Botanical Biofilters for the Phytofiltration of Urban Air Pollutants

By Thomas Pettit

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy under the supervision of Dr Fraser Torpy and Dr Peter Irga

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Certificate of Original Authorship

I, Thomas Pettit, declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Life Sciences at the University of Technology Sydney. This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

Signature: Production Note: Signature removed prior to publication. Date: 06/11/2021

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Format of Thesis

This thesis is submitted as a *thesis by compilation*. This thesis consists of seven chapters. Chapters 1-6 represent separate articles, all of which have been peer-reviewed, accepted and published in scientific journals. As such, parts of this thesis are presented verbatim to their published form; consequently, some repetition occurs in regards to themes and style. To prevent unnecessary duplication, a single reference list has been provided at the end of the thesis.

This thesis is a compilation of my own work with guidance from my supervisors and additional assistance from others. I conceptualized my research, designed the experiments including choice of methods and instrumentation, conducted all data collection and analysis, and wrote the manuscripts. My supervisors and co-authors proof-read and edited the final peer reviewed manuscript versions. Publication details and contributions of co-authors are detailed below.

List of peer-reviewed publications contributing to this thesis

Chapter 1:

Pettit, T., Irga, P.J. and Torpy, F.R., 2018. Towards practical indoor air phytoremediation: a review. *Chemosphere*, *208*, pp.960-974.

Pettit, T., Irga, P. and Torpy, F., 2020, October. The evolution of botanical biofilters: developing practical phytoremediation of air pollution for the built environment. In *1st International Conference on Climate Resilient Built Environment iCRBE*. World Energy and Environment Technology Ltd-WEENTECH.

Chapter 2:

Pettit, T., Bettes, M., Chapman, A.R., Hoch, L.M., James, N.D., Irga, P.J., Torpy, F.R. and Plants and Environmental Quality Research Group, 2019. The botanical biofiltration of VOCs with active airflow: is removal efficiency related to chemical properties?. *Atmospheric Environment*, *214*, p.116839.

Chapter 3:

Pettit, T., Irga, P.J. and Torpy, F.R., 2019. The *in situ* pilot-scale phytoremediation of airborne VOCs and particulate matter with an active green wall. *Air Quality, Atmosphere & Health*, *12*(1), pp.33-44.

Chapter 4:

Pettit, T., Irga, P.J., Surawski, N.C. and Torpy, F.R., 2019. An Assessment of the Suitability of Active Green Walls for NO2 Reduction in Green Buildings Using a Closed-Loop Flow Reactor. *Atmosphere*, *10*(12), p.801.

Chapter 5:

Pettit, T., Torpy, F.R., Surawski, N.C., Fleck, R. and Irga, P.J., 2021. Effective reduction of roadside air pollution with botanical biofiltration. *Journal of Hazardous Materials*, *414,* p.125566.

Chapter 6:

Pettit, T., Irga, P.J. and Torpy, F.R., 2020. The botanical biofiltration of elevated air pollution concentrations associated the Black Summer wildfire natural disaster. *Journal of Hazardous Materials Letters*, *1*, p.100003.

Co-author contribution

The contribution of each co-author is stated in the preface to each chapter. Co-authors have provided their signatures to confirm their contribution in their respective publications as stated in the preface of each chapter:

Miranda Bettes:	Production Note: Signatures removed prior to publication.	13/04/2021
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Nic Surawski:	Production Note: Signatures removed prior to publication.	14/04/2021
Fraser Torpy:	Production Note: Signatures removed prior to publication.	14/04/2021

Other peer reviewed publications published during my candidature but not forming part of this thesis

Pettit, T., Irga, P.J., and Torpy, F.R., 2018. Functional green wall development for increasing air pollutant phytoremediation: Substrate development with coconut coir and activated carbon. *Journal of Hazardous Materials*, *360*, pp.594-603.

Irga, P.J., Pettit, T., and Torpy, F.R., 2018. The phytoremediation of indoor air pollution: a review on the technology development from the potted plant through to functional green wall biofilters. *Reviews in Environmental Science and Bio/Technology, 17*(2), pp.395-415.

Torpy, F.R., Pettit, T. and Irga, P.J., 2018. Applied horticultural biotechnology for the mitigation of indoor air pollution. *Journal of People, Plants, and Environment*, *21*(6), pp.445-460.

Leonard, R.J., Pettit, T.J., Irga, P., McArthur, C. and Hochuli, D.F., 2019. Acute exposure to urban air pollution impairs olfactory learning and memory in honeybees. *Ecotoxicology*, *28*(9), pp.1056-1062.

Irga, P.J., Pettit, T., Irga, R.F., Paull, N.J., Douglas, A.N. and Torpy, F.R., 2019. Does plant species selection in functional active green walls influence VOC phytoremediation efficiency?. *Environmental Science and Pollution Research*, *26*(13), pp.12851-12858.

Fleck, R., Gill, R.L., Pettit, T., Irga, P.J., Williams, N.L.R., Seymour, J.R. and Torpy, F.R., 2020. Characterisation of fungal and bacterial dynamics in an active green wall used for indoor air pollutant removal. *Building and Environment*, *179*, p.106987.

