Active green wall technology for the phytoremediation of indoor air pollutants

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Introduction

Whilst physiochemical methods used to control indoor air quality can be effective in the short term, they have many disadvantages (Torpy et al., 2015). One flaw is that no physiochemical method has the ability to filter CO_2 (Torpy et al., 2015), one of the primary pollutants of indoor air. Other disadvantages range from high costs associated with installation and regular maintenance, being hazardous in relation to VOC or ozone emission and an inability to remove all gaseous pollutants at once (Soreanu et al., 2013). Most methods also require significant energy input, with the exception of the emerging plant and microbial biofiltration processes (Luengas et al., 2015). Recent advances in green wall technology have led to the rate at which they can modulate the interior atmospheric envdevelopment of activated systems that move air through the plant wall to increase the ironment. These systems have enhanced pollutant removal capabilities.

Aims:

1. Determine the CO_2 removal ability of an active green wall system
2. Determine the PM removal ability of an active green wall system
3. Calculate the CADR of the system for both CO_2 and PM

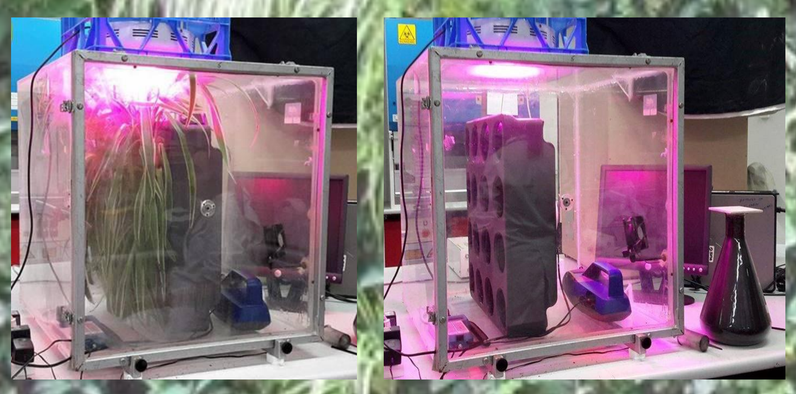

Figure 3: The experimental set up including the test active *Breathing Wall* modules; left hand side containing plant species *C. Comosum variegatum* and right hand side the system containing just packing media.

Materials and Methods

Chamber studies conducted (air-tight Perspex chambers 0.216 m^3 internally). Single modules were tested at five operation modes; axial impellers off, 3.75 L/s, 7.5 L/s, 11.25 L/s, 15 L/s. The packing media (without plants) was also tested to compare the efficiency of the packing media independently. Particulate matter was produced from the burning of candles containing 40:60 retail grade Shell diesel:wax and was injected into the chamber by a syringe. Changes in chamber TSP air concentrations was recorded with a DustTrack II 8532 laser densitometer (TSI, Shoreview, Minnesota).

Chamber CO_2 levels were elevated to 1000 ± 50 ppmv by the operator exhaling into the chambers for ~ 1 min and was recorded with a portable Infra-Red Gas Analyser (IRGA; TSI IAQ-CALC, TSI Inc., MN, USA) at 1 min intervals for 40 min. *Chlorophytum* modules were tested at full, half and nil assisted aeration speeds and at 10, 50 and 100 µmol m^{-2} s^{-1} light regimes.

Equation 1

Total decay constants (k) were calculated using the following equation:

$$C=Coe-kt$$

Where $k=-\ln((Co/C)/t)$

Where C = aerosol concentration at time t, (µg. m^{-3}),
Co = peak aerosol concentration, (µg. m^{-3}),
k = overall rate constant of concentration decay (h^{-1})
t = time, (h).

Equation 2

The clean air delivery rate of the system was calculated for both PM and CO_2 using the following equation:

$$CADRd=V(Ke-Kn)$$

Where: V = the volume of the test chamber (m^3), Ke = the total decay rate with air cleaner operating (h^{-1}), Kn = the natural decay rate without air cleaner operating (h^{-1}).

