from the main restaurant room (without any material influence), followed by another 2 hours under illumination of AIRCORAL+ lamps at the bar (S105) as well as the sample S106 being captured inside the plexiglass box with AIRCORAL+ tiles.

Results

Figure 12 shows the results obtained. The concentrations of trace metals measured were very low, with only copper being significant. However this showed a **decrease in concentration of 41% after illumination with the AIRCORAL+ light fittings**.



	Ag 328.068	Cd 228.802	Cu 324.754	Mn 257.610	Ni 231.604	Pb 220.353	Zn 206.200
S104 - room air without AIRCORAL+	30.7	7.7	265.9	10.3	24.0	25.7	119.3
S105 - room air with AIRCORAL+	20.2	6.8	155.0	12.1	55.5	18.3	133.6
S106 - box with AIRCORAL+	13.7	6.5	111.6	9.0	24.0	20.0	97.8

Figure 12 - **S104** control sample from an adjacent room (restaurant) -> WITHOUT the AIRCORAL+ influence. **S105** in the bar area after 4 hours of illumination → WITH AIRCORAL+. **S106** in the box -> box WITH the AIRCORAL+.

As proven by traces analyses also at the Hospital, **a significant decrease of dust elements is noticed also at the Restaurant. In particular by silver (Ag), copper (Cu) and zirconium (Zn).**

EFFECT ON DUST PARTICLES CONCENTRATION BY AIRCORAL + → SUMMARY OF RESULTS

The following table shows the metal traces reductions according to the air samples of the previous experiments. **The % are calculated against the air sample WITHOUT any AIRCORAL+ influence**.

Table 3 - Reduction in trace elements observed after exposure to AIRCORAL materials.

	Metal traces variation in the air room after 2 hours of illumination WITH AIRCORAL+		Metal traces variation after 2 hours within the plexiglass box WITH AIRCORAL+	
	%	ug/m3	%	ug/m3
Ag	**-34%**	-10.5	**-55%**	-17.0
Cd	**-12%**	-0.9	**-15%**	-1.2
Cu	**-42%**	-110.9	**-58%**	-154.3
Mn	**+17%**	+1.8	**-13%**	-1.3
Ni	**+131%**	+31.5	**0%**	0.0
Pb	**-29%**	-7.5	**-22%**	-5.8
Zn	**+12%**	+14.3	**-18%**	-21.5

Gas Sensing

An array of gas sensors were deployed in the bar area of the Restaurant, to monitor:

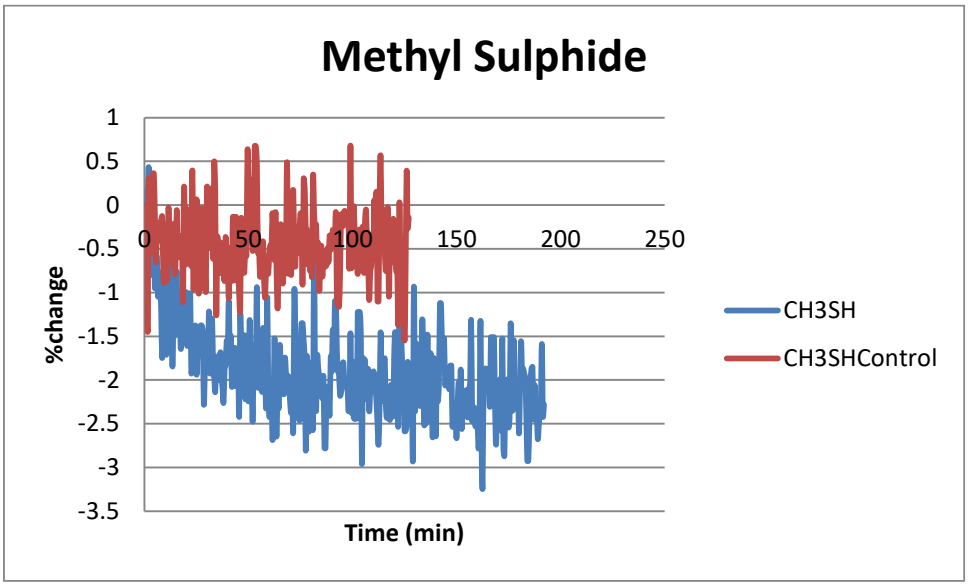
- oxygen,
- methyl sulphide,
- hydrogen sulphide,
- volatile organic hydrocarbons,
- carbon dioxide,
- methane,
- carbon monoxide
- ammonia.

The aim was to determine if any change of the environment occurred as a result of the AIRCORAL+ catalytic and anti-bacterial material lamps being deployed.

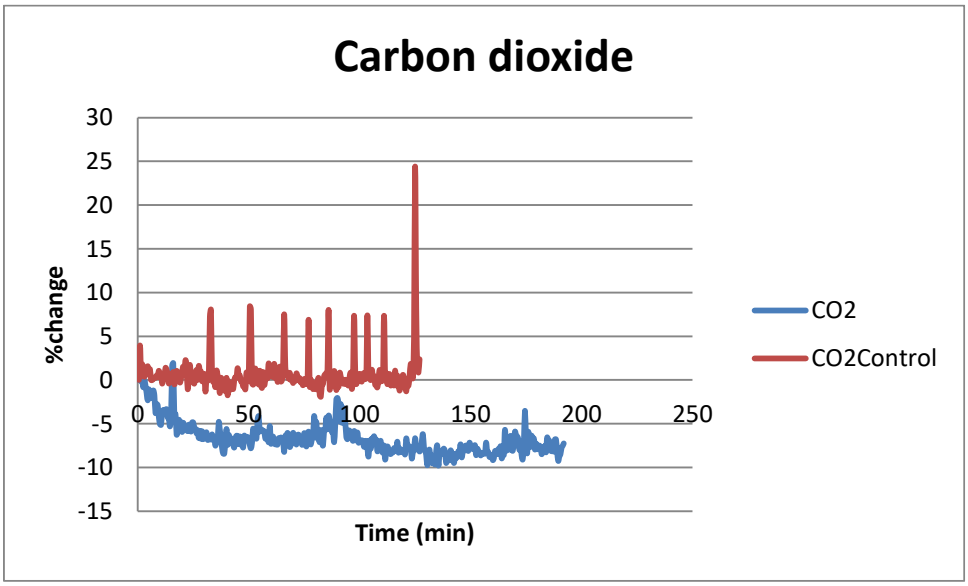
This instrument recorded data at 1 minute intervals during the day.

The results can be commented as follow:

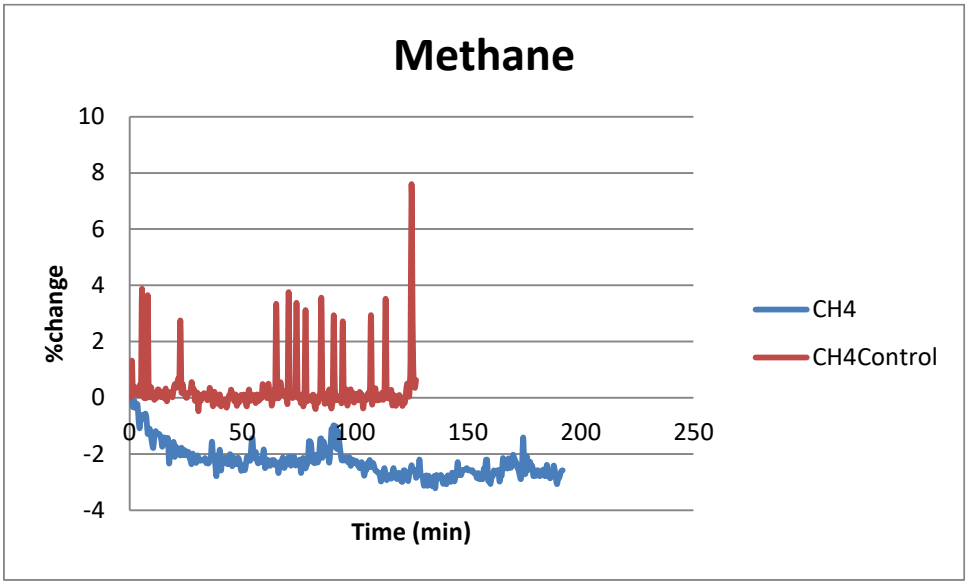
- with **oxygen** there was no particular change during the day.
- For **hydrogen sulphide (H2S), volatile organic hydrocarbons** and **Carbon monoxide (CO)** - monitored by the photoionisation detector (PID)) - their initial concentrations present in the environment were very small to measure any significant (positive or negative) trends.
- **Methyl sulphide (CH3SH)**. A decrease in concentration is seen over three hours with exposition to AIRCORAL+ (blue line) against the control sample (in red) without any material influence.



