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# Growing Aesthetics into the Biowall

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## ABSTRACT

Indoor Air Quality (IAQ) is an increasing concern in residential construction, particularly homes that are consciously designed for high efficiency. The IAQ problem occurs because efficient homes tend to be air tight, but without adequate exchange of outside air pollutants such as Volatile Organic Compounds (VOC's) can achieve concentrations that are higher than desired. Biowalls' are an innovative technology for addressing IAQ concerns by using the natural ability of plants to remove airborne contaminants. This paper summarizes Biowall research that was conducted in a research home located in the Midwest with a particular emphasis on aesthetic considerations. It is difficult to find plants that thrive in a Biowall environment. A study identifying varying species of plants which will survive in this environment enhances the Biowall designer's ability to add a variety of colors, textures, and sizes to plant trays and achieve a presentation that is appealing for a Biowall owner.

## 1. INTRODUCTION

Current work on botanical air filtration has benefitted from previous research on improving residential Indoor Air Quality (IAQ). Understanding the researchers' motivation for this research requires knowledge of IAQ, insight into residential air filtering methods, Heating Cooling Ventilating and Air Conditioning (HVAC) trends, and a background in phytoremediation research.

### 1.1 Indoor Air Quality (IAQ)

The air that fills the space within a building is called indoor air. The amount of contaminates within the indoor air determines IAQ. After being exposed to the people and processes occurring within a building, indoor air will pick up contamination that is harmful to people. The Environmental Protection Agency (EPA) identifies indoor air pollution as one of the top five environmental health risks (EPA, 2008).

Table 1 identifies three categories of indoor air pollutants identified by the EPA. Particulate matter includes dust, smoke and pollen. Common Volatile Organic Compounds (VOC's) include formaldehyde and toluene. Biologicals include bacteria, mold spores, and byproducts of activities people do indoors. There is not one air cleaning technology that removes all three categories of contaminants shown in Table 1. The value in this research is realized in providing a variety of technologies that can be deployed for improving residential IAQ.

**Table 1:** Summary of Indoor Air Contaminates (EPA, 2008)

| **Indoor Air Pollutants** | **Pollutant Source** |
|---|---|
| Particulate Matter | Dust, smoke, pollen, animal dander, tobacco smoke |
| Volatile Organic Compounds (VOC's) | Formaldehyde, toluene, adhesives, paints, cleaning products, pesticides, some air fresheners |
| Biologicals | Bacteria, mold spores, viruses, dust mites |

1.1.1 ASHRAE & IAQ: Recognizing the impact poor IAQ is having on people, a report at the 2016 American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) IAQ Conference stated; "there is strong evidence that investments in home IAQ can reduce healthcare costs" (Bahnfleth, 2018). Exposure to poor IAQ is magnified by both efficient building design and energy saving practices for HVAC systems. Energy efficient buildings are sealed off from the outside to avoid venting treated air to the environment. Indoor air is recirculated into the air supply for its temperature and humidity properties, requiring an HVAC system to perform less heating or cooling, but makes people increasingly vulnerable to poor IAQ (AHRAE, 2016).

## 1.2 Sick Building Syndrome (SBS)

Studies have shown that the amount of time spent indoors increases Sick Building Syndrome (SBS) occurrences (EPA, 1991). Symptoms like prolonged coughs, headaches, tiredness, and respiratory issues, regularly written off as common illnesses, correlate with time spent indoors and an inadequate supply of fresh air (EPA, 1991). SBS health concerns are not surprising given that Americans spend more than 90% of their time indoors; where the indoor air is 2-5 times more polluted "than the worst outside air" (EPA, 2004). This concern is not new. SBS has been recognized as a major issue facing Americans health for some time. As early as 1999, the conditions that lead to high SBS occurrences were profiled on the CBS news show "60 minutes" (1999).

