NEW EARTH SOLUTIONS

THE RESPIRA GREEN WALL FOR COMMERCIAL AND RESIDENTIAL USE

WHITE PAPER BY
CORBIN SPARKS

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INDOOR AIR QUALITY: AN INTRODUCTION

In the Global North, we spend up to 90% of our time indoors (Pettit et al., 2018). This time is generally split between several types of indoor spaces, such as places of residence, workplaces, and recreational spaces. With how ubiquitous indoor spaces are, it can be easy to overlook the air we breathe within these spaces.

"WE SPEND UP TO 90% OF OUR TIME INDOORS"

Indoor Air Quality (IAQ) is a general measure of how safe the air around us is. Three of the main contaminants of concern in indoor air are particulate matter (PM), volatile organic compounds (VOCs), and carbon dioxide (CO2) (Su & Lin, 2015). Generally, these pollutants have a much higher concentration in indoor air than in outdoor air (Pettit et al., 2018).

PARTICULATE MATTER

Solid or liquid particles suspended in the air (Weerakkody et al., 2017). Some examples include dust, smoke, small droplets of liquid, and pollen.

VOLATILE ORGANIC COMPOUNDS

These are chemicals that stay in the air as gasses (dela Cruz et al., 2014). Typical sources of VOCs are adhesives and glues, paints, stains, varnishes, fabric treatments, and some chemical cleaning products.

HOW POLLUTANTS ARE REMOVED FROM INDOOR AIR

There are many methods for removing pollutants from indoor air, but most buildings use replaceable filters built into their heating, ventilation, and air conditioning (HVAC) systems. The filters used by most buildings focus on removing PM from the air, however, some buildings use additional filters designed to remove VOCs and other chemicals (Seppanen & Fisk, 2006).

In addition to these more traditional methods for removing pollutants from indoor air, natural methods such as plants and algae can also be used to filter the air indoors (Pettit et al., 2018). Unlike HVAC filters that rely on capturing pollutants, plants are able to break down chemical pollutants into CO2 and other less harmful products (Mikkonen et al., 2018).

TRADITIONAL HVAC SYSTEMS

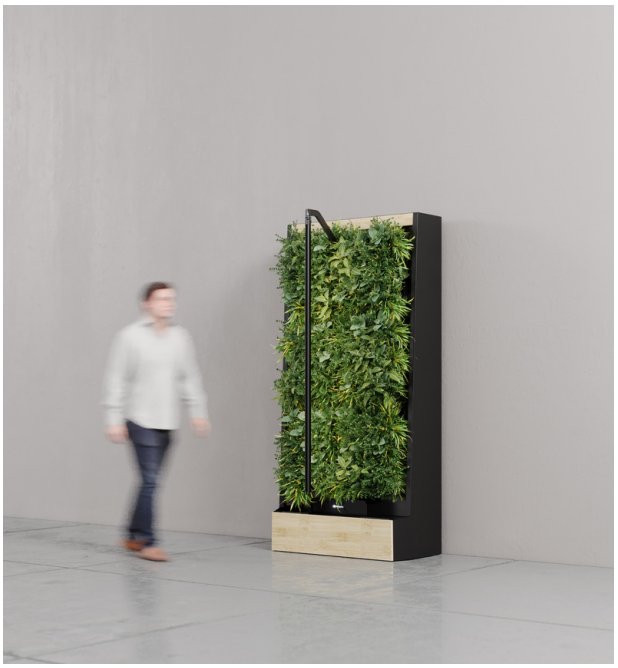
To improve IAQ in buildings with HVAC systems, outdoor air is first brought into the building. The air from outside typically only passes through a particle filter to remove PM from the air (Wang & Zhang, 2011). This filtered air is then heated or cooled according to what the building temperature is set to and is pumped into the building, and the air indoors is pushed out through the vents (Llewellyn et al., 2002).

LIMITATIONS OF TRADITIONAL HVAC SYSTEMS

The simple particle filters used by many buildings generally remove very little PM, such as the minimum efficiency reporting value (MERV) filters that remove less than 20% of particles from the air (Stephens & Siegel, 2013). Using a more complex filter system to remove more pollutants from the air requires a more powerful fan system, increasing the energy consumed by the building (Pettit et al., 2018).