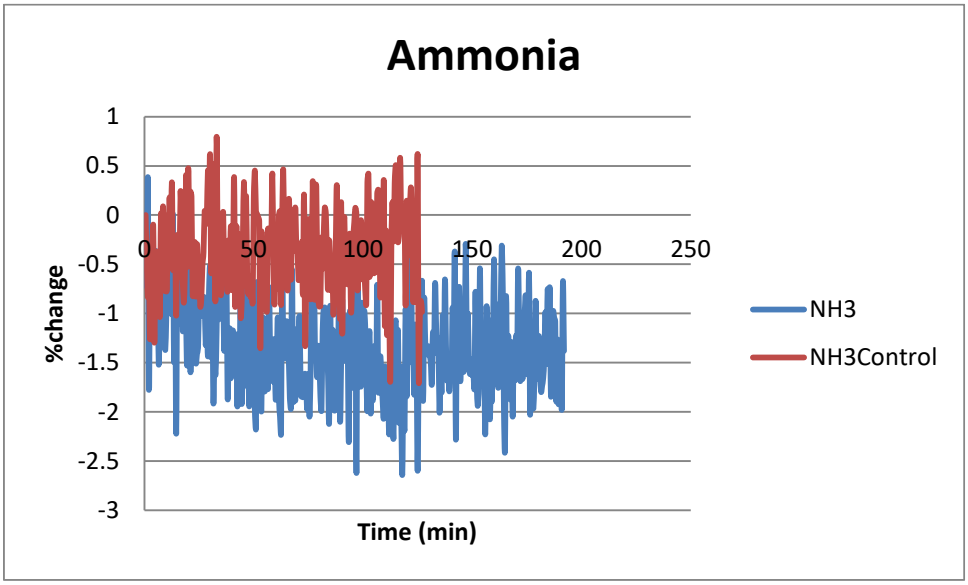
- **Carbon dioxide (CO2),** a relevant decrease in concentration is seen over three hours with exposition to AIRCORAL+ (blue line) against the control sample (in red) without any material influence.



- **Methane (CH4),** a relevant decrease in concentration is seen over three hours with exposition to AIRCORAL+ (blue line) against the control sample (in red) without any material influence.



- **Ammonia (NH3)**, a relevant decrease in concentration is seen over three hours with exposition to AIRCORAL+ (blue line) against the control sample (in red) without any material influence.



Microbiology

Trial Setting and Configuration

Airborne samples were taken using the Sartorius sampler (approx. 100 litres of air) from an adjacent area (the restaurant area) that was not illuminated by the AIRCORAL+ lamps while another sample was captured within the plexiglass box that contained illuminated AIRCORAL+ tiles.

The agar strips were then incubated in brain-heart media and tryptic-soy media to allow optimal growth of a range of different airborne bacteria.

Results

The results are shown in Figures 13 to 14. The samples taken from within the plexiglass container with illuminated AIRCORAL+ tiles showed no growth (Figure 13). While the samples taken from the control area not illuminated by the AIRCORAL+ lamps showed heavy growth of airborne bacteria (Figure 13).

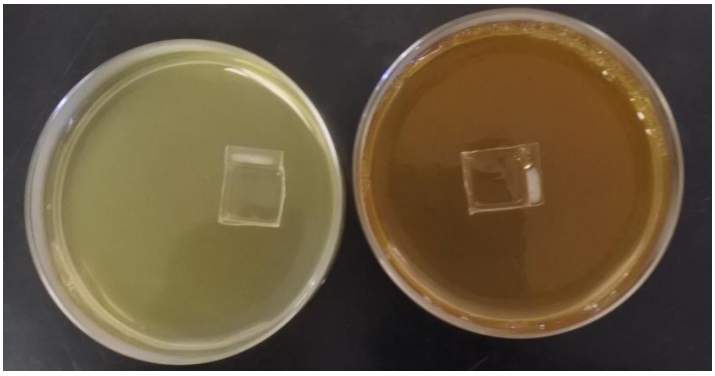


Figure 13 Airborne bacteria samples from inside the plexiglass box WITH AIRCORAL+ tiles. Left -> samples grown in brain-heart media, Right -> samples grown in tryptic-soy media. No growth found.

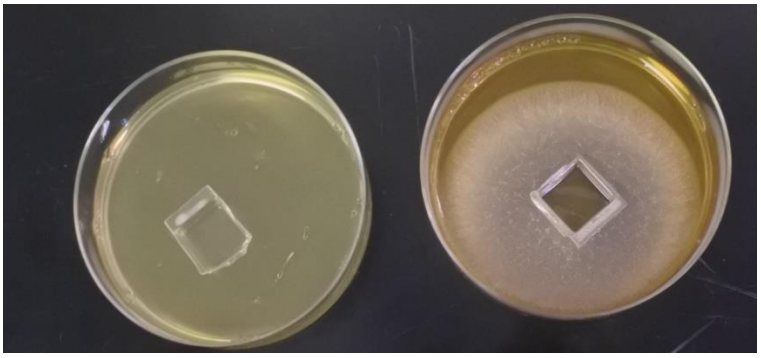


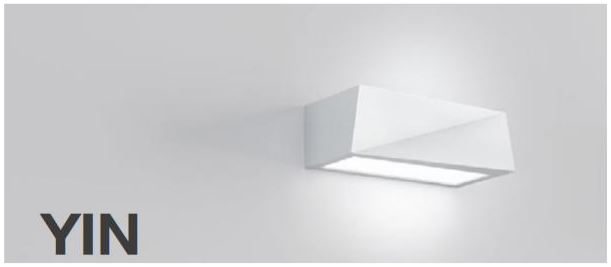
Figure 14 Airborne bacteria samples taken from adjacent area WITHOUT AIRCORAL+. Left -> samples grown in brain-heart media. Right -> samples grown in tryptic-soy media. Substantial bacterial growth was observed in all cases.

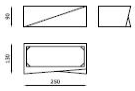
Scenario 4. Kindergarten school

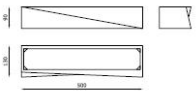
Deployment of sensing systems at the Kindergarten school 'Gianni Rodari' in the suburb of Milano (IT).

The study was carried out within a classroom 40 m^2 (4 metres height) housing 25 children students and 4 adults, on 24th November 2017. The average temperature was 21^oC and the air pressure was between 1020 and 1025 mbar.

6 AIRCORAL+ body-lamps by Yin and Yang models were laid out in the classroom.







Indoor measurements

Effect on PM Concentrations

Trial Setting and Configuration

Instruments for particulate size monitoring, gas sensing, dust collection and microbial air monitoring were deployed. The experiment involved monitoring the ambient air in the room for a period of 70 minutes followed by deployment of AIRCORAL+ material and monitoring the same area over a further 70 minutes. The material was then removed and the area continued to be monitored.

- The kindergarten classroom, setting of our measurements -

Results

Figure 15 shows the configuration of the measurement equipment. This was placed inside the classroom. After recording data without AIRCORAL+ for 70 minutes, the AIRCORAL+ lamps were then set out as shown in Figure 15(b) along the perimeter of the classroom, laid on chairs.

The averaged difference between PM concentrations measured is shown in Figure 15(c) with the data recorded shown in Figure 16.

(a) WITHOUT AIRCORAL+

(b) WITH AIRCORAL+

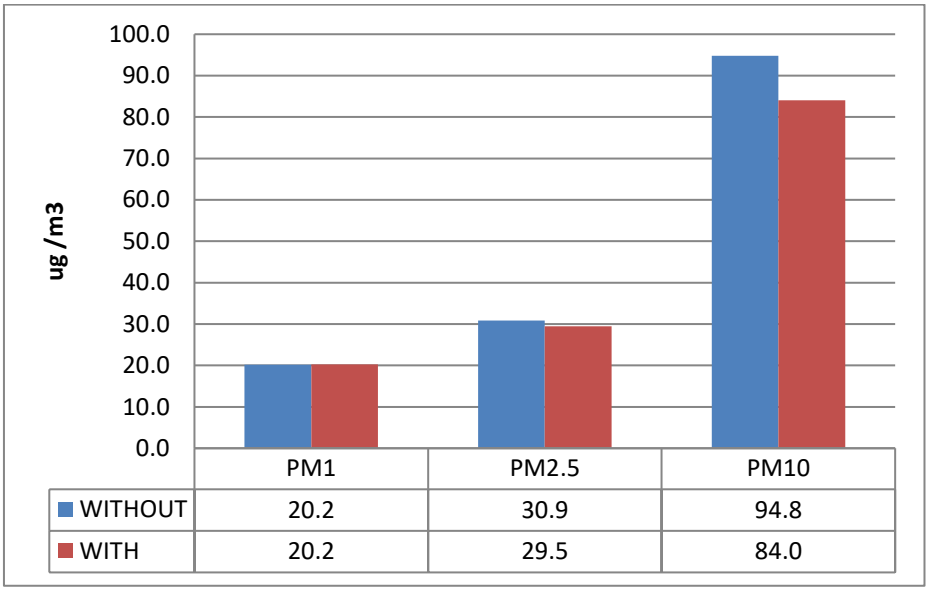


Figure 15 Particulate matter average measurements. (a) Classroom occupied by children – sensing equipment set out in the class. (b) Classroom with AIRCORAL+ deployed. (c) PM concentrations measured WITHOUT and WITH AIRCORAL+ deployed. **A relevant change in PM10 was observed of 10.8 µg m^{-3} (-11%) was observed, a -5% decrease of PM2.5, but no significant change in PM1**.