Results and Discussion

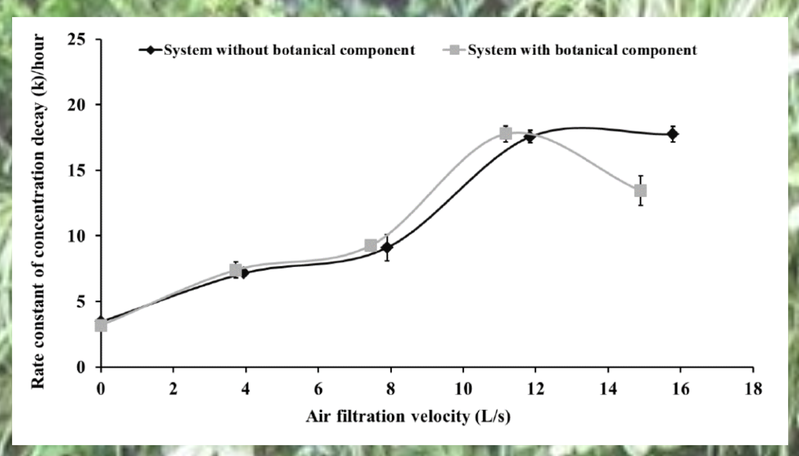

Figure 2: Total suspended particle decay constants (K) across air flow rates of the system; with systems containing just packing media (diamond) and with the botanical component present (square).

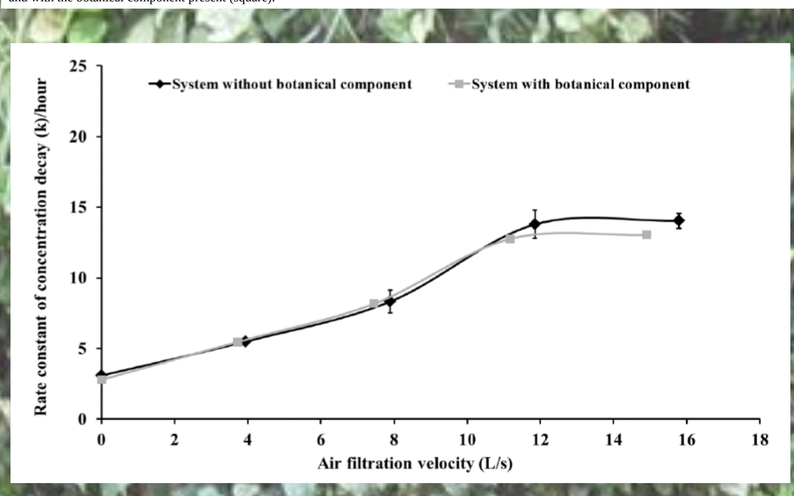

Figure 3: PM_{10} decay constants (K), across air flow rates of the system; with system containing just packing media (diamond), and the system botanical component present (square).

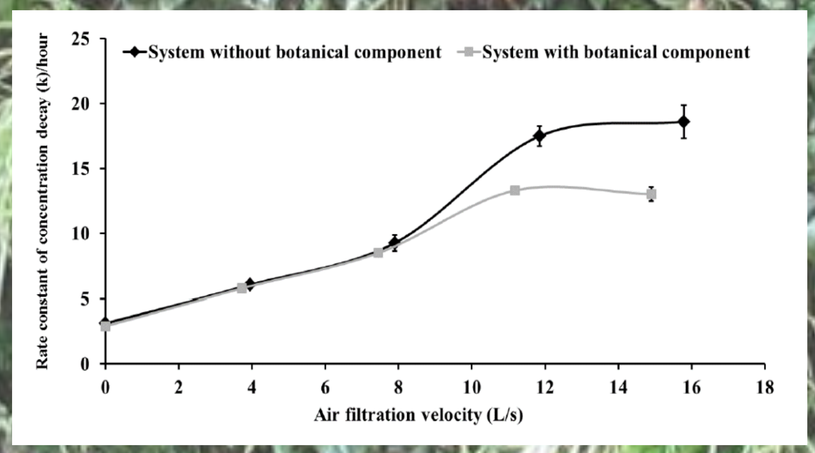

Figure 4. $PM_{2.5}$ decay constants (K), across air flow rates of the system; with system containing just packing media (diamond), and the system botanical component present (square).

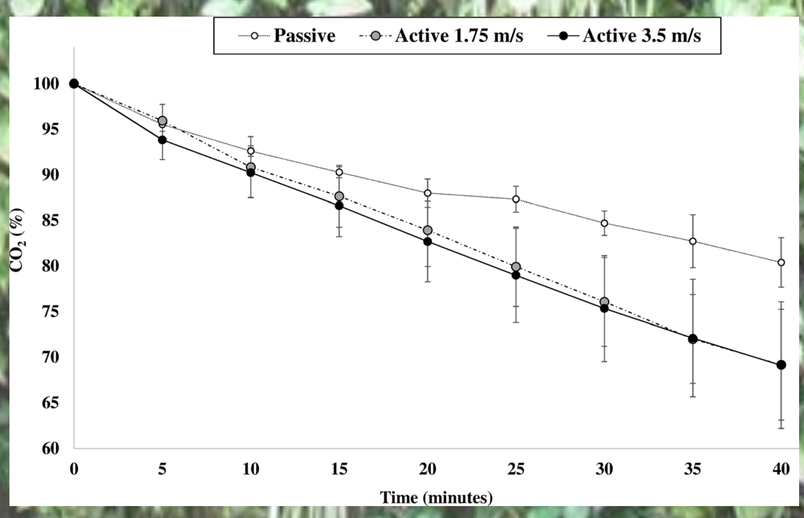

Figure 5. Chamber trials of CO_2 draw down (as % of a starting concentration of ~1000 ppmv) for *Chlorophytum* at 100 µmol m^{-2} s^{-1}, with module impellers off, running at full output (3.5 m s^{-1}) and half full output (1.75 m s^{-1}). Data are corrected for chamber losses (leakage). Data are means ± SE, n = 3

