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The Development, Testing and Verification of Airora's Patented Technology

1 Introduction

Airora's multi-million pound scientific, technical and engineering journey has taken over ten years and has involved several phases of prototype development. As the science is both relatively new and challenging we have required extensive independent testing to ensure both the safety and efficacy of the resulting product.

The journey has involved the expert and professional capabilities of a number of internationally renowned independent design, research and testing organisations, including:

- The UK Building Research Establishment's Internal Air Quality Team and Laboratories
- PA Consulting
- The UK Government's Health Protection Agency
- The UK Government's Health and Safety Laboratory
- FDA Laboratory, Rochester, New York State
- The University of Leeds
- The University of York
- The University of Ottawa

Underpinning the whole Airora journey has been the culture of generating sound evidence based on good science.

2 Developmental timeline

2007 Extensive microbiological testing of prototype engines at the UK Government's Health Protection Agency at Porton Down.

Granted initial patent in GB followed by 60 jurisdictions.

2008 Prototype designated T250 developed leading to radical steps in the understanding of the technology and device design.

2010 T250 learning leads to concept design of 'domestic' prototype room scale devices, termed T35 (without a fan) and T50 (with a fan).

2011 - 2013 In-depth independent testing to confirm all aspects of safety and emissions and the associated regulatory requirements word-wide, with a target to reduce all emissions to < 1/10 of the acceptable regulatory limits.

2013 Prototype T60 developed to embody and exceed all regulatory and other requirements.

T60 subject to further extensive efficacy and safety testing.

2014 Additional, new patents applied for and subsequently granted.

2015 – 2016 Further developments and simplifications with a focus on Allergens and Asthma, leading to the development of the Airora 4-in-1.

2017 - 2018 Industrial design, final pre-sales testing, manufacture and launch!

3 How it works

Airora technology replicates the purifying power of outdoor air chemistry, but inside buildings. It mimics the effect of sunlight on external air to create a safe and natural hydroxyl radical cascade throughout every corner of a room. Those hydroxyl radicals are ever present throughout the external environment and are nature's most powerful decontaminant.

Proprietary and third party data show that hydroxyl radicals can rapidly:

- neutralise airborn allergens such as pollens, spores, pet dander, cat saliva and house dust mite excretions
- eliminate all common lung irritants and other pollutants such as ozone, volatile organic compounds (VOCs), formaldehyde and carbon monoxide
- remove all odours from the air, and
- kill all airborne bacteria and viruses that are known to harm people, such as Colds, Flu, MRSA, C-difficile and Norovirus, and quickly strip them, layer by layer, from smooth exposed

The result is a fresh, clean, pleasant internal environment.

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4 Safety (Air Quality)

Throughout the development of the technology the utmost concern has been to ensure the safety of the devices. To this end there has been extensive testing of the emissions starting with the earliest prototypes.

The Indoor Air Quality team at BRE undertook most of this work, with additional input from the University of Leeds and University of York.

At the outset a thorough study was carried out by BRE to determine international regulations and limits for various relevant compounds. From this the tightest limits were taken as the starting point for compliance. However, working with various third parties, who were interested in the technology, key limits were further tightened.

The testing at BRE was carried out in a specialist 18m^3 chamber designed for air quality studies. This was chosen as it represented a small bedroom sized space reflecting the smallest room in a house where a consumer version of the device might be used. Testing in a small chamber like this represents a tougher challenge from an air quality point of view.

The results below are for the most recent development prototype, which could be set to low, medium and high outputs.

Parameter	Limit	Units	Low Setting	Medium Setting	High Setting
Ozone	50	ppb	6	11	30
TVOC	100	µg/m^3	5	7	8
Formaldehyde *	2.5	µg/m^3	-8	-4	-1
PM2.5	15	µg/m^3	<2	<2	<2

*The negative formaldehyde values are because the device had reduced the original background level of the test chamber.

BRE and the University of York were, together, able to identify <u>all</u> trace compounds resulting from the use of our technology and were able to confirm that all were safe.

5 Efficacy

5.1 Airborn Allergens

Independent third party research relating to hydroxyl radicals and their effect on in-door allergens illustrates how hydroxyl radicals can prevent the onset of allergic reactions.

Pollens, Fungal Spores, Pet Dander

Hydroxyl radicals have been shown to reduce IgE-binding capacity in pollens, spores and pet dander through the degradation and modification of the tertiary structure and/or the induction of protein denaturation and/or aggregation. This allergen structure is no longer recognised by the body's immune system and therefore histamine and other chemical mediators are not released.

While the references below refer in their titles to cluster ions, the text makes it clear that the recorded effects are achieved by hydroxyl radicals which result from the chemical interactions between the cluster ions.

