# PLANT-BASED AIR FILTERS
# FOR FORMALDEHYDE REMEDIATION IN FEMA TRAILERS


**By:**

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### NASA Studies

In 1980 NASA scientists at the John C. Stennis Space Center in Mississippi first discovered that interior plants could remove VOCs from sealed test chambers. After many repetitive chamber tests, NASA's findings were published in 1984. As a result of the discovery, the Associated Landscape Contractors of America (ALCA) {*recently renamed the Professional Landscape Network [PLANET]}* jointly funded with NASA a two-year study to further evaluate twelve common interior plants for their ability to remove three common airborne contaminants: formaldehyde, benzene and trichloroethylene from sealed test chambers. This study produced additional test results proving that interior plants can consistently remove airborne contaminants. Interestingly, it showed that some plants are more effective in its removal capacity than others. The results of this study were published in September 1989 and released in a press conference held at the National Press Club in Washington, D. C.

To further investigate these findings, NASA had constructed a "Biohome" made of all synthetic materials and engineered to achieve maximum air and energy closure. As shown in *Fig. 1*, its exterior consisted of molded plastic panels designed to resist normal weather conditions with minimal maintenance. Fiberglass insulation in the walls (30 cm thickness) provided a thermal insulation value of R-40, making it super energy-efficient. The Biohome's dimensions are 43 ft (13.1 meters) in length with 640 $ft^2$ (59.5 $m^2$) if total interior space. The interior space is subdivided into a 334 $ft^2$ (27.5 $m^2$) section housing bioregenerative components whose basic end products were reclaimed water and food.


*Fig. 1*

The Biohome was comprised primarily of synthetic building materials and furnishings. Therefore, it was assumed that off-gassing of VOCs would create indoor air quality problems. Upon entering the Biohome, most exhibited symptoms such as burning eyes and throats and respiratory problems.

Foliage plants that thrive in low-light conditions were placed throughout the living quarters to evaluate their ability to remove VOCs built-up from off-gassing of the newly constructed facility. Scientists placed an array of interior plants growing in commercial potting soil throughout the Biohome. Additionally, scientists placed one experimental fan-assisted planter containing a plant growing in a mixture of soil and activated carbon. This unique plant filter had the VOC removal capacity of 15 regularly potted plants. *(Fig. 2)*

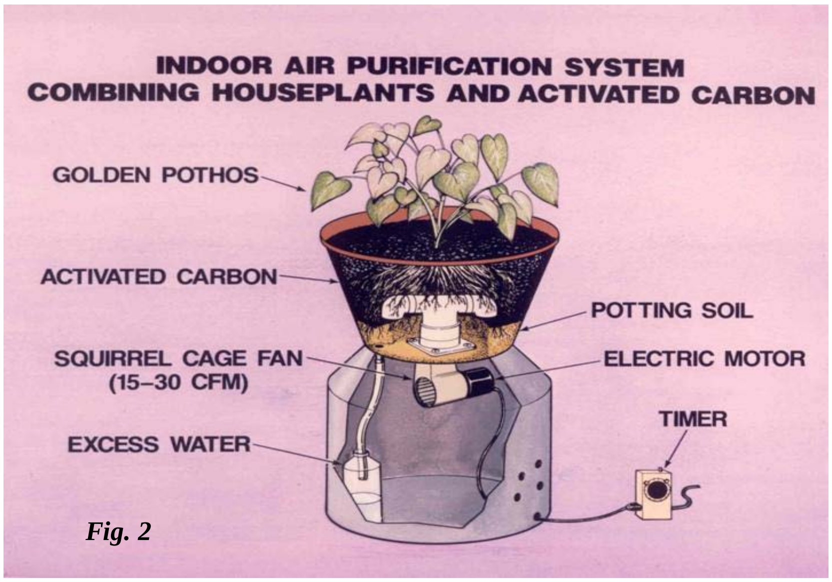

***Fig. 2***

Air quality was tested several days later by mass spectrometer/gas chromatograph analyses showing that nearly all of the VOCs had been removed. *(Fig. 3)*

