Improving Indoor Air Quality with Plant-Based Systems

By

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Introduction

In the United States (U.S.), energy consumption has continually spiraled upward. This increased demand for energy has resulted in energy costs also rising. As a result, the building industry strives to tightly seal buildings to conserve energy. According to the U.S. Department of Energy and the U.S. Green Building Council, commercial and residential buildings account for more than 60 percent of the total electrical consumption in the U.S. When buildings are tightly sealed, a buildup of human bioeffluents, airborne microbes and volatile organic chemicals (VOCs) often leads to poor indoor air quality.

In 1989 the U.S. Environmental Protection Agency (EPA) submitted a report to the U.S. Congress on the quality of air found inside energy efficient public buildings. The study included offices, hospitals, nursing homes and schools. This report stated that more than 900 VOCs were identified that may pose serious acute and chronic health problems to individuals who live and work inside these buildings.

Even though it is important to reduce energy costs, there are other health-related savings that should be stressed as well. According to studies conducted more than ten years ago at the Lawrence Berkley National Laboratories by Dr. William J. Fisk and Dr. Arthur H. Rosenfeld, companies in the U.S. can save as much as $58 billion annually by preventing sick building illness. An additional $200 billion savings in worker performance could be realized by creating buildings with better indoor air quality. When adjusted for inflation, today's figures would be even higher.

It is not surprising that EPA currently ranks indoor air pollution among the top five threats to human health. In an effort to maintain indoor air quality, the standard remedy within the building industry is to increase mechanical ventilation, bringing in even greater volumes of outside air. However, higher ventilation rates have yet to solve the indoor air quality problem. Increased ventilation also produces its own set of problems: (1) Energy efficiency is compromised. Outside air must be either heated or cooled to obtain a temperature range for human comfort. (2) In metropolitan areas, outside air is often highly polluted. It is not environmentally responsible to purge indoor air pollutants into the outdoor environment.

Carbon dioxide (CO_2) levels are currently used as an indicator of indoor air quality. Higher concentrations generally indicate the buildup of airborne chemicals, stale or stagnant air and sometimes human body odors. However, CO_2 is not harmful to humans, except at extremely high concentrations. In the 1960s, Dr. K. E. Schaefer conducted studies demonstrating that CO_2 levels in closed systems at concentrations between 5,000 and 8,000 ppm did not produce stress on the human body.

The U.S. Occupational Safety and Health Administration (OSHA) standard for CO_2 is 5,000 ppm. Workers may be exposed to this level for a work week of 40-hours. OSHA also recommends workplace oxygen levels drop no lower than 19.5 percent for a full work shift exposure. Oxygen levels in the outdoor environment are normally 20.9 percent. For the oxygen level in the indoor workplace to reach 19.5 percent, CO_2 levels, through the displacement of oxygen, would have to increase to about 14,000 ppm.

NASA Research

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 several years of research, NASA first published its findings in 1984.

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. 1.1*, 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. Its interior comprised 640 ft^2 (59.5 m^2) of living space.

Fig. 1.1

The Biohome was primarily constructed of synthetic building materials and furnishings. Upon entering the Biohome, most people experienced symptoms of sick building syndrome, such as burning eyes and throats and respiratory problems.

Interior foliage plants, which thrive in the low-light conditions of the indoor environment, were placed throughout the living quarters to evaluate their ability to remove the buildup of VOCs that were offgassing from the newly constructed and furnished facility. *(Fig. 1.2)*

Scientists placed an array of interior plants growing in commercial potting soil throughout the Biohome. Air quality was tested several days later by mass spectrometer/gas chromatograph analyses showing that nearly all of the VOCs had been removed. *(Fig. 1.3)*