The reports and studies mentioned in ("60mins," 1999); (EPA, 1991); (EPA, 2004); (ASHRAE, 2016); share a common theme about IAQ. Filtration of air contaminants prior to circulation to the building and its inhabitants is important to providing a good IAQ. A proper air filtration strategy developed with knowledge of the processes occurring within the building can reduce SBS occurrences and improve Americans health (Bahnfleth, 2018).

## 1.3 Residential Air Filtration Technologies

Understanding widely used residential air filtration methods is essential to developing a new technology to improve IAQ in a residential building. The mechanical filter shown in Figure 1 is the primary method used to clean the air supply into a residential building. Air filters are designed to improve the quality of air by removing the particulate contamination summarized in Table 1. Filtering is accomplished by forcing return air flow into the HVAC system through the filter. Filters are generally made of spun fiberglass material, pleated paper, or cloth and are most homeowners main line of defense for insuring appropriate IAQ (Davis, 2015).

**Figure 1:** New Air Filter

Mechanical air filters vary in their effectiveness in removing contaminants from air. ASHRAE and other organizations took on this variation and developed the Minimum Efficiency Reporting Value (MERV) for mechanical air filters. The MERV system establishes a metric for air filter effectiveness that is expressed as a number from 1 to 16, where a higher number indicates a higher level of contaminant removal. Table 2 shows the MERV rating chart from ASHRAE Standard 52.2 that identifies lower MERV rated filters as limited to filtering larger particulate matter. Higher MERV ratings can remove smaller particulates like tobacco smoke and remove some biologicals.

**Table 2**: ASHRAE Standard 52.2 MERV Rating Chart

**MERV RATING CHART**

| Standard 52.5 Minimum Efficiency Reporting Value | Dust Spot Efficiency | Arrestance | Typical Controlled Contaminant | Typical Applications and Limitations | Typical Air Filter/Cleaner Type |
|---|---|---|---|---|---|
| 20 | n/a | n/a | < 0.30 pm particle size | Cleanrooms | ≥99.999% eff. On .10-.20 pm Particles |
| 19 | n/a | n/a | Virus (unattached) | Radioactive Materials | Particles |
| 18 | n/a | n/a | Carbon Dust | Pharmaceutical Man. | Particulates |
| 17 | n/a | n/a | All Combustion smoke | Carcinogenetic Materials | ≥99.97% eff. On .30 pm Particles |
| 16 | n/a | n/a | .30-1.0 pm Particle Size | General Surgery | **Bag Filter**- Nonsupported microfine fiberglass or synthetic media, 12-36 in. deep, 6-12 pockets<br>**Box Filter**- Rigid Style Cartridge Filters 6 to 12" deep m ay use lofted or paper media. |
| 15 | >95% | n/a | All Bacteria | Hospital Inpatient Care | |
| 14 | 90-95% | >98% | Most Tobacco Smoke | Smoking Lunges | |
| 13 | 89-90% | >98% | Proplet Nuceli (Sneeze) | Superior Commercial Buildings | |
| 12 | 70-75% | >95% | 1.0-3.0 pm Particle Size<br>Legionella | Superior Residential | **Bag Filter**- Nonsupported microfine fiberglass or synthetic media, 12-36 in. deep, 6-12 pockets<br>**Box Filter**- Rigid Style Cartridge Filters 6 to 12" deep m ay use lofted or paper media. |
| 11 | 60-65% | >95% | Humidifier Dust<br>Lead Dust | Better Commercial Buildings | |
| 10 | 50-55% | >95% | Milled Flour<br>Auto Emissions | Hospital Laboratories | |
| 9 | 40-45% | >90% | Welding Fumes | | |
| 8 | 30-35% | >90% | 3.0-10.0 pm Particle Size<br>Mold Spores | Commercial Buildings | **Pleated Filters**- Disposable, extended surface area, thick with cotton-polyester blend media, cardboard frame<br>**Cartridge Filters**- Graded density viscous coated cube or pocket filters, synthetic media<br>**Throwaway**- Disposable synthetic panel filter. |
| 7 | 25-30% | >90% | Hair Spray<br>Fabric Protector | Better Residential | |
| 6 | <20% | 85-90% | Dusting Aids<br>Cement Dust | Industrial Workplace | |
| 5 | <20% | 80-85% | Pudding Mix | Paint Booth Inlet | |
| 4 | <20% | 75-80% | >10.0 pm Particle Size<br>Pollen | Minimal Filtration | **Throwaway**- Disposable fiberglass or synthetic panel filter.<br>**Washable**- Aluminum Mesh<br>**Electrostatic**- Self charging woven panel filter. |
| 3 | <20% | 70-75% | Dust Mites<br>Sanding Dust | Residential | |
| 2 | <20% | 65-70% | Spray Paint Dust<br>Textile Fibers | Window A/C Units | |
| 1 | <20% | <65% | Carpet Fibers | | |