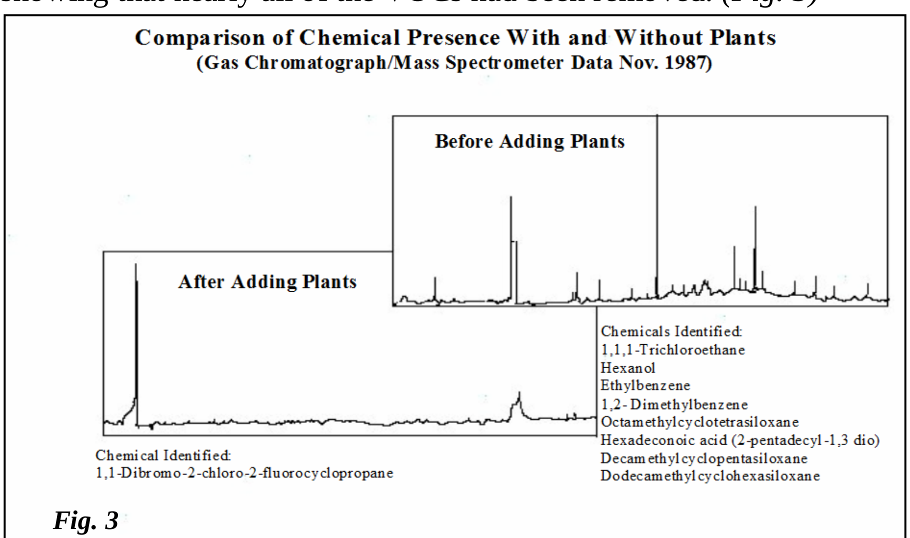

***Fig. 3***

Sophisticated chemical analyses are necessary for scientific validation. However, the definitive proof lay in the fact that one no longer experienced burning eyes or other classic symptoms of sick building syndrome when entering the Biohome. This was the first "real world" application of interior plants for alleviating sick building syndrome. A student lived for one summer in the Biohome and experienced no discomfort from indoor air quality. *(Fig. 4)*


***Fig. 4***

After the research program concluded, NASA moved the Biohome to the Visitor's Center and renamed it "One Mainstreet Mars." It continued its role as a valuable educational tool by simulating a life support module on Mars where the air and waste are treated by interior plants. For many years, One Mainstreet Mars was one of the most popular exhibits for young and old alike. Unfortunately, it was destroyed on August 29, 2005 by Hurricane Katrina.

**Post NASA Studies**

Technology termed "phytoremediation" utilizes plants and their root microbes to remove contaminants from both air and water. During the early 1990s, studies sought to determine the mechanisms plant ecosystems utilize to remove VOCs from sealed chambers. The NASA studies employed only a one-time injection of VOCs into the test chambers.

***Fig. 5***

Questions arose whether plants could remove VOCs that were continuously off-gassed from synthetic materials as commonly occurs in an indoor environment. To answer this issue, Wolverton Environmental Services, Inc. (WES), had constructed two Plexiglas test chambers. Scientists placed into each chamber two sections of interior paneling comprised of urea-formaldehyde resins. A lady palm *(Rhapis excelsa)* was added to one chamber and the other chamber, serving as a control chamber, did not contain a plant. Plants, through their natural process of transpiration, cause humidity to rise in sealed chambers. To equalize humidity in both chambers, a beaker of water was placed in the plant-free chamber. *(Fig. 5)*