Fleck, R., Pettit, T.J., Douglas, A.N., Irga, P.J. and Torpy, F.R., 2020. Botanical biofiltration for reducing indoor air pollution. In *Bio-Based Materials and Biotechnologies for Eco-Efficient Construction* (pp. 305-327). Woodhead Publishing: Sawston, United Kingdom.

Pettit, T., Irga, P.J., Torpy, F.R., Shagol, C.C. and Kim, K.J., 2020. Technological aspects of the removal of air pollutants by phytosystems. In *From Biofiltration to Promising Options in Gaseous Fluxes Biotreatment* (pp. 263-281). Elsevier.

Irga, P.J., Shagol, C.C., Kim, K.J., Pettit, T. and Torpy, F.R., 2020. Plant–microbe interaction within phytosystems used for air treatment. In *From Biofiltration to Promising Options in Gaseous Fluxes Biotreatment* (pp. 245-262). Elsevier.

Irga, P.J., Pettit, T., Shagol, C.C., Kim, K.J. and Torpy, F.R., 2020. Phytosystems implementation: examples of application in practice. In *From Biofiltration to Promising Options in Gaseous Fluxes Biotreatment* (pp. 283-299). Elsevier.

Kim, K.J., Shagol, C.C., Torpy, F.R., Pettit, T. and Irga, P.J., 2020. Plant physiological mechanisms of air treatment. In *From Biofiltration to Promising Options in Gaseous Fluxes Biotreatment* (pp. 219-244). Elsevier.

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List of Abbreviations

ANOVA: Analysis of variance

CADR: Clean air delivery rate

CO_2: carbon dioxide

df: Degrees of freedom

HDPE: High density polyethylene

HSD: honestly significant difference

HVAC: Heating, ventilation and air conditioning

GAC: Granular activated carbon

MERV: Minimum efficiency reporting value

NASA: National Aeronautics and Space Administration

NO: Nitrogen oxide

NO_x: Oxides of nitrogen

NO_2: Nitrogen dioxide

O_3: Ozone

PERMANOVA: Permutational analysis of variance

PM: Particulate matter

PM_x: Particulate matter, where x denotes the maximum aerodymanic diameter of the particles in μm.

ppb: Parts per billion

ppm: Parts per million

PVC: Polyvinyl chloride

SPRE: Single pass removal efficiency

TSP: Total suspended particles

TVOCs: total volatile organic compounds

VOCs: volatile organic compounds

WHO: World Health Organisation

Abstract

Air quality is of emerging importance due to the rapid growth of urban populations that are exposed to air pollution in both indoor and outdoor environments. As a potential solution, active green walls or botanical biofilters have been developed to assist in the removal of air pollutants directly from environments where people live. Through the use of active airflow, these vertically orientated, botanical systems pass a contaminated airstream through the plant growth substrate and foliage to filter air pollutants. The work presented here explores the capacity of active green walls to filter air pollution through laboratory, indoor and outdoor studies. Firstly, laboratory-based experiments revealed that the single pass removal efficiency (SPRE) of different volatile organic compounds (VOCs) by active green walls is influenced by the VOC's chemical properties, with average SPREs ranging from 19.76-96.34%. Modelling revealed that highly polar, small molecular weight molecules were removed with greatest efficiency. Secondly, pilot-scale trials assessed an active green wall's pollutant removal within a classroom, with average total VOC and PM concentrations reduced by ~28% and ~42.6% respectively, over 30 min trial periods, compared to levels with no green wall but having a HVAC-filtration system in operation. Thirdly, botanical biofiltration of NO_2 was assessed at ambient and elevated concentrations within a closed-loop flow reactor, while the concentrations of NO and O_3 were simultaneously monitored. Biofilter treatments using two plant species (*Spathiphyllum wallisii* and *Syngonium podophyllum*) exhibited exponential decay for the biofiltration of all three pollutants at ambient concentrations. Furthermore, both treatments removed elevated concentrations of NO and NO_2. Subsequently, botanical biofilters were field-assessed for the filtration of traffic associated air pollutants – NO_2, O_3 and $PM_{2.5}$ – from roadside ambient air in Sydney, Australia. Over two six-month research campaigns, all of the tested systems filtered NO_2, O_3 and $PM_{2.5}$ with average SPREs of up to 71.5%, 28.1% and 22.1% respectively. Clean air delivery rates of up to 121 m^3/h, 50 m^3/h and 40 m^3/h per m^2 of active green wall were achieved for the three pollutants respectively, with pollutant removal efficiency positively correlated with their ambient concentrations. An additional trial identified that active green walls filtered elevated air pollutant concentrations associated with the *Black Summer* wildfires, with average SPREs of 63.17%, 38.79% and 24.84% for NO_2, O_3 and $PM_{2.5}$ respectively. These cumulative

findings reveal that active green walls may have the capacity to play an important role in enhancing air quality and reducing air pollution exposure.