Fig. 1.2

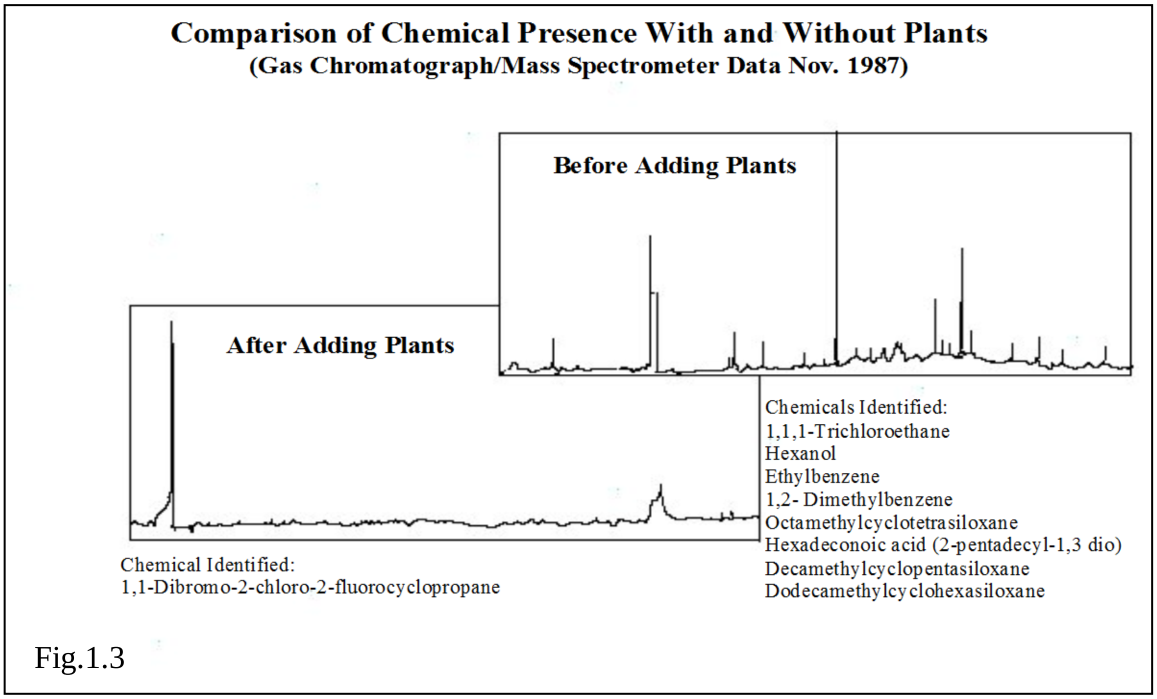


Fig.1.3

Wolverton Environmental Services, Inc. (WES)

NASA conducted all of their interior plant studies using commercial potting soil as the growth substrate. Beginning in 1990, WES has sought to build upon the pioneering interior plant research of NASA. WES has conducted extensive studies on the ability of interior plants to improve indoor air quality. Dr. Wolverton rates fifty interior plants in his widely acclaimed book, *"How to Grow Fresh Air"* (Penguin, 1997). Plants were rated for four criteria: (1) removal of chemical vapors; (2) ease of growth and maintenance; (3) resistance to insect infestation and (4) transpiration rates.

WES now concentrates its studies on the use of hydroculture rather than potting soil. Hydroculture uses lightweight, inert expanded clay and shale pebbles as the plant growth media. Dr. Wolverton and his co-author, Kozaburo Takenaka, detail these findings in their book, entitled, *'Plants: Why You Can't Live Without Them'* (Roli Books, 2010)

Advantages of Hydroculture

► Uses no soil:
Inert pebbles are clean and odorless. Unlike soil, expanded clay/shale pebbles never need replacing and as such are an environmentally sustainable product. Pebbles can simple be washed off and reused indefinitely.

► Reduces over-watering and spillage:
Unlike standard containers with drain pains, hydroculture containers are watertight. Water is introduced through a portal and a water gauge indicates minimum and maximum water levels. Spilling water onto floors, especially carpeted floors, can lead to mold growth. Any time a surface remains wet for 48-hours or more, mold growth is likely to occur.

► Reduces risk of growing molds:
Damp potting soil provides an environment that encourages mold growth. With hydroculture, the surface layer of pebbles remains dry. Hydroculture does not harbor fungus spores that can become airborne. This is very helpful to those who suffer allergies.

► Plants take up only the moisture they need:
Hydroculture containers maintain a water reservoir and so plants require less frequent watering. Also, pebbles wick moisture up to the plant roots allowing plants of varying water needs to thrive in the same container.

► Reduces the need to transplant:
Nutrients and water are constantly available to the plants. Plants do not send out roots to search for them. As a result, hydroculture plants generally have a smaller root ball and become less root-bound.

► WES hydroculture studies show that plants emit substances from their leaves that reduce the number of molds and bacteria in the ambient air. It is believed that these substances are negative ions.