The limitation to all mechanical air filters is revealed through their design life (ASHRAE, 2017). As the filter captures contaminants from passing air, it becomes restricted, loses effectiveness, and looks dirty. Figure 2 shows a dirty air filter with a relatively low MERV rating that should be replaced. Dirty or forgotten air filters are a large contributor to poor IAQ to a building. It is recommended that a filter be checked once a month and changed before it appears like the one shown in Figure 2. Forgotten air filters are common, and a leading source of HVAC malfunction is due to the high restriction of airflow caused by a dirty filter (Davis, 2015).

**Figure 2:** Dirty air filter to be replaced

Other air filtration methods can target specific contaminants and supplement mechanical air filters. The EPA (2008) summarizes these technologies in Table 3. Ultraviolet (UV) and gaseous air filtration technologies are available to target gaseous phase contaminants, and biologicals from the contaminants described in Table 1. With their effectiveness in specific targeting, brings tradeoff in limitations. The EPA (2008) highlights the limitations in each technology in Table 3; UV lights can target some of the biologicals listed in Table 1; Gas Phase filters target gasses and odors; PCO cleaners use UV lights and introduce a substance to react with the light to destroy gaseous pollutants; Ozone generators use UV light with electrical discharge (experimental) (EPA, 2008).

**Table 3:** Air Cleaning Technologies and Limitations (EPA, 2008)

| **Air Cleaning Technologies** | | **Pollutants Addressed** | **Limitations** |
|---|---|---|---|
| Filtration | Air Filters | Particles | Ineffective in removing larger particles because most settle from the air quickly and never reach filters. |
| | Gas-Phase Filters | Gases | Used much less frequently in homes than particle filters. The lifetime for removing pollutants may be short. |
| Other Air Cleaners | UVGI | Biologicals | Bacterial and mold spores tend to be resistant to UV radiation and require more light or longer time of exposure, or both, to be killed |
| | PCO | Gases | Application for homes is limited because currently available catalysts are ineffective in destroying gaseous pollutants from indoor air. |
| | Ozone generators | Particulates, gases, biologicals | Solid as air cleaners, they are not always safe and effective in removing pollutants. By design, they produce ozone, a lung irritant. |

## 1.4 Phytoremediation & Botanical Air Filtration

In the late 1960's environmental scientist Bill Wolverton, working for the U.S military led a team which discovered that plants roots filtered Agent Orange from Florida waterways (NASA, 2007). Following this work the National Aeronautics and Space Administration (NASA) funded Wolverton to explore phytoremediation-or using the rhizosphere of plants roots to filter contaminants from an air supply, for deep space exploration (Wolverton, 1997).

Based off 27 years of research, "The NASA Guide to Air-Filtering Houseplants" list was derived. These plants are identified for; their ability to remove carbon based and VOC contaminants from the air; non-toxicity to human plant owners; ease of growth; and extended lifespan (Rokas, 2017).

Research into botanical air filtration led to the development of a residential application (Leuner, 2016). Botanical air filtration targets VOC's through phytoremediation (Alraddadi, 2016), and some particulates with a growth medium inspired by Wang (2011). A Biowall can assist a traditional MERV-rated air filter to improve IAQ.