References:

1. Kawamoto S et al. Decrease in the Allergenicity of Japanese Cedar Pollen Allergen by Treatment with Positive and Negative Cluster Ions, International Archive of Allergy and Immunology, 2006, Vol.141, No. 4
2. Kazuo Nishikawa et al. Exposure to positively and negatively charged plasma cluster ions impairs IgE binding capacity of indoor cat and fungal allergens, World Allergy Organization Journal 2016

House Dust Mites

Hydroxyls instantly denature the allergen Der p1 and Der f1 found in house dust.

Hydroxyls oxidise their protein structures, for example protein backbone damage due primarily to a hydrogen atom abstraction at the alpha carbon. This process leads to backbone fragmentation.

Side-chain damage is another possible protein oxidation mechanism and can occur through hydrogen abstraction or oxygen addition. Both hydroxyl radical initiated oxidation mechanisms result in a modified allergen structure. This allergen structure is no longer recognized by the body's immune system and therefore histamine and other chemical mediators are not released.

References:

1. Garrison W M. Reaction mechanisms in the radiolysis of peptides, polypeptides, and proteins. Chem Rev 1987:381-398 -9920.
2. Singh J & Thornton J M. Atlas of Protein Side-Chain Interactions, Vols. I & II, 1992 IRL press, Oxford.

5.2 Malodours

Malodour experiments are undertaken either by chemical analysis or by human noses. While there is extensive literature demonstrating the ability of hydroxyl radicals to react with, break down and remove malodours, Airora has also undertaken field tests to demonstrate the effects.

<u>Blind-fold Test – Consumer Reactions July 2013</u>

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Airora has undertaken several human nose experiments, the most significant of which was in 2013. Using a professional consumer research firm Airora took 12 groups of recruited consumers, both women and men through a blindfold experience of an Airora device inside two different test houses. Each of the groups was then de-briefed which were captured on video (over 7hrs), with a two minute video summary (available under NDA) produced to illustrate the overwhelming reactions of the groups.

The language used by these consumer groups to express the beneficial effect of the T60 included:

- “outdoors”
- “in a spa”
- “on holiday by the sea”
- “feel energised”
- “motivated”
- “mountains”
- “forests”

5.3 Removal of VOC’s and other pollutants / Asthma triggers

It is well documented that the powerful oxidisation effect of hydroxyl radicals eliminates pollutants and common lung irritants such as ozone, volatile organic compounds (VOCs), formaldehyde and carbon monoxide.

BRE has undertaken months of air quality testing of Airora’s various prototype devices. As part of these tests BRE attempted to qualify and quantify the test chamber air prior to, as well as during and after testing, in order to ascertain exactly the air emissions created by the Airora technology versus the background air.

VOCs

BRE has carried out extensive testing of an Airora development prototype to measure its performance in reducing VOC concentrations in the air. The following VOCs typical of domestic life were employed in the tests:

VOC	CAS Number	Boiling Point °C	Reason for Inclusion
Butan-1-ol	71-36-3	117	Representative of the family of alcohols, including ethanol (alcohol, perfume),

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VOC	CAS Number	Boiling Point °C	Reason for Inclusion
			propan-2-ol (sanitising gel, cleaning agent, IPA).
Butan-2-one (Methyl ethyl ketone, MEK)	78-93-3	80	Representative of ketones, a common solvent in industrial paints, glues.
Dodecane	112-40-3	215	Representative of alkanes, aliphatic hydrocarbons often found in paints, glues, fuels
Limonene	138-86-3	179	Representative of terpenes, found in air fresheners, scents, as well as citrus fruits.
Octamethyltrisiloxane (OMTS)	107-51-7	153	Representative of siloxanes, often found in personal care products and cosmetics, as well as dry cleaning.
Toluene	108-88-3	111	Representative of aromatic hydrocarbon compounds, found in pyrolysis products and solvents.

Identical VOC concentrations were released into a controlled environment, when no Airora device was active and where an Airora device was active.

VOC decay with a prototype Airora device

VOC	RT	Time in minutes after spiking / Concentration in air								
		5	30	60	90	120	150	180	210	240
C4 hydrocarbon	5.05	2385	1708	1243	966	785	233	434	344	325
C5 hydrocarbon	6.20	8	7	6	6	6	8	6	6	6
Butan-2-one	8.00	194	126	88	61	41	29	21	17	16
Butan-1-ol	10.95	134	185	125	83	57	39	31	26	25
X2	11.70	4	3	4	4	3	4	3	3	3

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VOC	RT	Time in minutes after spiking / Concentration in air								
		5	30	60	90	120	150	180	210	240
Toluene	13.15	183	168	120	79	54	36	27	22	19
Octamethyltrisiloxane	16.75	28	58	71	55	38	23	18	14	13
Limonene	27.35	26	49	80	68	50	29	18	14	10
Linalool	33.05	5	3	5	4	4	3	4	5	3
Dodecane	33.60	7	13	30	34	36	36	39	30	40
TVOC		473	484	449	342	255	193	146	132	118

- All concentrations are in μgm^{-3}.
- RT denotes the approximate retention time in minutes, rounded to the nearest 0.05 minute.
- ND denotes less than 2 μgm^{-3}.
- C4 and C5 hydrocarbons are not accurately quantified by this technique.