► Hydroculture plants are more effective in removing VOCs:
Plants grown in hydroculture are 30 to 50 percent more effective in removing airborne pollutants than plants grown in potting soil. *(Fig. 1.4)*

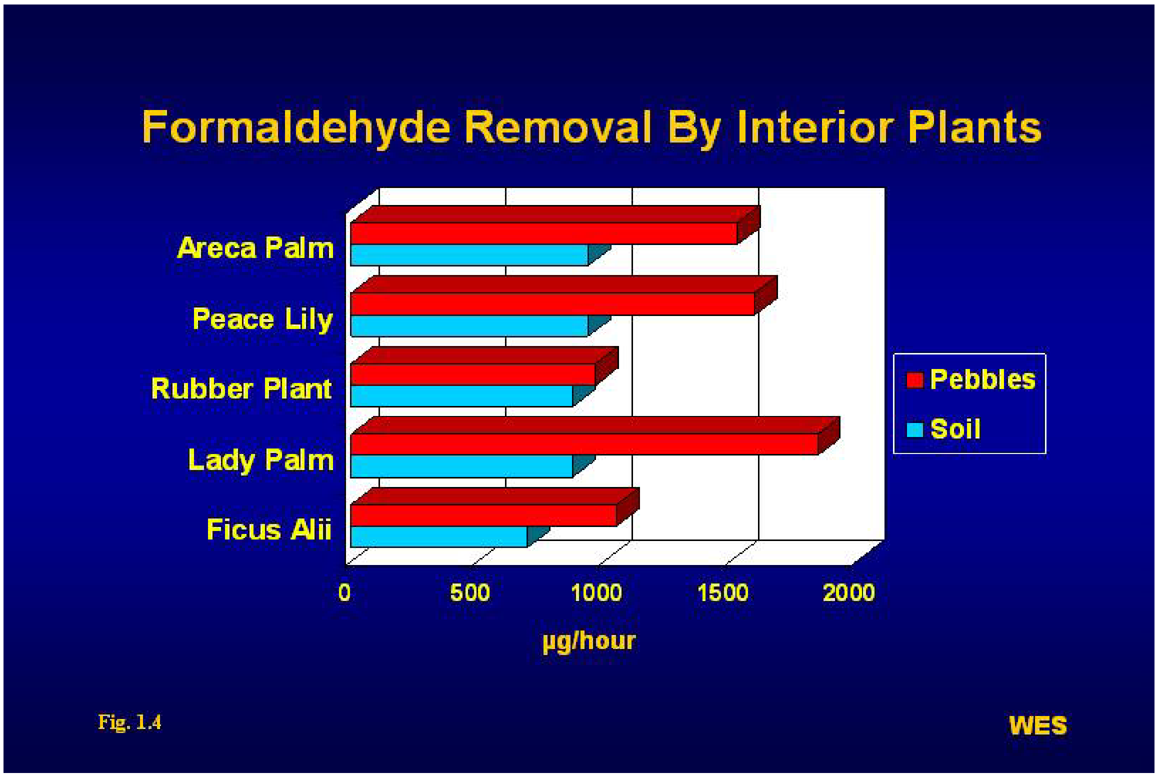


Fig. 1.4

Many people mistakenly believe that LECA™ pebbles, produced in Germany, are the only source for hydroculture pebbles. Actually, there are several types of expanded clay/shale pebbles that function equally as well and are produced in the U.S. However, their appearance may be

Fig. 1.5

somewhat less aesthetically pleasing. They are not currently marketed as hydroculture pebbles but are produced for other purposes. If the demand for hydroculture pebbles were great enough, producers would manufacture more aesthetically appealing pebbles. Some examples of hydroculture pebbles are shown in *Fig. 1.5*.

Other Research

Extensive studies by WES as well as other scientists in Europe, Canada, India, Korea, Australia and Japan have provided scientific evidence that interior plants can help improve the air quality within tightly sealed buildings. Interior plants are more effective in removing harmful airborne pollutants in tightly-sealed buildings than in ventilated buildings. No filtering device can effectively clean the air within a building when mechanical ventilation is constantly bringing in outside air. Outside air, especially in metropolitan areas, is often heavily polluted. Additionally, a building is not energy efficient if outside air must be continually heated or cooled to produce a temperature range for human comfort.

Research has shown that when workers are in close proximity to living plants productivity increases, morale improves and stress is reduced. Evidence collected during the past thirty years overwhelmingly supports the beneficial health effects of interior plants. Living plants also remove carbon dioxide and produce oxygen. These can be important functions when large numbers of plants are placed in greenhouse roof gardens, sunrooms or atriums.