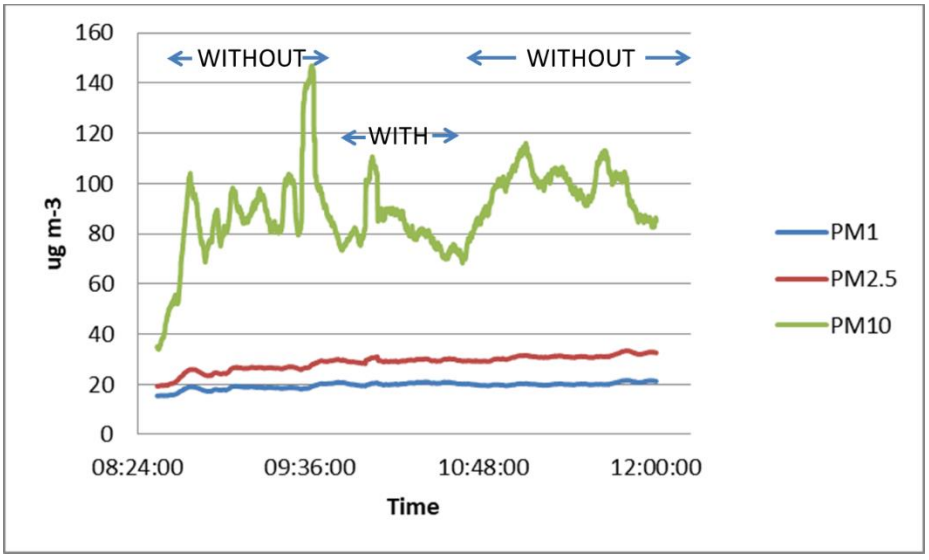


Figure 16 The real time measurements of particulate matter recorded. Due to the large amount of activity in the classroom, there is great variation in the PM10 particles measured. However, there is a noticeable relevant decrease in PM10 in the period WITH AIRCORAL+ deployed.

EFFECT ON PM CONCENTRATION BY AIRCORAL + → SUMMARY OF RESULTS

Summary Results PM Measurements – average data

Scenario	PM	WITHOUT AIRCORAL+ µg.m^{-3}	WITH AIRCORAL+ µg.m^{-3}	Variation in PMs observed µg.m^{-3}	% change
Field Trial Kindergarten school	**PM1**	20.20	20.20	**0**	**0%**
Field Trial	**PM2.5**	30.88	29.45	**-1.43**	**-5%**

Kindergarten school					
Field Trial Kindergarten school	**PM10**	94.82	84.01	**-10.82**	**-11%**

Trace Element Analysis of Dust Samples

Trial Setting and Configuration

Dust collected over the period of measurement WITHUT and WITH AIRCORAL+ was analysed for trace elements.

The data are shown in Figure 17. A relevant decrease in concentration was observed for Copper, Manganese, Nickel and Lead. All other elements were barely present.

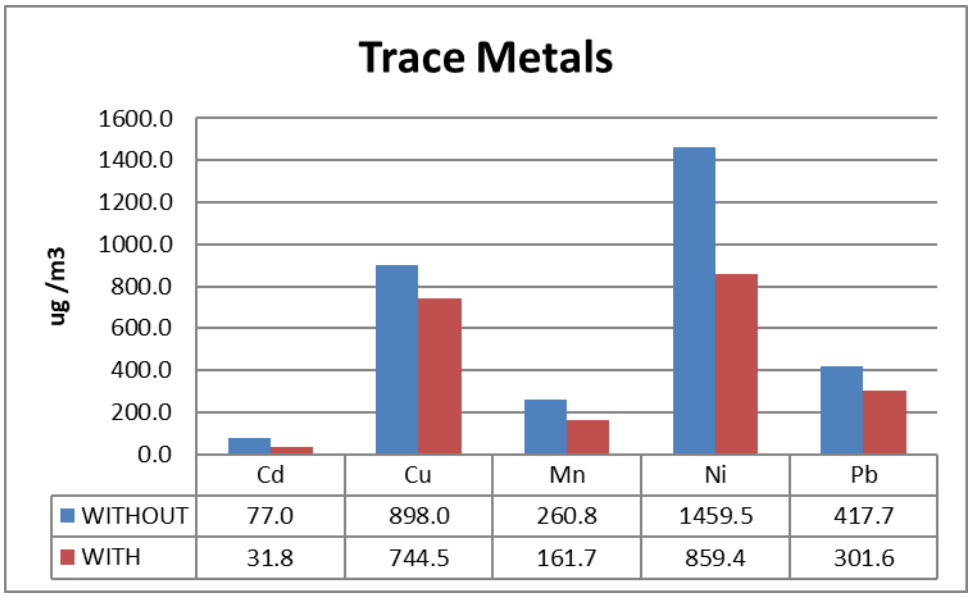


Figure 17 Trace element analyses of dust samples collected WITHOUT and WITH AIRCORAL+ deployed.

EFFECT ON DUST PARTICLES CONCENTRATION BY AIRCORAL + → SUMMARY OF RESULTS

The following table shows the metal traces reductions according to the air samples of the previous experiments. The % are calculated against the air sample WITHOUT any AIRCORAL+ influence.

Table - Reduction in trace elements observed after exposure to AIRCORAL+ materials.

	Metal traces in the air room WITHOUT AIRCORAL+ ug/m³	Metal traces in the air room WITH AIRCORAL+ ug/m³	Difference %	Difference ug/m³
Cd	77.0	31.8	**-59%**	-45.2
Cu	898.0	744.5	**-17%**	-153.5
Mn	260.8	161.7	**-38%**	-99.1
Ni	1459.5	859.4	**-41%**	-600.1

Pb	417.7	301.6	**-28%**	-116.1

Gas Sensing

An array of gas sensors was deployed in the classroom, to monitor SO2 and NO2.

Gas measurements indicated a decrease in Nitrogen dioxide after AIRCORAL+ was deployed but no relevant change in Sulphur Dioxide was detected (Figure 18 & 19).

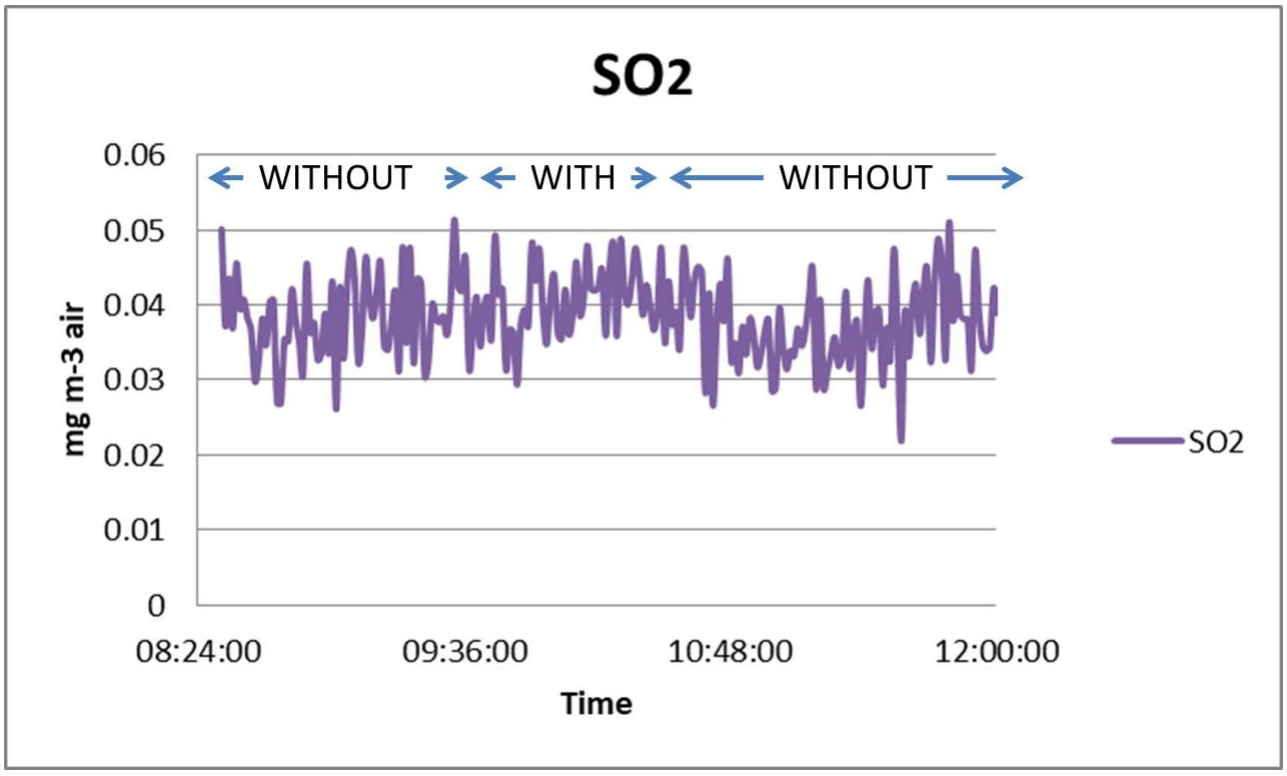


Figure 18 Sulphur dioxide concentrations. Very low-level present and no relevant change observed.