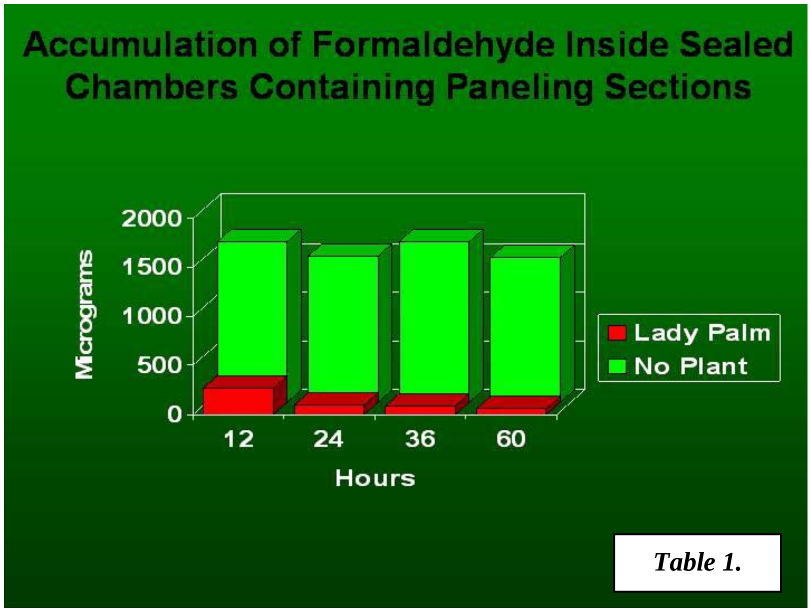


***Table 1.***

As shown in *Table 1.*, the lady palm removed formaldehyde as it continuously off-gassed from the paneling sections. Temperature influenced the rate at which formaldehyde off-gassed from the paneling. The greater the temperature, the more rapidly formaldehyde was released. There was no removal of formaldehyde in the control chamber.

The lady palm showed no ill effects after extended exposure to formaldehyde. In fact, the lady palm increased its ability to remove formaldehyde as its exposure time increased. These studies indicated that plant root microbes had rapidly mutated and adapted to the presence of formaldehyde and had contributed significantly to the chemical removal process. Further studies sought to determine the extent of plant root and soil microbe involvement in the removal of chemicals. Formaldehyde and xylene were introduced individually into sealed chambers containing plants having either exposed soil or soil covered with sterilized sand. The studies showed that 50 to 65 percent of VOC removal is attributed to root and soil microbes. These findings indicate that both plants and the microbes around their roots and in the soil contribute significantly to the removal of VOCs.

To further show the important role of soil microbes in reducing formaldehyde concentrations, researchers placed a dwarf azalea *(Rhododendon simsii* “Compacta”) into a sealed chamber and tested its ability to remove formaldehyde. The azalea was then removed from its container and the container of soil placed back into the chamber. Formaldehyde removal was reduced by 22 percent after two days and 70 percent after thirty days. Soil bacterial counts showed that without their host plant, the microbial population also decreased. The plant’s root system is essential for providing an environment conducive for the growth of microbes. When plants are removed from the potting soil, the ability to remove formaldehyde from the air slowly decreases.

Due to the presence of microbes in the rhizosphere, interior plants are not damaged when exposed to high concentrations of VOCs but continue to improve in their ability to remove chemicals over time. The root/soil microbes rapidly adapt, producing new generations of microbes that are even more effective in using the chemicals as a source of food and energy. Scientists at the University of Technology in Sidney, Australia later conducted similar studies and obtained similar results. The ability of soil microbes to degrade organic chemicals has been known for many years. Among the most effective microbes in degrading organic chemicals is *Pseudomonas sp.*, commonly found around plant roots.

Studies show that both the plant leaves and root microbes contribute to the removal of VOCs from the indoor environment. It has been well documented that plant leaves can absorb, metabolize and/or translocate certain VOCs to the root microbes where they are broken down. Studies show that 90 percent of these substances are converted into sugars, new plant material and oxygen. Scientists at the GSF-National Research Center for Environment and Health in Neuherberg, Germany produced the most definitive study yet on this phenomenon. They used radioactive carbon tracers to follow how the spider plant *(Chlorophytum comosum* L.*)* was able to breakdown and destroy formaldehyde.

Plants also employ another mechanism to move air down to their root system. Plants transpire (emit water vapor from their leaves) by moving water up from their roots to their leaves. In the process, a small convection current is created pulling air down to the root zone. Through the transpiration process, a plant not only moves atmospheric gases such as oxygen and nitrogen to its root zone, but also any airborne chemicals present. Because of this action, generally a plant with a high transpiration rate is more effective in its VOC removal capacity.

**Hydroculture**

Hydroculture simply stated means "water culture." Hydroponics differs in that water and nutrients intermittently flow past the plant's roots. Hydroponics is primarily used in commercial agricultural food production. However, the two terms are often mistakenly interchanged. Hydroculture consists of a water-tight container, pebbles as a growth substrate and a constant water level in the container. Some hydroculture systems also use an inexpensive liner pot that sits inside of a decorative container. *(Fig. 6)* The benefits are