Table 1: Net effective CO_2 removal from a sealed room by four modules containing two different plant species, at two different light intensities and with module impellers off and running at full output (3.5 m s^{-1})

Light level (µmol m^{-2} s^{-1})	Fan speed (m s^{-1})	Volume of CO_2 removed (mL h^{-1})	Mass CO_2 removed (g h^{-1})	CADR (m^3 m^{-2} green wall h^{-2})	ACH (m^{-2} green wall)
50	0	2418	4.43	0.21	0.014
50	3.5	2221	4.07	0.26	0.017
250	0	2688	4.92	0.31	0.020
250	3.5	2999	5.49	0.33	0.021

Table 1: $CADR_d$ calculated from filtration decay rate tests. Data is expressed as m^3/h

Pollutant	Presence of botanical component	Air flow rates 13.5	27	40.5	54
TSP	NO	0.85	1.22	3.05	3.09
	YES	0.85	1.25	3.09	2.16
PM_{10}	NO	0.58	1.19	2.37	2.43
	YES	0.57	1.16	2.15	2.21
$PM_{2.5}$	NO	0.67	1.37	3.15	3.39
	YES	0.61	1.20	2.24	2.19

The active biofilter successfully filtered both ambient CO_2 and PM levels.

An increase in air flow through the system, resulted in a significant increase of particle removal from the chamber air.

The botanical treatment maximum filtration efficiency for TSP, PM_{10} and $PM_{2.5}$ peaked at 11.25 L/s, with increased air flow rate met with a reduction in efficiency.

The system without the botanical component of the biofilter maintained the same removal efficiency with increased air flow rate for TSP, PM_{10} and $PM_{2.5}$.

The difference in removal efficiency between the vegetated and non vegetated biofilters at the higher air flow rates may be a result of the *Chlorophytum* roots altering the air fill porosity of the packing media, in turn affecting the filtration matrix and thus the PM removal efficiency.

In most cases the CADR values were marginally higher for the non-vegetated modules, increased as assisted aeration increased, and were lowest for PM_{10}; likely due to a decreased filtering efficiency of the systems for larger particles.

With the fans off, the *Chlorophytum* modules removed 80% of the chamber CO_2, however with fans on either half or full speed, removed a further 10% of chamber CO_2 .

A 1 m^2 green wall containing *Chlorophytum* at 250 µmol m^{-2} s^{-1} with substrate ventilation would be capable of balancing ~16% of the respiratory CO_2 from a single occupant. Twenty 0.25 m^3 modules would thus balance out one person's respiratory emissions.

The results presented here provide an indication that active biofilters can be used for ambient CO_2 filtration. However, for enhanced removal higher light levels and substrate ventilation rates should be used in conjunction with higher preforming species such as *Chlorophytum.* It is suggested that future experiments incorporate a larger variety of plant species to better identify the highest performing species for *in situ* use.

The majority of previous research has focused primarily on VOC removal, making the demonstrated PM removal ability of the active biofilter of great significance. It has now been proven that active biofilters are able to reduce ambient CO_2 ,VOC and PM levels, all air pollutants of great concern, within laboratory chamber environments.

Due to the inaccuracy of extrapolating chamber results to real world environments, it is now pivotal to implement these systems *in situ* to determine their full potential for indoor pollutant remediation.

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Irga, P.J., Paull, N.J., Abdo, P. & Torpy, F.R. 2017, 'Assessment of the removal efficiency of atmospheric particles by an in-room botanical biofilter system', Building and Environment. DOI 10.1016/j.buildenv.2017.01.035

Torpy, F.R., Zavattaro, M. & Irga, P.J. 2017, 'Green wall technology for the phytoremediation of indoor air: a system for the reduction of high CO_2 concentrations', Air quality, atmosphere and health. DOI 10.1007/s11869-016-0452-x.

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Soreanu, G., Dixon, M. & Darlington, A. 2013, 'Botanical biofiltration of indoor gaseous pollutants – A mini-review', Chemical Engineering Journal, vol. 229, pp. 585-94.
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