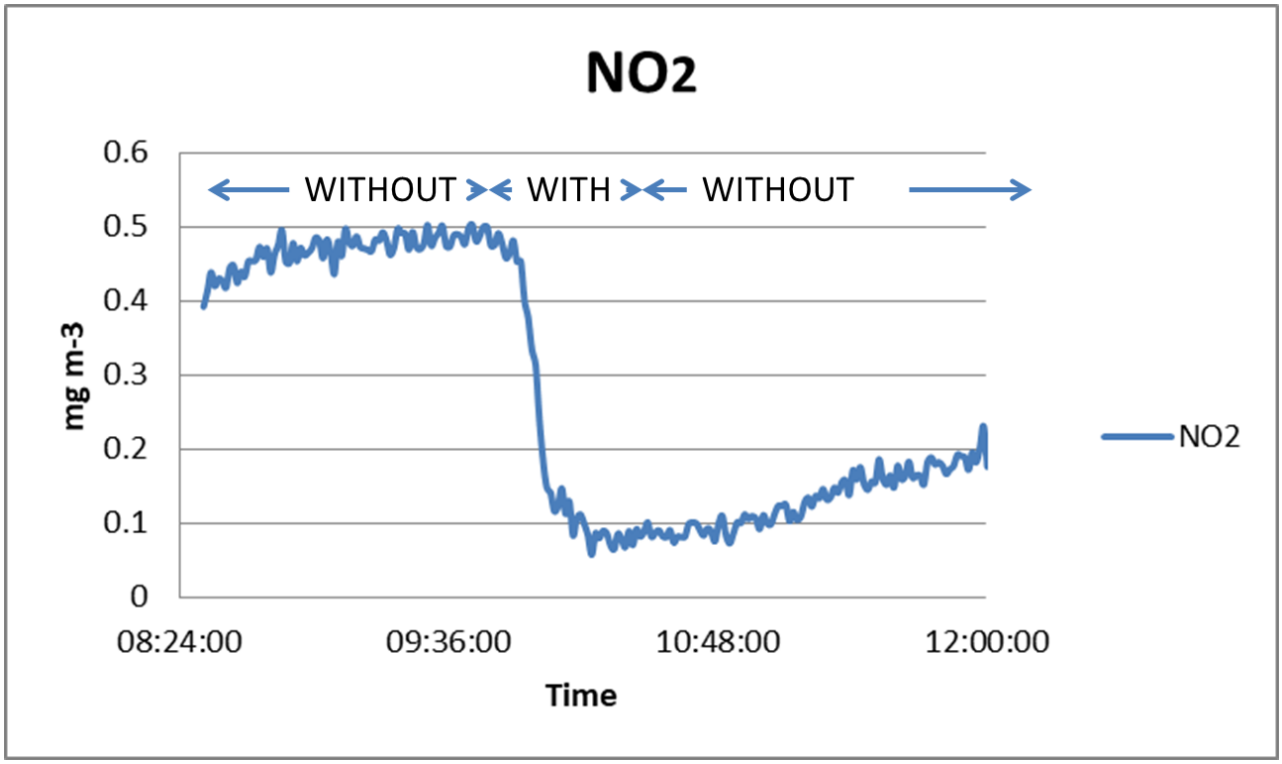


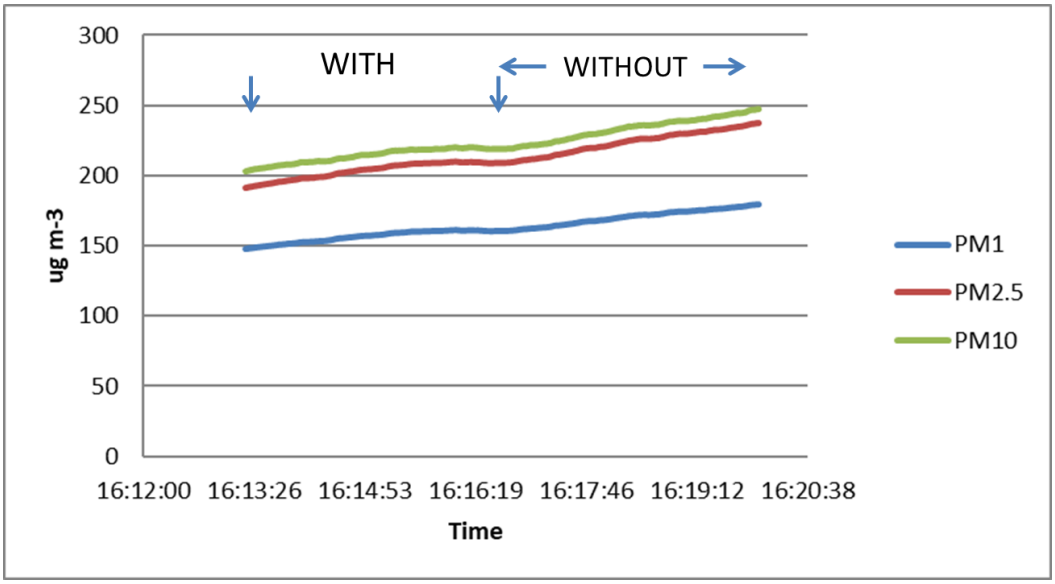
Figure 19 Nitrogen dioxide concentrations were much higher than sulphur dioxide. A large decrease was observed when the AIRCORAL+ material was deployed in the classroom, and this started to increase again when the material was removed.

Outdoor measurements

The measurement equipment was set up outside the entrance of the kindergarten school at the end of the school day.

The experiment consisted of measuring particulate matter WITH AIRCORAL+ deployed when some of the parents exited the school with their children and then measuring particulate matter WITHOUT AIRCORAL+ when other parents and children were leaving the kindergarten.

The window of time was limited to a few minutes. The data recorded are shown in Figure 20 below.



When AIRCORAL+ was set out near the entrance there was a noticeable change in the slope of the curves for PMs, indicating that there was some reduction. The particulate matter continued to rise over the period of measurement WITHOUR AIRCORAL+.

It was not possible to quantify this effect due to variables inherent in this outdoor experiment.

Microbiology

No viable airborne bacteria were collected in this experiment.

Scenario 5. High school

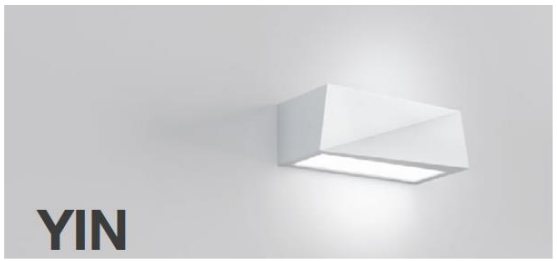
Deployment of sensing systems at the high school 'Liceo Giordano Bruno' in the suburb of Milano (IT).

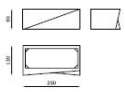
LICEO SCIENTIFICO LINGUISTICO STATALE
GIORDANO BRUNO
20066 MELZO, VIALE SVEZIA 4 COD. MIN. MIPS210009 20062 CASSANO D'ADDA, VIA GIOVANNI XXIII, 223 COD. MIN. MIPS21002B

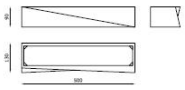
The study was carried out within a classroom 40 m^2 housing 14 students and 1 professor, on 23rd November 2017 as shown ahead in the pictures.


The temperature was on average 21-22^{o}C, with relevant variation from the early morning at lessons start and noon.

9 AIRCORAL+ body lamps by Yin (5) and Yang (4) models were laid out in the classroom.





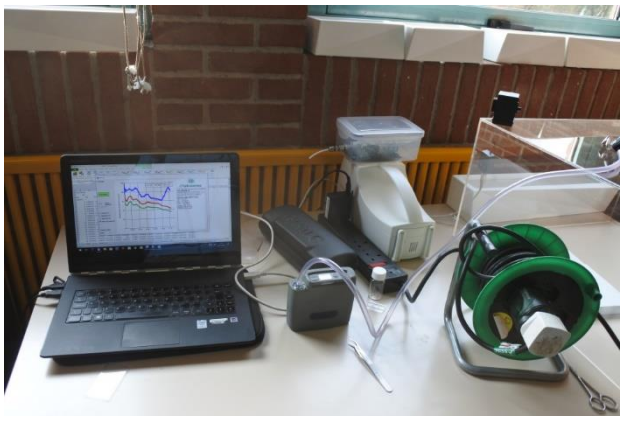
Indoor measurements

Effect on PM Concentrations

Trial Setting and Configuration

Instruments for particulate size monitoring, gas sensing, dust collection and microbial air monitoring were deployed. The experiment involved monitoring the ambient air in the classroom for a period of 90 minutes followed by deployment of AIRCORAL+ material and monitoring the same area over a further 90 minutes.