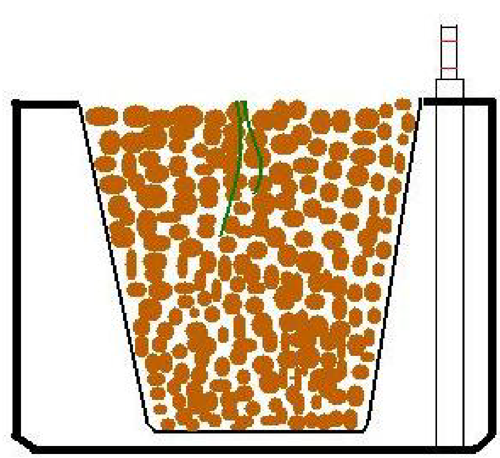

***Fig. 6***

obvious in that the inner pot can simply be lifted out and placed in another decorative container. It also provides for a simple means to rotate various plants without having to move the heavier outside container or to re-pot the plant.

The majority of indoor plants in European countries are grown in hydroculture. It has been slower in some other countries to gain acceptance. It is thought to be too complicated or too scientific, when in reality it is a much simpler, cleaner concept. The determining factors in its lack of acceptance have been cost and availability. Most hydroculture systems currently sold in the U.S. are imported from Europe. Manufacturing and shipping costs have made it cost prohibitive to compete with soil-based planters. Growers have mistakenly believed that only expanded clay pebbles from Europe would function properly in a hydroculture system.

Some of the many advantages of hydroculture are:

► Uses no soil.

Inert pebbles are clean and odorless. Unlike soil, hydroculture does not harbor fungus spores that can become airborne in the ambient air. This is very helpful to allergy sufferers.

► Plants are not subject to soil-borne diseases or pests.

The surface of soil-based plants is often moist. As a result, they often harbor mold and the damp conditions encourage pests and disease.

► Water level indicator.

Just keep the water level between the "minimum" and "maximum" markers. Because of the water reservoir, plants do not need caring for during weekends or vacations.

► Inert pebbles never need replacing.

Unlike soil that needs refreshing or replacing, pebbles can be washed off and reused indefinitely.

► Plants take up only the moisture they need.

Because the pebbles provide a moist zone, plants having varying water requirements can be planted in the same container.

► Reduces the need to transplant.

Nutrients and water are constantly available to the plant. Therefore, plants do not need to send out roots to search for them. So, they become less root-bound.

► Studies show that hydroculture plants are more effective in removing VOCs.

As a plant transpires, it pulls air down to its root zone where an abundance of microbes thrive. Any pollutants in the air are also pulled down to the root zone where they are broken down and become food and energy for the plant and the microbes. Air can pass more easily down to the root zone through pebbles than through soil.

**Plant-based Air Filters**

In our modern, fast-paced society, plant-filled rooms help to keep us in touch with nature. Just the ability to view living plants enhances our psychological and physiological well-being. However, in many buildings today, the amount of space allotted for the placement of plants is limited. Through man's ingenuity, even this obstacle is surmountable.

Scientists at NASA's Stennis Space Center originally developed the concept of placing a plant in a mixture of soil and activated carbon and mechanically moving air down to the plant's roots. A working model equaled the VOC removal capacity of 15 regularly grown interior plants. *(See Fig. 2)*

In 1990, WES scientists set about to further develop this bio-technology. The first plant-based air filter did not use soil but a substrate consisting of expanded shale or clay, activated carbon and zeolite. *(See Fig. 7)*

*Fig. 7*

These soil-free filters employed a mechanical fan to pull air down through the highly adsorptive substrate in which an interior plant was grown. The substrate traps any airborne contaminants where naturally occurring microbes, living on and around the plant's root system, biologically break down the trapped chemicals. The plant and microbes use these end products as a source of food and energy. Thus, a bioregenerative or self-cleaning filter is created. As the microbes continue to break down chemicals, they rapidly mutate and adapt to become even more efficient with exposure. As a result, the filter media never becomes saturated or needs replacing, except under extreme conditions. The cleaned air is then returned to the room. This filter proved to be highly effective in removing formaldehyde and other VOCs from sealed test chambers and its efficiency increased as the microbes adapted to chemical exposure. A comparison of formaldehyde removal by a new filter and a two-year old filter is shown in *Table 2*.