## 1.5 The ReNEWW Home

The botanical air filter prototype for this research is installed in the Retrofitted Net-Zero Energy, Water and Waste (ReNEWW) Home in West Lafayette, IN.  Figure 3 shows that it is a typical bungalow style home. The home was originally built 80 years ago, but was heavily renovated as part of ongoing residential research. The ReNEWW home utilizes local resources to supplement consumption within the home to meet an annual net-zero energy goal.

**Figure 3:** The ReNEWW Home

The ReNEWW Home (Fig. 3) has a goal higher than net zero energy. It aims to match annual living consumption in energy and water with local resources and renewable systems output. The ReNEWW Home employs photovoltaic (PV) electricity, geothermal, rainwater catchment and filtration, solar thermal heat catchment, high efficiency appliances, smart building automation, and botanical air filtration to meet the net-zero energy mission.

## 2. THE CONDITONAL PLANT GROWTH STUDY

The experiment for this paper is a conditional plant growth study completed in the botanical air filter prototype (Biowall) located in the ReNEWW home. Plant growth in this artificial environment requires knowledge and practice. The purpose of this ongoing experimentation is to expand the types of plants used for botanical air filtration to target indoor contaminants. This study incorporated and evaluated more known air filtering plants into the list of Biowall acclimatable plants identified during previous research (Rajkhowa, 2016).

Bringing plant diversity into the Biowall growth trays adds an important aesthetic component to Biowall design. It widens a designer's ability to meet user tastes while meeting air filtration demands. During fall 2017 through spring 2018, plant growth experiments utilizing various known air filtering plants expanded the toolkit of which plants that can be grown in this Biowall environment.

### 2.1 The Biowall

The Biowall project conducted introductory research to evaluate VOC (Toluene) filtration ability in an environmental chamber setting (Alraddadi, 2016). The growth medium used for this research was selected through recommendations from previous research into botanical air filtration (Wang, 2011). The Biowall prototype, shown in Figure 4, was built prior to this work and orients four plant trays in a vertical duct that is an integral part of the ReNEWW Home HVAC system.

**Figure 4:** Biowall in the ReNEWW Home

Figure 4 shows the Biowall applied to the living room indoor air intake vent of the ReNEWW Home. It is a supplement to the home's HVAC mechanical air filter. The Biowall is designed to target VOC contaminations from the air.

A contribution to an energy efficient, sustainable, method of supplying quality indoor air, the Biowall prototype uses a Building Automated System (BAS) to control lights, irrigation, and data monitoring sensors. Its function and trend data are available to researchers through an online

WebCTRL website. When the HVAC system in the house is on, air is drawn through the plant trays before circulating it to the home.

2.1.1 Biowall Experimental Timeline**:** The Biowall prototype was installed in the ReNEWW Home in spring 2016. Commissioning work consumed the first year of operation. In spring 2017 through spring 2018, as part of this research a field test analysis of the Biowall systems was conducted; the home was occupied during this period. The field test provided an in-depth system validation, and the plant growth study presented in this paper is one result. Quantification of air filtration capability of this prototype within the ReNEWW Home will follow the validation phase during future research.

## 2.2 Experimental Methodology

Phytoremediation utilizes the rhizosphere of plants roots to complete the filtration process. Figure 5 shows plants in Biowall plant trays acclimating to the growth medium in an 'in lab' nursery on campus. This allows for root spread through the growth medium and increases filtration efficiency in the Biowall (the more roots, the higher capacity for phytoremediation). A three month acclimation period is needed for the plants roots to grow and develop in the trays.

The growth medium used in the plant trays (Fig. 5) are developed to be a porous semi-aqueous growth medium which air can be pulled through. The selection of this growth medium was aided by research conducted by Wang (2011). Care and fertilization followed a prescription derived by Rajkhowa (2016) and is an aqueous nutrition delivery method. Plant growth LED's were employed to supply lighting. Upon maturation, the plant tray is taken to the ReNEWW Home and placed in one of four shelves in the Biowall to filter indoor air. Figure 5 also shows propagation of new plants. Plants are prepared at a young age for use in Biowall plant trays. Propagation is completed four to twelve months in advance of Biowall use.