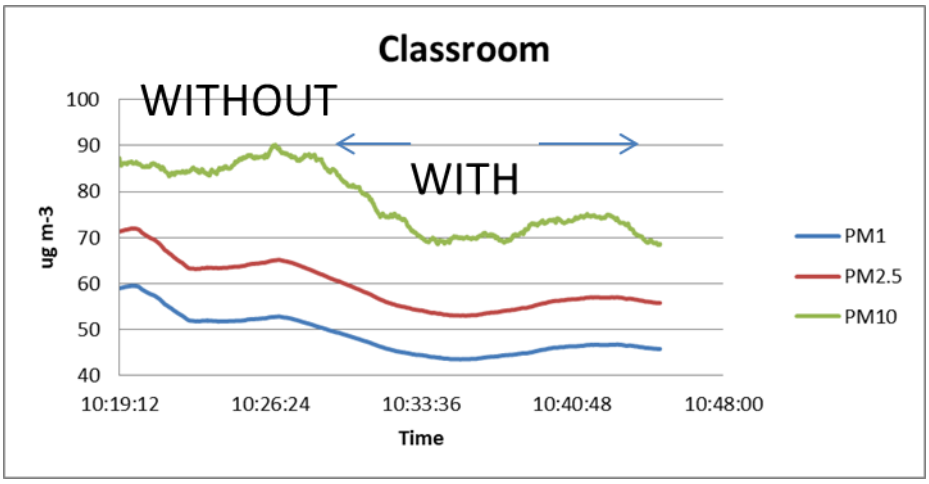
The figures below show the classroom, with the equipment deployed near to the window.

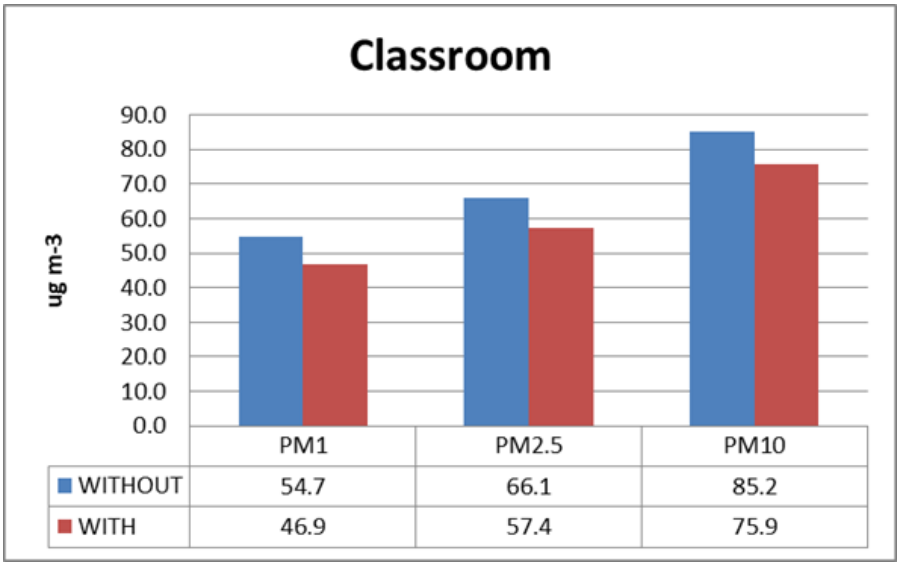


Results

The particulate matter was monitored continuously and the difference between PMs recorded WITHOUT and WITH AIRCORAL+ is shown in the next figure. The AIRCORAL+ body-lamps (tot of 9: 4 Yang and 5 Yin) were deploy on the windowsills.

It was noted that averaged **PM1 particulate matter decreased by 7 µg m^{-3} in the presence of AIRCORAL+. PM2.5 decreased by 8.7 µg m^{-3} and PM10 decreased by 9.3 µg m^{-3}.**





EFFECT ON PM CONCENTRATION BY AIRCORAL + → SUMMARY OF RESULTS

Summary Results PM Measurements – average data

Scenario	PM	WITHOUT AIRCORAL+ µg/m³	WITH AIRCORAL+ µg/m³	Variation in PMs observed µg/m³	% change
Field Trial high-school	**PM1**	54.65	46.95	**-7.71**	**-14%**
Field Trial high-school	**PM2.5**	66.12	57.40	**-8.72**	**-13%**
Field Trial high-school	**PM10**	85.21	75.91	**-9.30**	**-11%**

Trace Element Analysis of Dust Samples

Trial Setting and Configuration

Air was collected at 2 l/min on 0.45 µm cellulose acetate filters. These filters were subsequently digested in nitric acid and trace metal analysis was carried out using Inductive conductive plasma Optical Emission Spectroscopy (ICP-OES). Figure 21 shows the results observed WITHOUT and WITH AIRCORAL+. The elements monitored were copper, nickel and zinc. The greatest effect was with copper concentrations that reduced by 241 µg/m³ air.

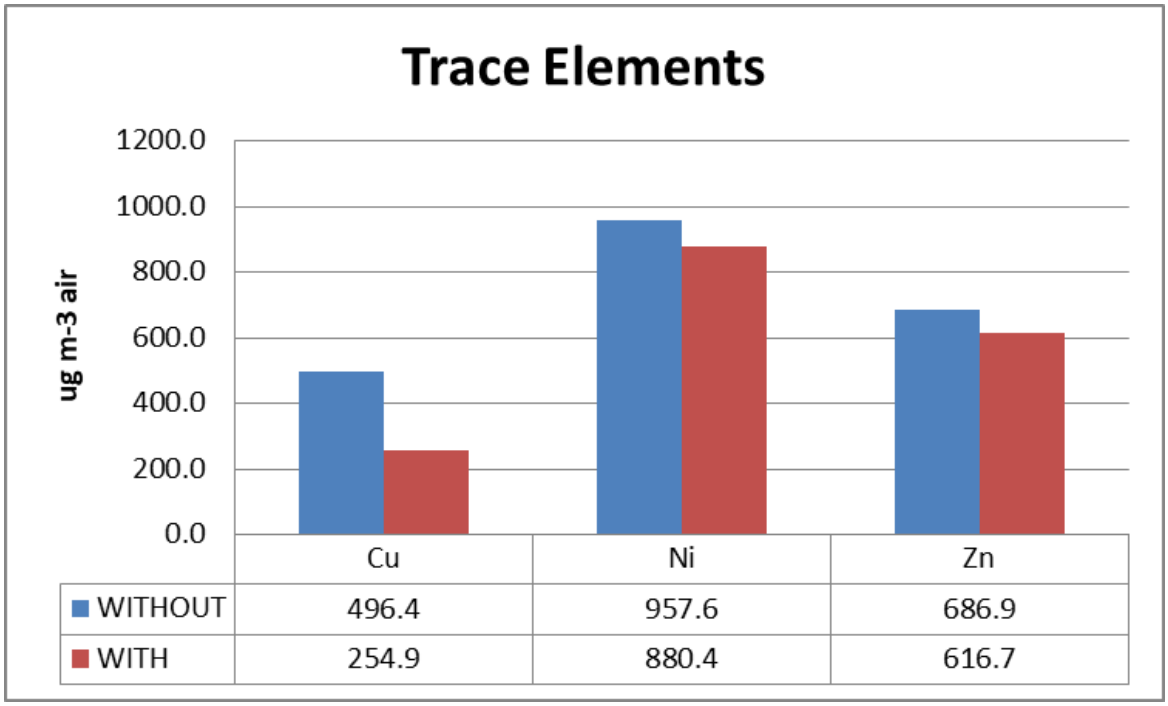


Figure 21 – Trace elements results observed WITHOUT and WITH AIRCORAL+

EFFECT ON DUST PARTICLES CONCENTRATION BY AIRCORAL + → SUMMARY OF RESULTS

The following table shows the metal traces reductions according to the air samples of the previous experiments. **The % are calculated against the air sample WITHOUT any AIRCORAL+ influence.**

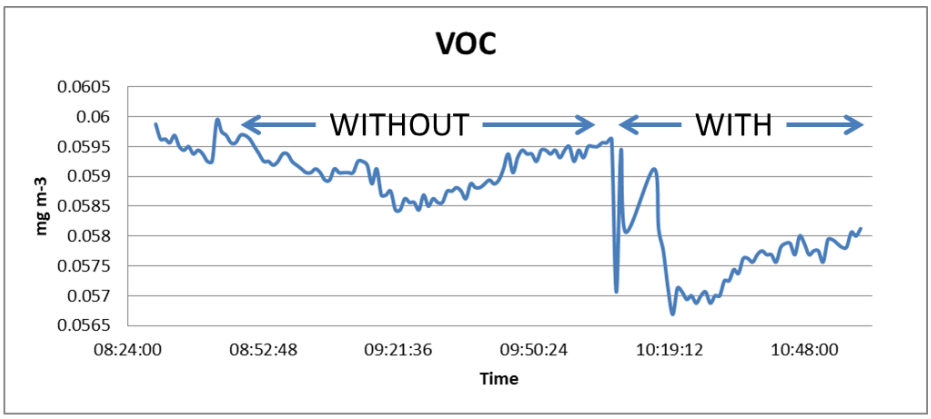
Table - Reduction in trace elements observed after exposure to AIRCORAL+ materials.