Formaldehyde

In nature, formaldehyde is produced from a variety of sources and by the action of hydroxyl radicals as they decompose VOC's and other organic compounds. As hydroxyl radicals decompose larger VOC's, smaller and smaller hydrocarbon compounds are formed. Formaldehyde is the smallest; it contains one carbon bonded to oxygen (H2C=O) and represents the last step before the final oxidation to produce carbon dioxide – carbon bonded to two oxygen atoms (O=C=O).

Formaldehyde is a common contaminant in indoor air as it outgases from fabricated wood products, paints, adhesives, fabrics etc. It is toxic and the US Occupational Safety & Health Administration (OSHA) guideline for formaldehyde exposure is less than 750 ppb (0.75 ppm) over an 8-hour period. Short-term exposure cannot exceed 2 ppm. Formaldehyde reacts rapidly with hydroxyl radicals, so hydroxyl radical generators used indoors are very effective in decomposing it.

The testing facilities at BRE filter as many complicating contaminants as possible from the air entering the test chamber prior to an Airora emissions test. It is impossible to remove all background compounds and some formaldehyde was inevitably present (formaldehyde is emitted by many surfaces used in the

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construction of the built environment). Throughout the many tests undertaken by BRE for Airora during the development of the prototypes, it has been shown that the technology breaks down and removes formaldehyde over time.

The data collected from the final low, medium and high device settings for the T60 development prototype illustrates this effect:

Test/Setting	Formaldehyde $\mu g/m^3$		
	Before test	At end of test	Change
1 Low	4	5	+1
2 High	7	6	-1
3 Medium	6	6	0
4 Low	10	2	-8
5 Medium	7	5	-2

References:

1. B. J. Finlayson-Pitts and J. N. Pitts, Jr., The Chemistry of the Upper and Lower Atmosphere, Academic Press, San Diego, 1999.
2. J. A. Logan, M. J. Prather, S. C. Wofsy, and M. B. McElroy, Atmospheric Chemistry: Response to Human Influence, Phil. Trans. Roy. Soc. (London) 290, 187 (1978).
3. C. J. Weschler and H. C. Shields, Production of the Hydroxyl Radical in Indoor Air, Environ. Sci. Tech. 30, 3250 (1996).

5.4 Destruction of pathogenic viruses and bacteria

Atmospheric hydroxyl radicals are proven to kill all human pathogens, be they bacteria or viruses, by a well understood process whereby they are able to penetrate the permeable cell membranes damaging the lipids and proteins that form the cell membranes, which result in leakage and cell death.

Conversely, humans, animals and plants have developed symbiotically with atmospheric hydroxyl radicals and thrive in their presence. Atmospheric hydroxyl radicals are a critical component of nature's dynamic ability to provide environments that are free of harmful chemicals and pathogens.

Airora's technology creates a constant cascade of hydroxyl radicals. Our extensive test data, from both the laboratory and the field, demonstrates its rapid effectiveness in destroying bacteria and viruses, and also fungal spores, as demonstrated below:

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Test Facility / Date	Test Type	Test Microbes	Test Method	Test Chamber Size	Results
HPA UK Jun 2006	Airborne	MS-2 Coliphage	Aerosolisation (high concentrations)	18m3	6 log (99.9999%) kill in less than 5 minutes
HPA UK Sep 2007	Airborne	1) Bacillus atrophaeus (gram +) "aerostable spore" 2) Staphylococcus epidermidis (gram -)	Aerosolisation (high concentrations)	18m3	1) 1 to 2 log (99%) kill in 60 minutes 2) 5 log (99.999%) kill in 2 minutes
HPA UK Nov 2007	Surfaces (steel & glass)	1) MRSA (low concentrations) 2) MRSA (high concentrations)	1) Tested over 1 & 4hrs. 2a) Tested at 24 hrs & 2b) Tested at 48hrs.	18m3	1) At 1 hour NO surviving MRSA on glass or steel. 2a) NO surviving MRSA on glass (greater than 6 log kill) & a 3 log kill on steel 2b) 4 log kill on steel
FDA lab USA Sep 2008	1) Airborne 2) Surface (steel / formica / textile)	Test 1) Bacillus atrophaeus Test 2a) MRSA & 2b) Bacillus atrophaeus (high concentrations)	1) Aerosolisation (high concentrations) 2) Tested over 26 – 36hrs.	15m3	1) 6 log kill after 20 minutes 2a) 3 log kill on all surfaces at 14-16hrs 2b) 2 log kill on steel & formica & 4 log kill on textile at 14-16hrs.
HPA UK Feb 2010	Airborne	MS-2 Coliphage	Aerosolisation (high concentrations)	0.9m3 safety cabinet	4 to 6 log kill in 30 mins to 2 hrs.
HPA UK Feb 2010	Surface (stainless steel)	MS-2 Coliphage & MRSA	Both tested at 0, 2, 4, 24 & 48hrs.	0.9m3 safety cabinet	1.5 log reduction at 24 & 48 hrs (faulty units)
Real world test in a Coffee Shop (1 week period) Jul 2010	Airborne	1) Bacteria 2) Fungal Spores 3) Enterobacteriaceae	Real world samples taken from a working coffee shop over 1 week.	Approx 300m3 with front & rear entrances in constant use.	1) 95% kill 2) 90% kill 3) 100% kill
Real world test in a Cinema (1 week period) Jul 2010	Airborne	1) Bacteria (human) 2) Bacteria (environmental	Real world samples taken from a working cinema auditorium over 1 week.	Approx >1000m3	1) 95% kill 2) 86% kill Plus positive observations by cinema staff on effect on malodours
Real world test in a Care Home (1	Airborne	1) Bacteria (human) 2) Bacteria	Real world samples taken from a working	Approx 400m3 sited in main dining hall	1) 91% kill in dining hall & 98% kill in common room