**Figure 5:** in lab Biowall plant tray acclimation nursery

As a limitation of this research, fertilizer was not used in the growth trays while installed in the Biowall. Possible unknown effects on resident health demanded further investigation into fertilization prior to use. For that reason, the plant trays have an expectancy of 3-6 months of EFFECTIVE filtration capability due to the lack of nutrients. A plain indicator of the Biowall filtration efficiency status is plant health; an unhealthy plant is not performing filtration efficiently.

## 2.3 Experiment Plant Selection

The golden pathos, chlorophytm comosum, philodendron cordatum, and hiedra helix are plants from the NASA Guide to Air-Filtering Plants that showed success in growth from previous Biowall research conducted by Rajkhowa (2016) and were included in this study as well. The ficus benjamina, dracanea marginata, aglaonema modestum, sansevieria trifasciata laurentii, trascenda zebrina, and tradescantia spathacea were also added to this study for their air filtering properties as well as variation in colors and growth. These plants and more are shown in the NASA Guide to Air-Filtering Houseplants (Rokas, 2017).

# 3. RESULTS

The study started with an initial set of filtration trays deployed prior to this research; trays dating to the Biowall prototype installation (spring, 2016). Those trays embodied the initial data set (Fig. 6, left). The initial data (left) is limited in plant species to those listed in section 2.3. Once acclimated and deployed to the Biowall, the plant trays prepared as part of the conditional plant growth study replaced the initial data set and are the after data (Fig. 6, right). There is a marked increase in plant species variation in Fig. 6 (right) as compared to the initial data set Fig. 6 (left).

**Figure 6**: Biowall before (left); Biowall after (right)

The conditional plant growth study required a period of in-lab plant growth verification and preparation followed up with regular ongoing plant growth maintenance.  During this time, plant/root dimensions were recorded, growth medium nutrition measurements were made, and plant growth observations were conducted to record plant behavior. This data served as the documentation that identified successful plants; the results being a documentation of known air filtering plants with a demonstrated ability to survive in the Biowall environment.

Through the methodical use of varying plant species, the ability to bring variation in color to manipulate plant tray appearance with known air filtering plants is demonstrated.  Figure 6 shows limited plant variations initially (left), and increased plant variation after (right).

## 3.1 Biowall Plants

Table 4 identifies the eight plant species that survived the initial plant tray growth period, and the conditional plant growth study performed in the Biowall. The result of this research provides a variation of known filtering plants for the Biowall designer, or owner to make aesthetically pleasing plant trays. Also, as each plant can target different contaminates (Wolverton, 1997), this work is a caveat to future research into contamination targeting.

**Table 4:** Eight successful air filtering plants that grow in the Biowall

| Plant Name | Picture | Plant Name | Picture |
|---|---|---|---|
| Chlorophytm comosum (Spider Plant) |  | Tradescantia spathacea |  |
| Ficus benjamina |  | Philodendron cordatum (Heartleaf philodendron) |  |
| Dracanea marginata |  | Hiedra helix (English Ivy) |  |
| Epipremnum aureum ( Golden Pathos) |  | Trascenda Zebrina |  |

## 6. CONCLUSIONS

The conditional plant growth study within the Biowall is an expansion from the four-original known air filtering plant species verified through Rajkhowa (2016). The eight successful plants from NASAs know air filtering plant list which thrived in the Biowall environment, are shown in Table 4. The plants are; chlorophytm comosum; darcaena marginata; ficus benjamina; golden pathos; hedera helix; philodendron cordatum; tradescantia spathacea; tracenda zebrina.

This research addresses a need to understand plant behavior in the Biowall and increases variation in plant species known to grow in this environment. The result brings color, size, and plant arrangement capabilities to the Biowall designer or owner; inviting a day where a functional Biowall will not only contribute to a healthy indoor environment, but add beauty to the home by providing plant tray arrangements for holidays, change of season, or meet the owner's personal preference.

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