	Metal traces in the air room WITHOUT AIRCORAL+ ug/m³	Metal traces in the air room WITH AIRCORAL+ ug/m³	Difference %	Difference ug/m³
Cu	-496.4	-254.9	**-49%**	**-241.5**
Ni	-957.6	-880.4	**-8%**	**-77.2**
Zn	-686.9	-616.7	**-10%**	**-70.2**

Gas Sensing

Real time gas measurements were carried out. This apparatus measured nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2) and volatile organic compounds (VOC) with a sampling interval of 1 minute. Single point measurements of formaldehyde were also carried out using an indicator tube, but this gas was not detected. The concentrations measured were very low but changes were observed in VOCs and Ozone concentrations with decreases observed in the period after AIRCORAL+ material was deployed. Figure 22 shows the real-time traces for VOCs (a) and Ozone (b). **It can be seen that there was a clear and relevant decrease in the concentrations of these gases after AIRCORAL+ was deployed**.

(a)



(b)

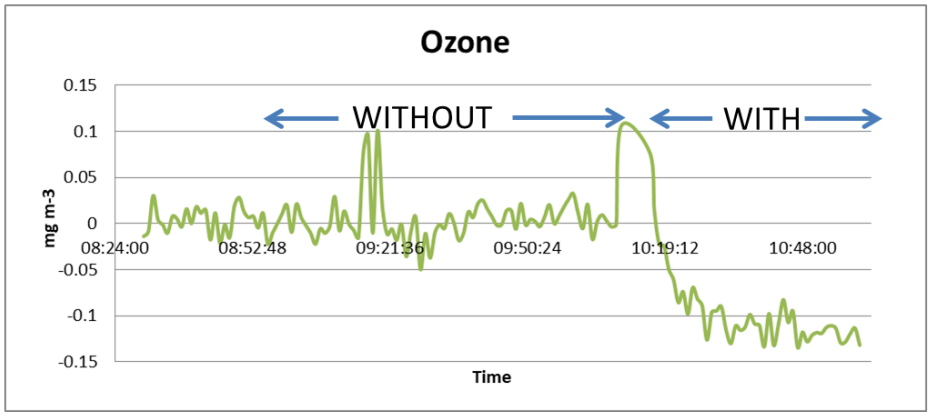


Figure 22 Real time traces of VOC concentrations and Ozone concentrations demonstrating **a relevant decrease after AIRCORAL+ was deployed.**

Outdoor measurements

The equipment was deployed outdoors at the entrance of the school as shown in the following figures.

The experiment carried out was to monitor the air at that point at the end of the school day when students were leaving the school, WITHOUT and WITH AIRCORAL+ deployed. The time available was very limited as the students left the school within a 5 minutes period. The figures show the equipment WITHOUT and WITH AIRCORAL+ deployed. Figure 23 shows the raw data of particulates measured with arrows indicating the period WITHOUT and WITH AIRCORAL+ deployed. There was a **decrease in the slope of the all the PM size concentrations recorded**. Because of the great variability, it was not possible to quantitate this measurement.


Above, the setting to measure air quality WITH AIRCORAL+ material/lamps deployed at the school exit.


Above, the setting and equipment to measure air quality WITHOUT AIRCORAL+

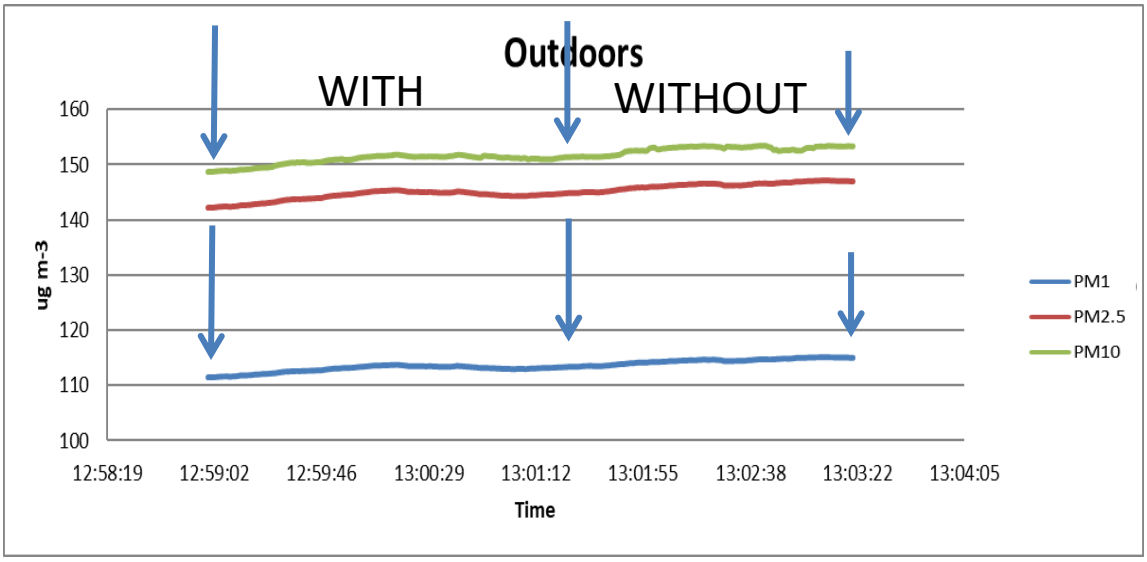


Figure 23 - Raw data of PMs measured WITHOUT and WITH AIRCORAL+ deployed.

EFFECT ON PM CONCENTRATION OUTDOOR BY AIRCORAL + → SUMMARY OF RESULTS

Summary Results PM Measurements – average data.

Scenario	PM	WITHOUT AIRCORAL+ µg/m³	WITH AIRCORAL+ µg/m³	Variation in PMs observed µg/m³	% change
Field Trial high-school outdoor	**PM1**	114.27	112.87	**-1.40**	**-1.22%**
Field Trial high-school outdoor	**PM2.5**	146.00	144.23	**-1.76**	**-1.21%**
Field Trial high-school outdoor	**PM10**	152.53	150.76	**-1.77**	**-1.16%**

Microbiology

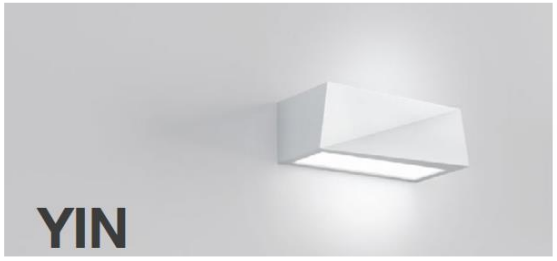
No viable airborne bacteria were collected in this experiment.

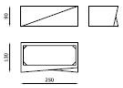
Scientific measurements at the UniMAN laboratories

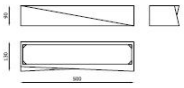
Further measurements were carried on in a **scientific environment** – namely at The University of Manchester, at the School of Chemical Engineering and Analytical Science -, that was kept under precise conditions and controlled for the whole analysis duration.

Trial Setting and Configuration

AIRCORAL+ Yin and Yang light fittings were mounted in a darkroom shown in Figure 24. This allowed tests to be done on air quality over an extended period. Airborne microbes were sampled in this room and in an adjacent common room. Similarly, gas sensing experiments were carried out in this room and the adjacent common room.







Mueller-Hinton experiments were carried out using two types of bacteria. These were Stapyloccoccus aureus and Pseudomonas aeruginosa. Kirby-Bauer discs containing penicillin were used as a control.

An incubator made of plexiglass was set up. Within this was placed an AIRCORAL+ lamp – model Yin - and also an AIRCORAL+ tile as shown in Figure 25. This incubator contained a heater controller that maintained the temperature at 37°C. Another incubator was used for growing bacterial samples in the dark at 37°C and these experiments were run in parallel.

The following experiments were carried out:

(a) Bacteria grown in lighted incubator vs bacteria grown in dark incubator using Mueller-Hinton media.

(b) Airborne bacteria samples from AIRCORAL+ illuminated darkroom compared with airborne samples from an adjacent common room.

(c) Airborne bacterial samples grown in the AIRCORAL+ lighted cabinet compared to samples grown in the dark incubator.

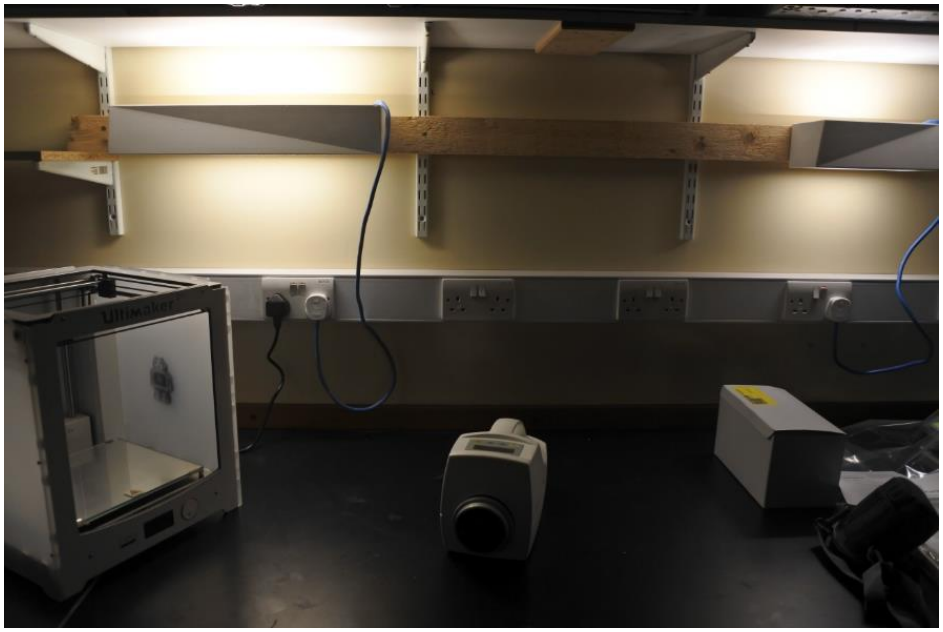


Figure 24 Darkroom illuminated with AIRCORAL+ light fittings used for laboratory experiments.