PLANTS AND GREEN WALLS FOR CLEANING INDOOR AIR

Plants are known to remove pollutants from the air around them, especially CO2, VOCs, and even PM through a number of natural processes (Irga et al., 2019; Torpy et al., 2014; Wang et al., 2014). These processes can be physical, such as particles sticking to the plant leaves (Irga et al., 2019; Paull et al., 2019), or chemicals, such as CO2 and some VOCs being absorbed and converted into sugars by the plant (Mikkonen et al., 2018; Su & Lin, 2015).



Green walls, also known as plant walls, living walls, or vertical gardens, are a collection of systems that allow plants to be grown along vertical surfaces (Bustami et al., 2018). Respira is classified as an active hydroponic green wall. ‘Active’ refers to the fans within the system that direct air through the root zone of the plants; ‘Hydroponic’ because the plants are grown using water rather than soil (Pettit et al., 2018).

HOW GREEN WALLS REMOVE POLLUTANTS

Although it may be assumed that the plants in the green wall are largely responsible for removing pollutants from the air around them, most pollutants are removed by the microbial ecosystem of bacteria and fungi living in and around the plant's roots (Mikkonen et al., 2018). This microbial ecosystem is very diverse, with many different species being specialized to break down and metabolize a variety of chemicals, including many VOCs (Fleck et al., 2020). However, in order for the root microbes to remove VOCs, they must be able to access the polluted air.

Respira is designed with this fact in mind, as it brings polluted air directly to the plant roots using its fans and watering system. Since bacteria and fungi do not have lungs, they are not able to access pollutants in the air directly, instead, they must absorb pollutants through their cell membranes (Zhang et al., 2013). By using fans to draw air through the plant roots and a hydroponic growth medium, a pressure drop is created (Irga et al., 2018), allowing Respira to help direct VOCs out of the air and into the watering system. This allows the roots of the plants, and their microbial ecosystem, to be in direct contact with pollutants from the air.

LAB TESTING OF RESPIRA

Thanks to grants and funding through MITACS and OCI, the VOC removal efficiency of Respira was tested at Toronto Metropolitan University (TMU), along with an investigation of the types of bacteria and fungi growing in the roots of the green wall plants.

REMOVAL OF VOLATILE ORGANIC COMPOUNDS BY RESPIRA

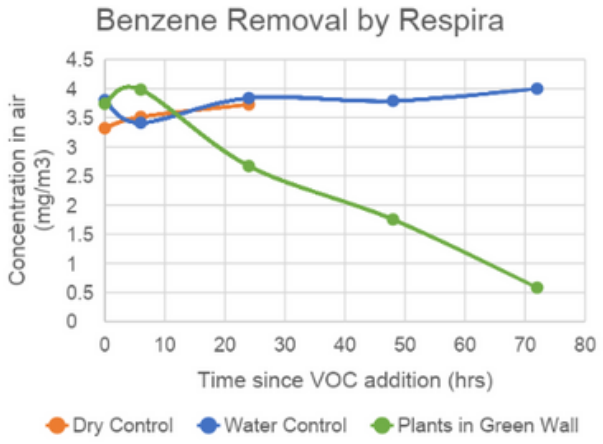
Preliminary tests of Respira show promising results for its ability to remove VOCs from the air. These tests were done in a sealed 30ft chamber where polluted air was allowed to circulate through Respira for 72 hours, with the exception of the dry control.

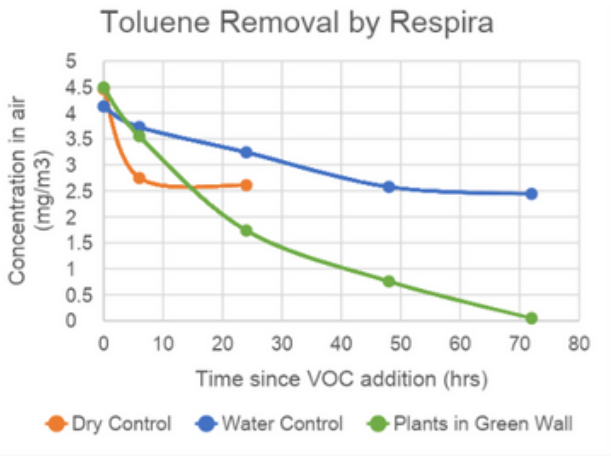
To determine how effective Respira is at removing VOCs, it was compared to other conditions, known as controls. For all tests, the fan and lighting systems were turned on. The first condition was the “dry” control, where Respira had no plants or water. The second condition was the “water” control, where water and fertilizer were added into Respira. The final condition was Respira when it was fully functional, with plants, water and fertilizer.