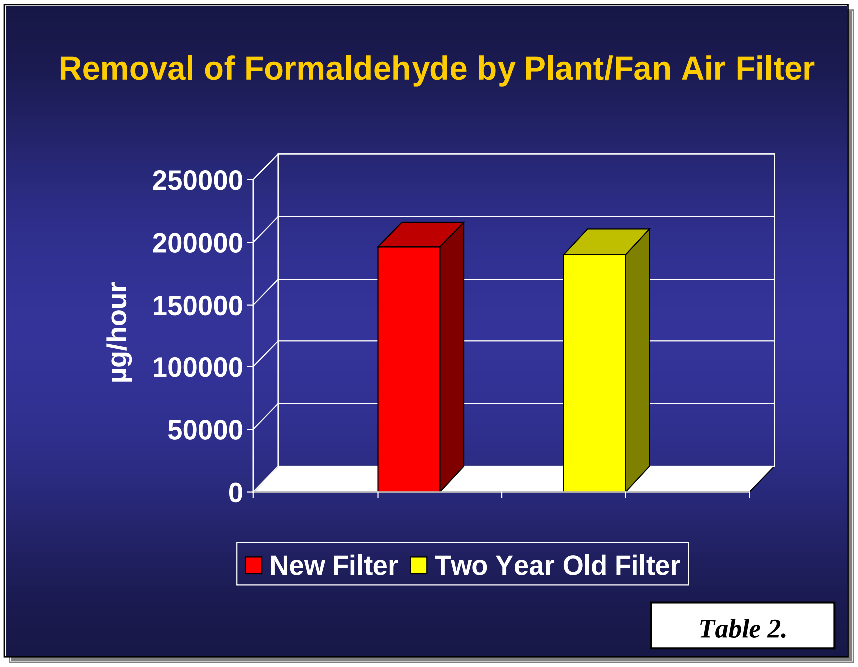


*Table 2.*

This first filter had several drawbacks. The fan motor was noisy and it was difficult to replace the plants. As a result, marketing of the filter was not successful.

WES later licensed the technology to Actree Corporation, a Japanese engineering and manufacturing company. Jointly, the two companies made further refinements. Actree Corporation now produces and markets in Japan a small, portable air filter termed the "EcoPlanter." *(See Figs. 8 and 9)*

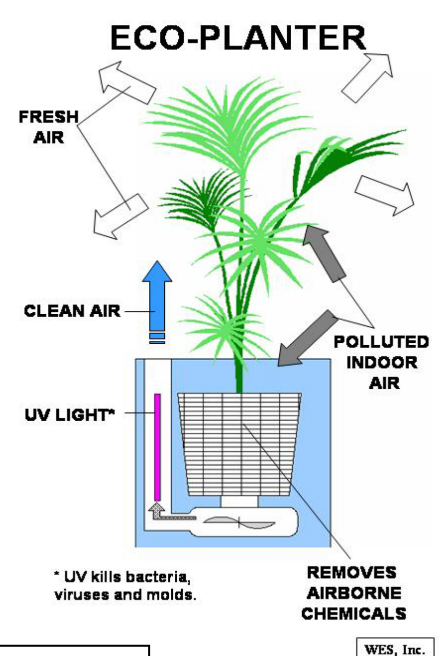


*Fig. 8*

*Fig. 9*

The EcoPlanter employs a quiet two-speed fan and contains an inner pot that is easily removed for plant replacement. Also, as a final step in the EcoPlanter, filtered air passes a germicidal ultra-violet (UV) light source to reduce or eliminate any remaining molds, bacteria and viruses before the air is returned to the room. The EcoPlanter is an attractive planter/air filter that increases the VOC removal capacity of a single interior plant by as much as 100 times. *(See Table 3.)*