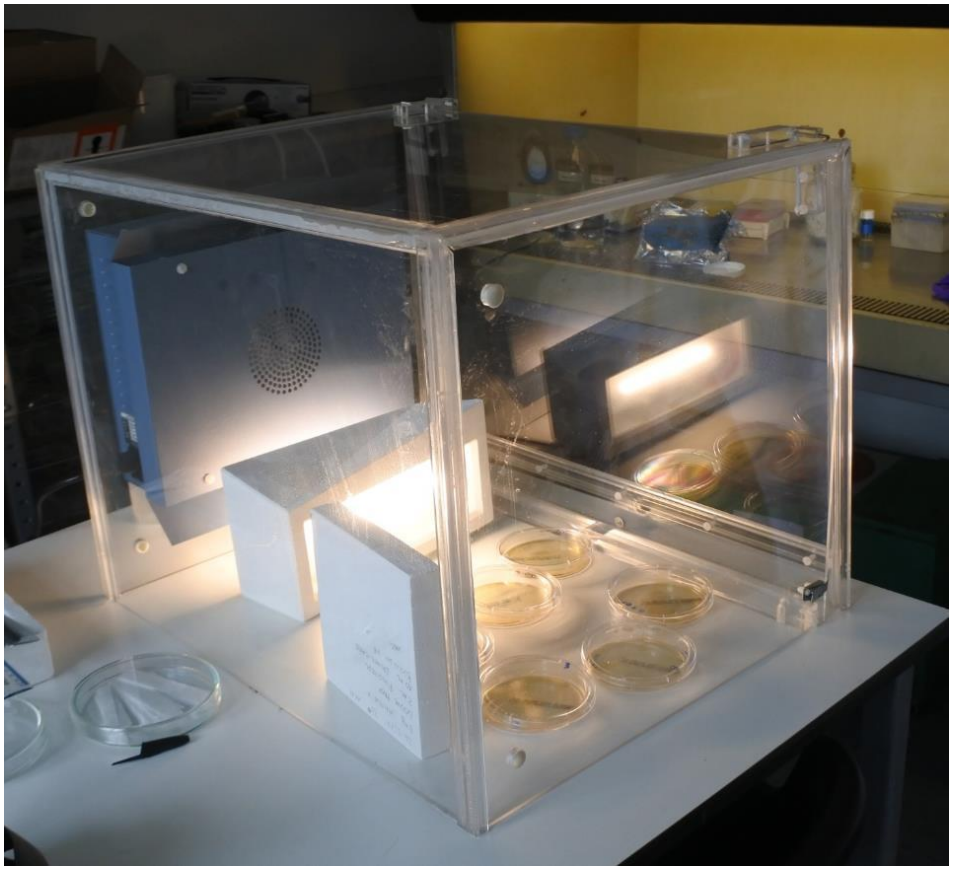


Figure 25 Incubation cabinet with AIRCORAL+ light fitting and AIRCORAL+ tile. This was used to incubate petri dishes containing bacterial samples. Parallel incubations at 37°C were carried out in an incubator in the dark.

Experiment (a)

Bacteria grown in AIRCORAL+ incubator VS Bacteria grown in the dark

Results

Figures 26 and 27 show the results obtained. Figure 26 left shows Staphylococcus aureus grown in the dark incubator while the right shows the same culture grown under the AIRCORAL+ light fittings in the incubator cabinet. **It can be clearly seen that no growth occurs under AIRCORAL+ illumination**.

With Pseudomonas aeruginosa (Figure 27) similar results were obtained.

This is the clear confirmation – in a scientific controlled environment - that the light fittings with AIRCORAL+ have a definite influence as inhibitor on the growth of bacteria.

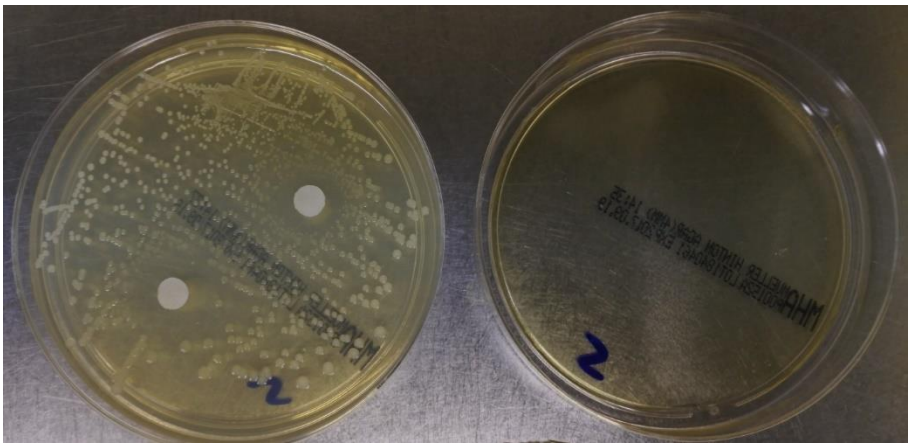


Figure 26 Staphylococcus aureus grown in Mueller-Hinton media. Kirby-Bauer penicillin discs were used to test growth inhibition. On the left is the sample grown in the dark, while on the right the sample under AIRCORAL+ illumination. Growth occurred only on the left plate.

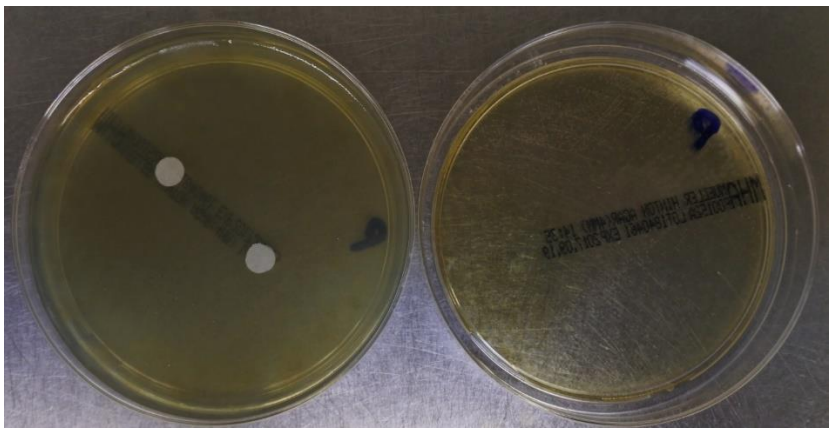


Figure 27 Pseudomonas aeruginosa grown in Mueller-Hinton media' Kirby-Bauer penicillin discs were used to test inhibition of growth. On the left is the sample grown in the dark, while on the right the sample under AIRCORAL+ illumination. Growth occurred only on the left plate.

Experiment (b)

Airborne bacteria samples from AIRCORAL+ illuminated darkroom compared with airborne samples from an adjacent common room

Results

75 litres of air from the AIRCORAL+ illuminated darkroom were captured on gelatin filters using the Sartorius MD8 air sampler. Similar samples were taken from the adjacent common room. The filters were then incubated on agar plates using the dark incubator and parallel samples were placed in the AIRCORAL+ illuminated incubator. Samples were gown in Tryptic-Soy media and Brain-Heart media. Figures 28-29 show the results obtained.

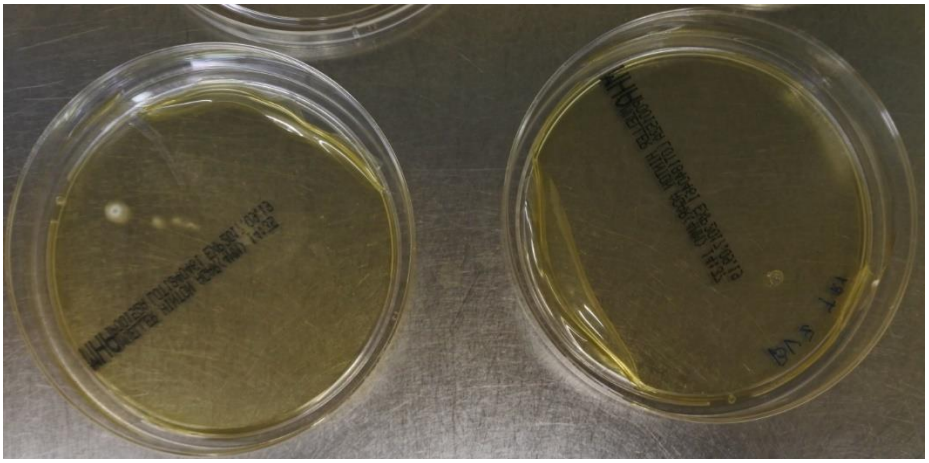


Figure 28 Two airborne bacteria samples taken from the AIRCORAL+ illuminated darkroom. Left-tryptic-soy media, right brain-heart media. On the left few small colonies are seen while on the right there is no growth.