Airborne particulate matter (dust) is most often introduced into buildings through mechanical ventilation systems, open doors or windows or by other means. Few, if any, public or commercial buildings are equipped with "wet scrubbers." This technology can effectively scrub particulate matter from the air before distribution throughout the building. Airborne particulate matter has been shown to produce allergic responses in many people. The young, elderly and those with asthma are particularly vulnerable. Dr. Virginia Lohr and colleagues at Washington State University have shown that foliage plants can reduce airborne particulate matter from the indoor environment. It appears that negative ions emitted by plant leaves attract dust particles. Airborne particles are collected on plant leaves so that plant leaves need occasional washing. Particulate levels in most indoor environments are not great enough to cause excessive dust collection on plant leaves.

One of the most ambitious and impressive uses of interior plants to improve indoor air quality is a building complex located in New Delhi, India. The Paharpur Business Center (PBC) in Nehru Place Green uses more than 1200 interior plants to help maintain air quality within the 50,000 ft^2 (4,647 m^2) complex. Outside air in New Delhi is heavily polluted. It has been said that as many as 10,000 people die each year from air pollution. In 2008 the Indian Government rated the PBC as the healthiest building in New Delhi. Kamal Meattle, Chief Executive Officer, placed interior plants into the building for the primary purpose of purifying and revitalizing the indoor air. As a result, human health issues, such as headaches, eye irritations and asthma, have been dramatically reduced. Additionally, energy costs have been reduced by more than 15 percent and worker productivity has increased by more than 20 percent. The PBC uses three species of plants: areca palm *(Chrysalidocarpus lutescens)*; mother-in-law's tongue *(Sansevieria trifasciata)* and golden pothos *(Epipremnum aureum)*. Air quality within the building is monitored on a daily basis and posted on the company's website. During fifteen year's of operation, healthy indoor air quality has been constantly maintained, even during periods of complete closure of the ventilation system.

High Efficiency Planter Filter

WES has developed a portable plant-based air filter that is 100 to 200 times more effective in removing VOCs from the indoor environment than regularly potted plants. A version of this filter is currently manufactured and marketed in the U.S. by U.S. Health Equipment Company (USHECO) located in Kingston, NY {http://www.plantairpurifier.com} *(See Fig. 1.6)*

Plant Air
PURIFIER

Fig. 1.6

Passive Modular Planter Systems

WES has also developed a plant-based hydroculture system to easily grow large numbers of interior plants in roof gardens, atriums or sunrooms for the purpose of purifying and revitalizing air within tightly-sealed, energy-efficient buildings. *(See Artist Concept in Fig. 1.7 and Design Specifications in Fig. 1.8)* An operational system has functioned successfully in Dr. Wolverton's home sunroom for more than 20 years. *(Fig. 1.9)*

Although hydroculture is the passive form of hydroponics, it is important to distinguish between the two. Built-in hydroculture modules do not require continuous recirculation of nutrient solution as is commonly applied to commercial hydroponic systems. These commercial systems are primarily used for vegetable production.

For ease of maintenance, hydroculture modules can connect to a buildings' internal plumbing. A float valve automatically maintains a constant water level of 2 to 3 inches (5.0 to 7.6 cm). *(See Figs. 1.7 and 1.8)* Plant roots receive water and nutrients through capillary action as water is wicked up to the plant root zone by expanded clay/shale pebbles. The water depth needed to provide moisture to the plant's root zone has been determined through years of research. The water level is dependent upon the depth of the plant growth containers. These modular systems allow for the easy removal of plants and containers. A mixture of plant species varying in size can thrive within a single module. In public or commercial buildings, modules may be attractively placed throughout the building, near windows, in atriums or roof gardens. These filters can strip the air of pollutants before it is returned into a room or building. When incorporated with standard HVAC systems, modular built-in units have the capacity to filter the air within much larger spaces. As these filters allow for greater recycling of air and reduced ventilation, an exciting aspect of the technology is energy savings. With today's spiraling energy costs, reducing energy consumption within a building is vitally important. However, its primary focus is to help alleviate the buildup of chemicals and other pollutants within the building that adversely affect its inhabitants.