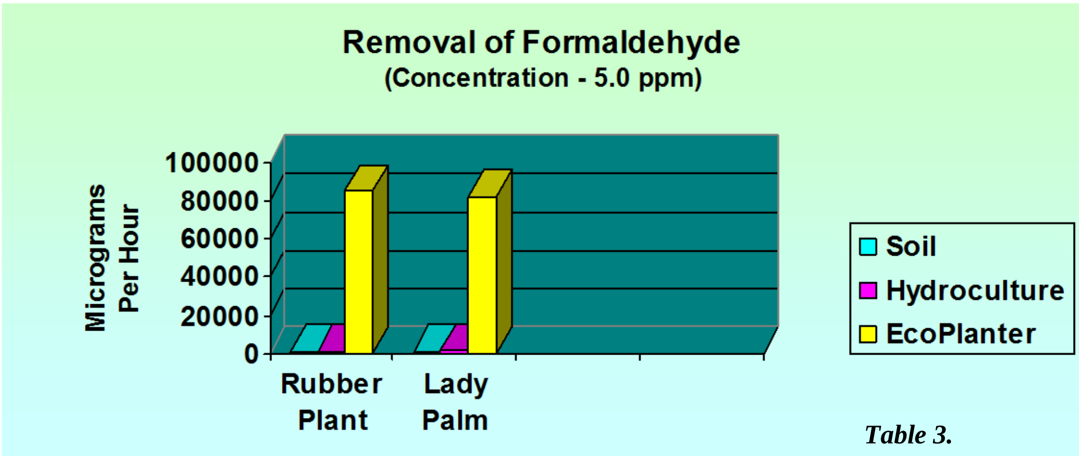


***Table 3.***

Most conventional air filtration devices on the market today use activated carbon and/or high efficiency particulate air (HEPA) filters. These filters are limited only to trapping airborne pollutants and do nothing to destroy them. A problem exists in that these filters become saturated and rely upon a strict maintenance routine to work properly. Often, due to neglect or costs associated with the purchase of replacement filters, proper maintenance does not occur. If activated carbon filters are not replaced before becoming saturated, toxic chemicals trapped on its surface may render the filter ineffective. Even worse, the chemicals may be released back into the room; thus, creating an even greater airborne chemical concentration in the indoor environment. If HEPA filters are not regularly replaced, they can become clogged and ineffective as a filtration device. Also, mold and other microbes trapped on the filter surface may flourish and multiply causing a potential health hazard. Pollutant-laden filters often are not disposed of in an environmentally friendly manner. EcoPlanters, having no filters to replace, overcome these problems. Unfortunately, due to manufacturing and shipping costs, the EcoPlanter was never introduced into the U.S. market.

**FEMA Trailers**

Following the devastating Hurricanes Katrina and Rita in August and September 2005, temporary housing was provided by the Federal Emergency Management Agency (FEMA) to thousands of victims along the Gulf Coast. 150,000 people were primarily housed in small travel trailers that became known as “FEMA trailers.” Almost immediately, many residents began to complain about the air quality within the trailers. Often, residents sought medical help for a variety of ailments such as respiratory problems, asthma, rashes, dizziness, etc. After conducting air quality tests, the Sierra Club determined that formaldehyde levels were excessively high due to the extensive use of particle board in the construction process. In fact, unsafe levels of formaldehyde were found in 30 out of 32 trailers tested. The World Health Organization (WHO) currently sets a safe range indoors of formaldehyde at 0.05 parts per million (ppm) or less.

In October 2006, Wolverton Environmental Services, Inc. (WES) and the local Sierra Club headed by Becky Gillette placed an EcoPlanter inside a FEMA trailer located in Bay St. Louis, Mississippi. The trailer was the temporary home of a young couple and their small child. Samples taken before placement of the EcoPlanter showed a formaldehyde concentration of 0.18 ppm. All samples were collected by the residents and shipped to an independent laboratory for analyses. Within several days, tests revealed that the EcoPlanter had reduced the formaldehyde concentration to 0.03 ppm. These preliminary findings revealed the potential for planter/air filters to remove harmful formaldehyde within the trailers. Unfortunately, air samples were only taken initially and five days later. Therefore, the actual time required for the plant/air filter to achieve this level of formaldehyde removal is unknown. It could have been days or only a matter of hours.

The details for the testing of the FEMA trailer are listed below.

**Location:** FEMA trailer in Bay St. Louis, MS

**Testing Began:** October 13, 2006

**Schedule:** 5 days off and on; airflow approximately 45.9 CFM

**Beginning Formaldehyde Concentration:** 0.18 ppm

**Ending Formaldehyde Concentration:** 0.03 ppm

**Formula:** formaldehyde ppm converted to µg/l (ppm x 1.34 = µg/l)

**FEMA trailer size:** 8’ x 30’ = 240 $ft^2$. Assuming a 7’ ceiling, the trailer volume is 1,680 $ft^3$ or 47.6 $m^3$ or 47,600 liters.