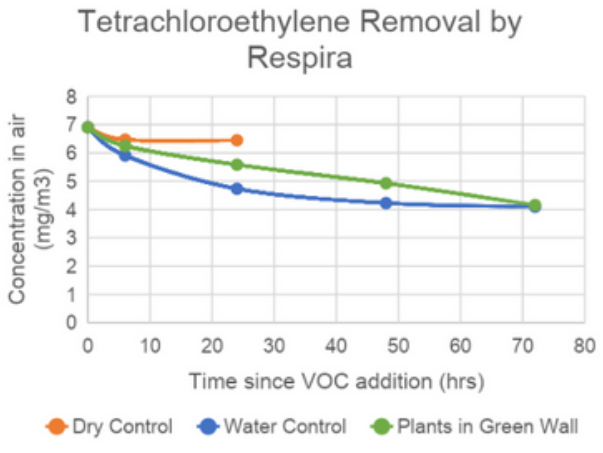
In the preliminary tests of Respira, three main VOCs were tested: benzene, toluene, and tetrachloroethylene (PERC). Benzene and toluene typically enter indoor air through adhesives, solvents, paints, and tobacco smoke (Health Canada, 2011, 2013). Tetrachloroethylene is usually found in homes near dry-cleaners who still use this particular chemical when washing garments, but can otherwise be introduced to indoor air through contaminated water and some fabric finishes (Health Canada, 2015; McKernan et al., 2008).

RESULTS

Preliminary tests of Respira showed that it could remove up to 2.68 mg of benzene and 3.77 mg of toluene in 72 hours, whereas water alone only removed up to 1.43 mg of toluene and no benzene. Interestingly, tetrachloroethylene concentrations slowly decreased at about the same rate no matter the testing conditions. This means any decrease in tetrachloroethylene over time is likely caused by a process known as dry deposition (Pettit et al., 2018), where chemicals in the air become stuck on solid surfaces, removing them from the air that was sampled.







FURTHER TESTING

These preliminary tests were just the start of the research being done on Respira. In addition to more VOCs being tested, such as acetaldehyde and m-xylene, the types of bacteria and fungi in the plants housed by Respira are also being investigated.

CONCLUSION

Contrary to popular belief, plants do not effectively remove toxins from the air using their leaves. The primary source of their ability to remove toxins stems from the root zone where a build of microorganisms capture and permanently destroy the airborne pollutants. Through preliminary testing, Respira proves to be an effective way of removing indoor air pollution. Respira also offers a more sustainable method for improving IAQ in comparison to the conventional HVAC approach, which uses disposable filters that are then discarded into a landfill only to release PM back into the air as it breaks down.

Through further research, we aim to investigate whether the technology and naturally occurring ecosystems of bacteria living in the roots of plants could lead to a reduced need for ventilation in buildings, thereby reducing the energy consumption of the building.

BIBLIOGRAPHY

Bakker, P. A. H. M., Berendsen, R. L., Doornbos, R. F., Wintermans, P. C. A., & Pieterse, C. M. J. (2013). The rhizosphere revisited: Root microbiomics. Frontiers in Plant Science, 4(MAY), 1–7. https://doi.org/10.3389/fpls.2013.00165

Bustami, R. A., Belusko, M., Ward, J., & Beecham, S. (2018). Vertical greenery systems: A systematic review of research trends. Building and Environment, 146(September), 226–237. https://doi.org/10.1016/j.buildenv.2018.09.045

dela Cruz, M., Christensen, J. H., Thomsen, J. D., & Müller, R. (2014). Can ornamental potted plants remove volatile organic compounds from indoor air? A review. Environmental Science and Pollution Research International, 21(24), 13909–13928. https://doi.org/10.1007/s11356-014-3240-x

Fleck, R., Gill, R. L., Pettit, T., Irga, P. J., Williams, N. L. R., Seymour, J. R., & 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. https://doi.org/10.1016/j.buildenv.2020.106987

Health Canada. (2011). Residential Indoor Air Quality Guideline: Toluene. http://www.hc-sc.gc.ca/ewh-semt/pubs/air/toluene/index-eng.php

Health Canada. (2013). Benzene in Indoor Air. http://www.hc-sc.gc.ca/ewh-semt/pubs/air/benzene_fs-fi/index-eng.php