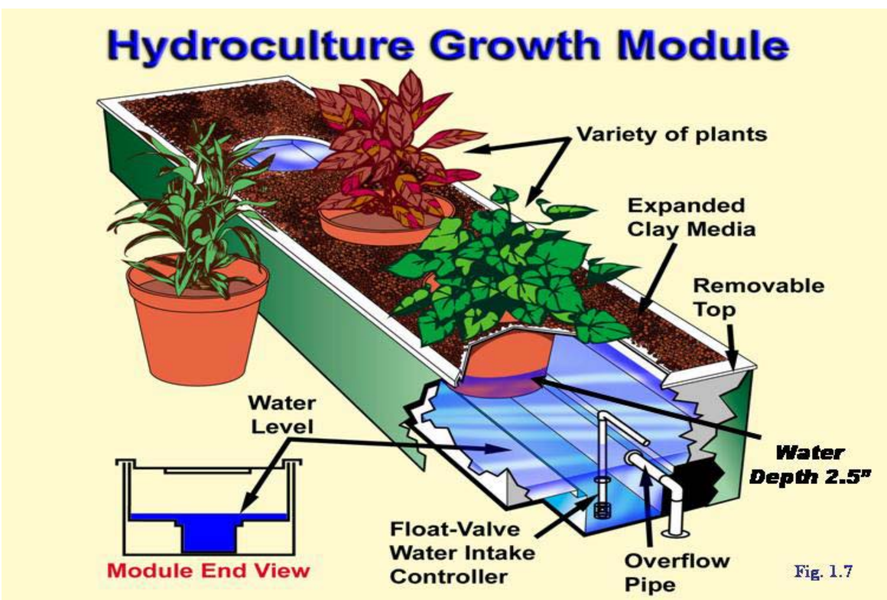
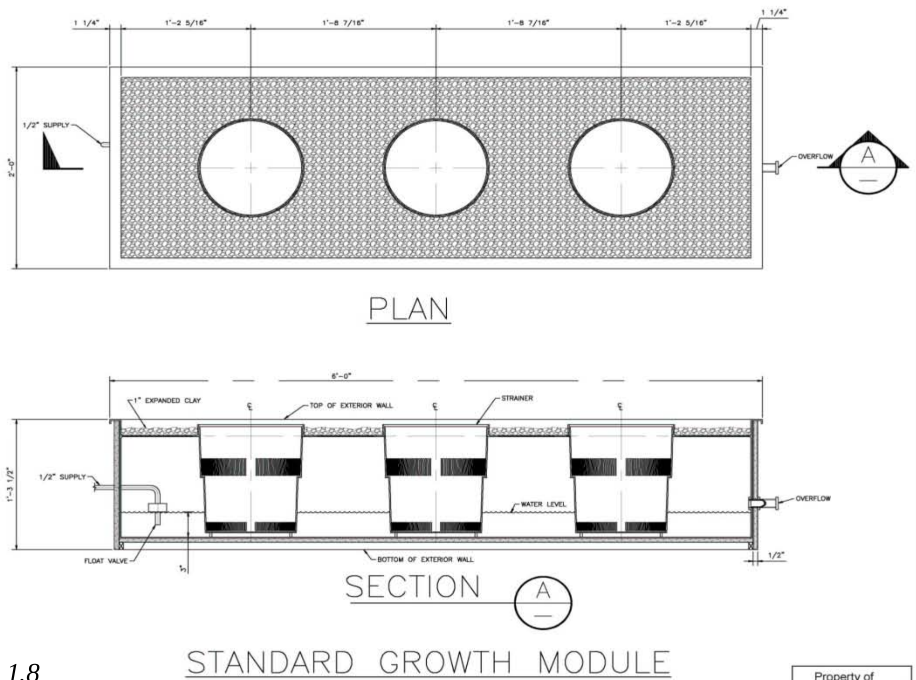


Fig. 1.7


1 1/4"
1'-2 5/16"
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1'-8 7/16"
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OVERFLOW
A
PLAN
6'-0"
1" EXPANDED CLAY
TOP OF EXTERIOR WALL
STRAINER
1'-3 1/2"
1/2" SUPPLY
WATER LEVEL
OVERFLOW
FLOAT VALVE
BOTTOM OF EXTERIOR WALL
1/2"
SECTION
A
STANDARD GROWTH MODULE
Property of WES, Inc.

Fig. 1.8


Plant Modules

Fig. 1.9

Completed Modular System

Fig. 1.10

The photo above is of the initial installation of a passive modular planter system in a public building. It was completed a number of years ago and served as a valuable learning tool. As a result, the design has undergone some modifications. The latest design is depicted in the artist concept shown in Fig. 1.7.