0.18 ppm = 0.24 µg/l x 47,600 liters = 11,424 µg of formaldehyde in this FEMA trailer

At this concentration, the EcoPlanter should remove approximately 3,000 µg/hr of formaldehyde. Small, portable air filters are only capable of producing a zonal effect (or circumference of filtering effectiveness). For more effective treatment, a cross-ventilation or lamina-type air flow is needed. However, given the above referenced parameters, an EcoPlanter should filter most of the air in a FEMA trailer within 24-hours.

The filtration efficiency of any air filter decreases as the concentration of VOCs in the air decreases. There are fewer molecules of chemicals in the same volume of air. To effectively remove airborne pollutants at lower concentrations, the air must make more passes through the filter as the concentration of VOCs decreases.

**Formaldehyde Removal by the EcoPlanter**
**(Formaldehyde Removal at Varying Concentrations)**

| Concentration (ppm) | Removal Rate (µg/hr) |
|---|---|
| 5.5 | 84,742 |
| 3.5 | 74,772 |
| 2.0 | 49,848 |
| 1.0 | 24,924 |
| 0.5 | 4,985 |
| 0.1 | 2,492 |

* Fan Speed: 45.9 cfm

**New Plant/Air Filter Technology**

In an effort to make the plant-based air filter technology more economically viable, WES is working with Usheco, Inc. located in Kingston, New York to design a plant/air filter for the U.S. market. This new design allows for a much larger water reservoir and makes it possible to place larger plants in the Filter. *See Fig.10.*

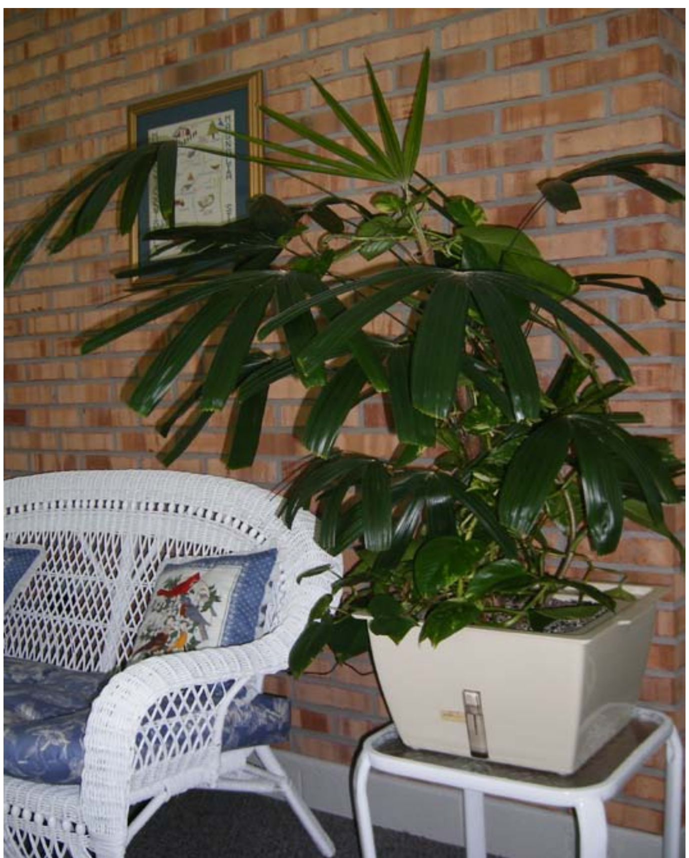

*Fig. 10*

WES and Usheco are also designing automatic built-in planter modules that can be installed in newly constructed buildings for the purpose of improving indoor air quality in larger buildings.

**Summary**

Much work has been done in the field of interior plants for the remediation of indoor air since the early NASA research in the 1980s. Scientists in Norway, Germany, Australia, Canada and Japan have not only duplicated but further substantiated NASA's initial findings. It is now established fact that interior plants have the ability to reduce levels of airborne pollutants from the indoor environment.

However, efforts are now underway to integrate these biological properties with man's mechanical ingenuity to help solve the serious issue of indoor air quality. Testing has now confirmed that the formaldehyde build-up within FEMA trailers is excessively high and detrimental to human health and well-being. The background information and data have been provided to inform those in the decision making process that a new method of reducing formaldehyde levels within FEMA trailers is available and that consideration should be given to this treatment alternative. Indoor air quality issues are by no means limited to trailers. EPA has confirmed that the air within most energy-efficient buildings contain unhealthy levels of volatile organic chemicals.

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