Health Canada. (2015). Tetrachloroethylene. In Guidelines for Canadian Drinking Water Quality. https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/water-tetrachloroethylene-eau/alt/water-tetrachloroethylene-eau-eng.pdf

Irga, P. J., Pettit, T., Irga, R. F., Paull, N. J., Douglas, A. N. J., & Torpy, F. R. (2019). Does plant species selection in functional active green walls influence VOC phytoremediation efficiency? Environmental Science and Pollution Research, 26(13), 12851–12858. https://doi.org/10.1007/s11356-019-04719-9

Irga, P. J., Pettit, T. J., & 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. In Reviews in Environmental Science and Biotechnology (Vol. 17, Issue 2, pp. 395–415). Springer Netherlands. https://doi.org/10.1007/s11157-018-9465-2

Llewellyn, D., Darlington, A. B., & Dixon, M. A. (2002). Temperature and Airflow Influences Indoor Air. In Proceedings of the 9th International Conference on Indoor Air Quality and Climate., 1044–1049.

McKernan, L. T., Ruder, A. M., Petersen, M. R., Hein, M. J., Forrester, C. L., Sanderson, W. T., Ashley, D. L., & Butler, M. A. (2008). Biological exposure assessment to tetrachloroethylene for workers in the dry cleaning industry. Environmental Health: A Global Access Science Source, 7, 1–10. https://doi.org/10.1186/1476-069X-7-12

Mikkonen, A., Li, T., Vesala, M., Saarenheimo, J., Ahonen, V., Kärenlampi, S., Blande, J. D., Tiirola, M., & Tervahauta, A. (2018). Biofiltration of airborne VOCs with green wall systems—Microbial and chemical dynamics. Indoor Air, 28(5), 697–707. https://doi.org/10.1111/ina.12473

Paull, N. J., Irga, P. J., & Torpy, F. R. (2019). Active botanical biofiltration of air pollutants using Australian native plants. Air Quality, Atmosphere and Health, 12(12), 1427–1439. https://doi.org/10.1007/s11869-019-00758-w

BIBLIOGRAPHY

Pettit, T., Irga, P. J., & Torpy, F. R. (2018). Towards practical indoor air phytoremediation: A review. Chemosphere, 208, 960-974. https://doi.org/10.1016/j.chemosphere.2018.06.048

Seppanen, O., & Fisk, W. (2006). Some Quantitative Relations between Indoor Environmental Quality and Work Performance or Health. HVAC&R Research, 12(4), 957-973. https://doi.org/10.1080/10789669.2006.10391446
Stephens, B., & Siegel, J. A. (2013). Ultrafine particle removal by residential heating, ventilating, and air-conditioning filters. Indoor Air, 23(6), 488-497. https://doi.org/https://doi.org/10.1111/ina.12045

Su, Y. M., & Lin, C. H. (2015). Removal of indoor carbon dioxide and formaldehyde using green walls by bird nest fern. Horticulture Journal, 84(1), 69-76. https://doi.org/10.2503/hortj.CH-114

Torpy, F. R., Irga, P. J., & Burchett, M. D. (2014). Profiling indoor plants for the amelioration of high CO2 concentrations. Urban Forestry & Urban Greening, 13(2), 227-233. https://doi.org/10.1016/j.ufug.2013.12.004

Wang, Z., Pei, J., & Zhang, J. S. (2014). Experimental investigation of the formaldehyde removal mechanisms in a dynamic botanical filtration system for indoor air purification. Journal of Hazardous Materials, 280, 235-243. https://doi.org/10.1016/j.jhazmat.2014.07.059

Wang, Z., & Zhang, J. S. (2011). Characterization and performance evaluation of a full-scale activated carbon-based dynamic botanical air filtration system for improving indoor air quality. Building and Environment, 46(3), 758-768. https://doi.org/10.1016/j.buildenv.2010.10.008

Weerakkody, U., Dover, J. W., Mitchell, P., & Reiling, K. (2017). Particulate matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station. Urban Forestry & Urban Greening, 27(July), 173-186. https://doi.org/10.1016/j.ufug.2017.07.005

Zhang, H., Pennisi, S. v., Kays, S. J., & Habteselassie, M. Y. (2013). Isolation and identification of toluene-metabolizing bacteria from rhizospheres of two indoor plants. Water, Air, and Soil Pollution, 224(9). https://doi.org/10.1007/s11270-013-1648-4