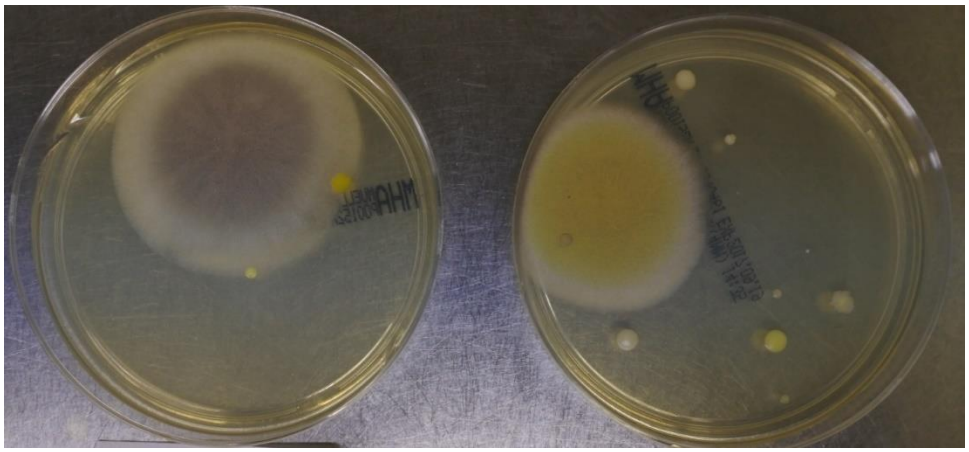


Figure 29 Airborne bacterial samples taken from the adjacent common room. Heavy bacterial growth is seen. Left – tryptic-soy media, right – brain-heart media.

Experiment (c)

Airborne bacterial samples grown in the AIRCORAL+ lighted cabinet compared to samples grown in the dark incubator

Results

Airborne bacterial samples were taken from the common room using the Sartorius MD8 sampler. The samples grown in the dark incubator are shown in Figure 30. However when parallel samples were grown in the AIRCORAL+ illuminated incubator, no growth occurred as shown in Figure 31.

This gives additional confirmation that AIRCORAL+ light fittings with catalytic and anti-bacterial material do have an effect in highly inhibiting the grown of microorganisms.

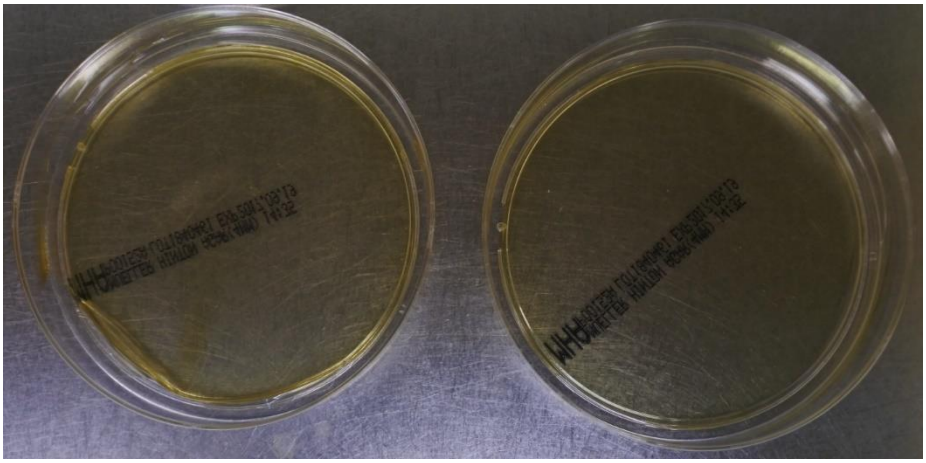


Figure 30 Two airborne bacterial samples from the common room grown in the AIRCORAL+ illuminated incubator. No growth is observed. Left samples gown in tryptic-soy media, right – brain-heart media.

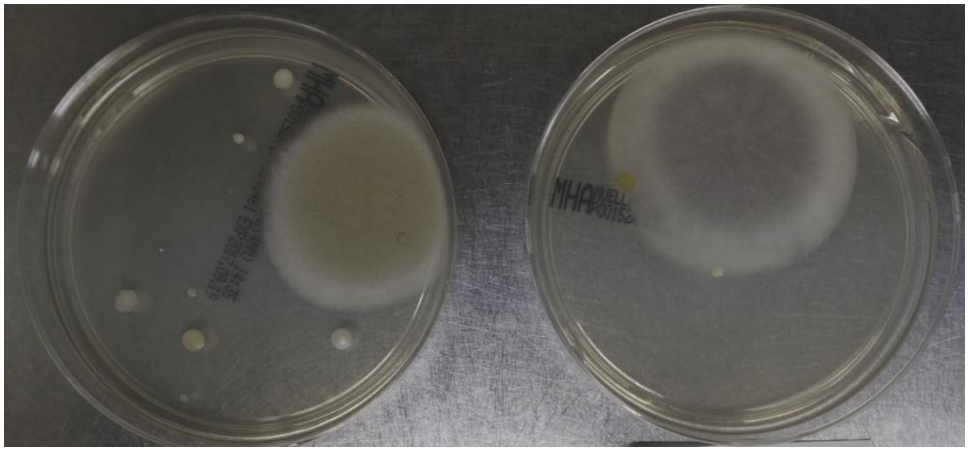


Figure 31 Samples grown in the AIRCORAL+ illuminated incubator, no growth occurred.

Summary of Results

In the present chapter we summarize the effects of AIRCORAL+ as average calculated among all data collected in all real scenarios.

For microbial and gas reductions, please refer to data of each single scenario.

Demonstrated high reduction of PM concentration

1. Tests in different real environments demonstrated large differences in PM concentrations from the ambient not exposed to AIRCORAL+ material to the environment illuminated by AIRCORAL+ light fittings.
2. AIRCORAL+ demonstrated to be effective in open environments - illuminated by AIRCORAL+ light fittings - to highly reduce PM10 concentrations as well as PM1 and PM2.5.

The following tables gathers all measurements data in all scenarios showing the average PM reduction thanks to AIRCORAL+.

Table - Summary AVERAGE Results PM Measurements in all different scenarios

Scenario	PM	Average WITHOUT AIRCORAL+ µg/m3	Average WITH AIRCORAL+ µg/m3	Avearge Variation in PMs observed µg/m3	% average variation
Field trial Brussels (Average over 2 days)	**PM1**	2.3	1.3	-1.0	**-40%**
Field Trial Milan Restaurant		8.45	3.23	-5.22	**-62%**
Field Trial Kindergarten school		20.20	20.20	0	**0%**
Field Trial high-school		54.65	46.95	-7.71	**-14%**
Average of all environments	**PM1**			**-3.5**	**-29%**
Field trial Brussels (Average over 2 days)	**PM2.5**	3.4	1.9	-1.7	**-50%**
Field Trial Milan Restaurant		25.89	4.89	-21.00	**-81%**
Field Trial Kindergarten school		30.88	29.45	-1.43	**-5%**
Field Trial high-school		66.12	57.40	-8.72	**-13%**
Average of all environments	**PM2.5**			**-8.2**	**-37%**
Field trial Brussels (Average over 2 days)	**PM10**	22	6	-16	**-72%**
Field trial Hospital in Brescia		31.01	17.06	-13.95	**-45%**
Field Trial Milan Restaurant		287.04	20.17	-266.87	**-93%**
Field Trial Kindergarten school		94.82	84.01	-10.82	**-11%**
Field Trial high-school		85.21	75.91	-9.30	**-11%**
Average of all environments	**PM10**			**-63.4**	**-46%**

Demonstrated high reduction of trace elements

All measurements correspond to EN 12341.

In the areas where there were significant amounts of dust with metallic impurities, **a clear relevant reduction of trace elements was observed after exposure to illuminated AIRCORAL+ material.**

The lowest effect was with Zinc and the highest effect was with Silver (Ag), Cadmium (Cd) and lead (Pb).

The following table shows results calculated as <u>average</u> of all measurements taken in the considered real scenarios.

	Metal traces AVERAGE variation in the air room of the ral scenarios after 2 hours of illumination WITH AIRCORAL+	
	%	ug/m3
Ag	**-53%**	-134
Cd	**-53%**	-80
Cu	**-37%**	-174
Mn	**-35%**	-88
Ni	**-40%**	-202
Pb	**-52%**	-135
Zn	**-10%**	-56

Demonstrated high reduction of microbial growth

Measurements in real scenarios were done on bacteria sampled from field environments and controlled pure organisms

- QC Organism Staphylococcus Aureus ATCC25923 for Kirby Bauer susceptibility testing
- QC Organism Pseudomonas Aerogines ATCC10145
- Airborne organisms from field environments.

In all cases **inhibition of bacterial growth was very clearly observed when they were exposed to illuminated AIRCORAL+ material.**

Effect on trace gas reduction

In the cases measured, the data of trace gas concentrations clearly showed relevant effects of **AIRCORAL+ on decreasing methyl sulphide, carbon dioxide, methane and ammonia.**