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Test Facility / Date	Test Type	Test Microbes	Test Method	Test Chamber Size	Results
week period) Jul 2010		(environmental	care home which had the windows open during the day over 1 week.	open to a L-shaped corridor & rooms off the corridor	2) 90% kill in dining hall & 89% kill in common room

University of Ottawa testing

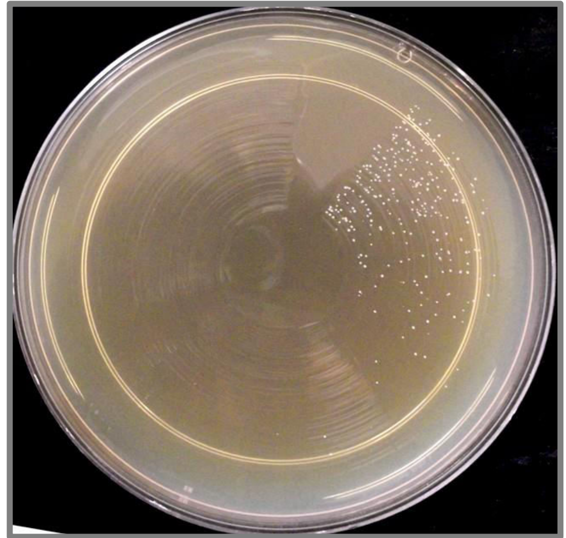
In addition to independent testing undertaken on our behalf, Dr. Sattar of Ottowa University, undertook testing on an Airora development prototype at the University of Ottawa on behalf of a third party. A summary of the results is shown below.

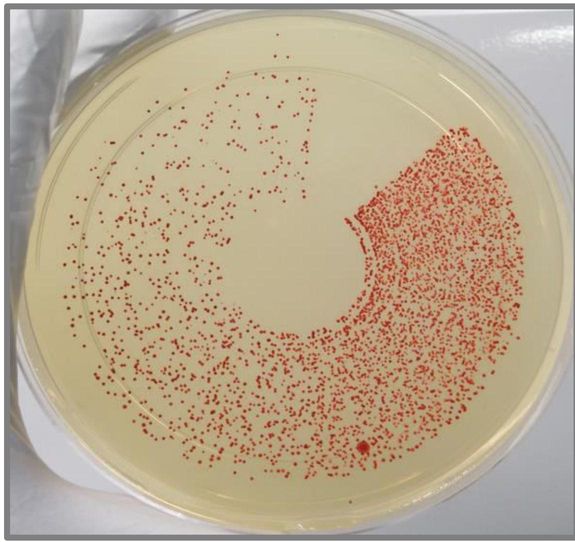
Photographs of recovery plates from the 120 minute Reyniers slit sampler:

The first stained photograph of the control plate (SE #1) shows the colony forming units (CFU) of Staphylococcus epidermidis recovered from the air of the aerosol chamber. The second photograph represents a preliminary examination (20 hours of incubation) of unstained bacteria of the test plate (T60- #1-1) representing the first evaluation of the development prototype (LED/35ppb O3).

Control Plate: Stability in Air (SE #1)

Test Plate: Device Test (#1-1)





It can be seen that the S. epidermidis has been reduced in numbers to undetectable in ~35-40 minutes (the challenge input – nebulizer fluid concentration of the SE#1 was 4.9Log10 and the #1-1 was 4.82Log10) these values show that the inoculums sprayed into the chamber are consistent and these plates can be compared to each other for the purposes of efficacy.