High-Efficiency (Active) Modular Planter Systems

The high efficiency Planter modules are a unique air filtration system that combines the proven filtration ability of activated carbon with the bio-regenerative (renewal process through biological activity) ability of microbes that thrive in the rhizosphere (root zone) of plants. *(See Figs. 1.11 and 1.12)* Because this bio-filter has a 'wet zone' that air must pass through as it is pulled down through the filter bed, it also acts as a 'wet scrubber.' Dry activated carbon does not effectively collect small water soluble molecules such as ammonia and formaldehyde. The addition of a wet zone to the filtration process insures that the filter can trap water soluble chemicals as well as dust and other particulate matter. Trapped chemicals in the wet zone are broken down by the plant-root microbes into elements that serve as food and/or energy for the plants and the microbes. This unique biological process destroys and consumes the trapped chemicals, removing them from the filter. Thus, the bio-regenerative process is sustained by the plants and their root microbes, thereby preventing chemical build-up in the filter. Under normal operating conditions, the filter media should never need replacing and negates costly filter replacement that is commonly required in mechanical air filters.

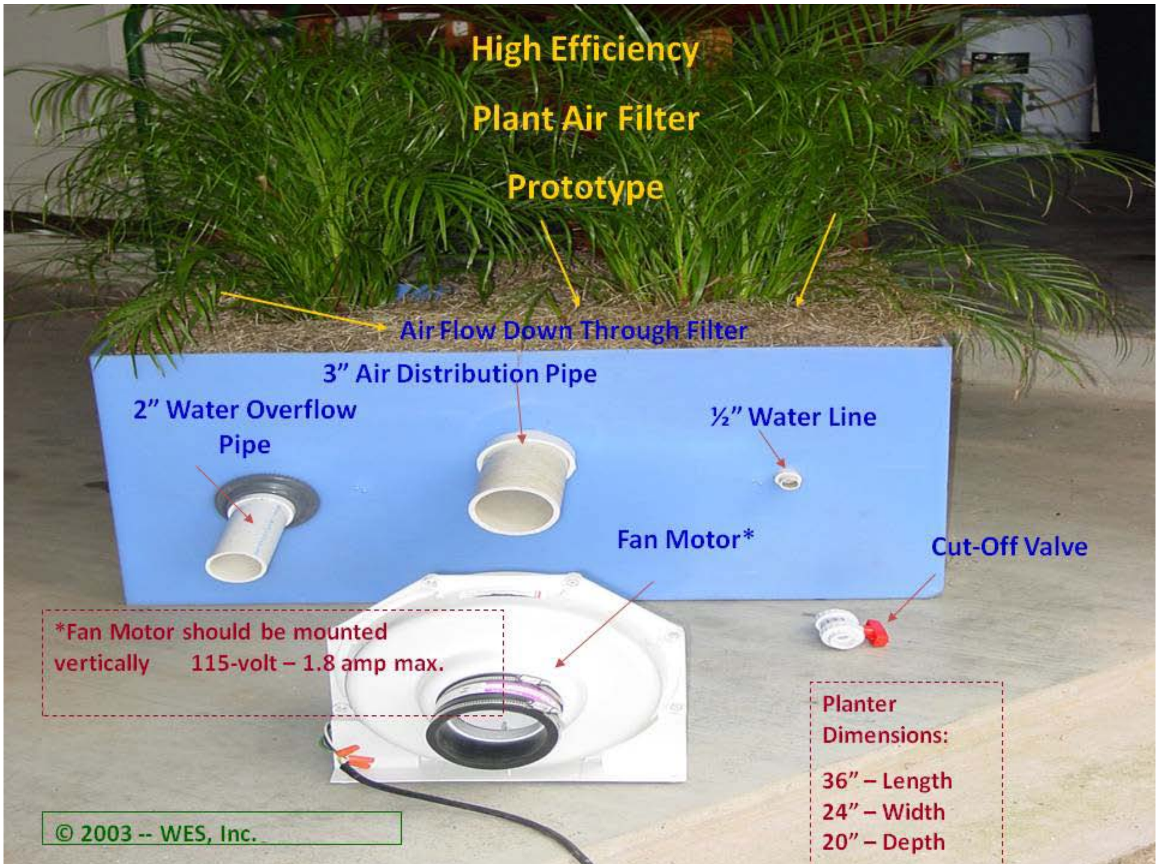

Fig. 1.11

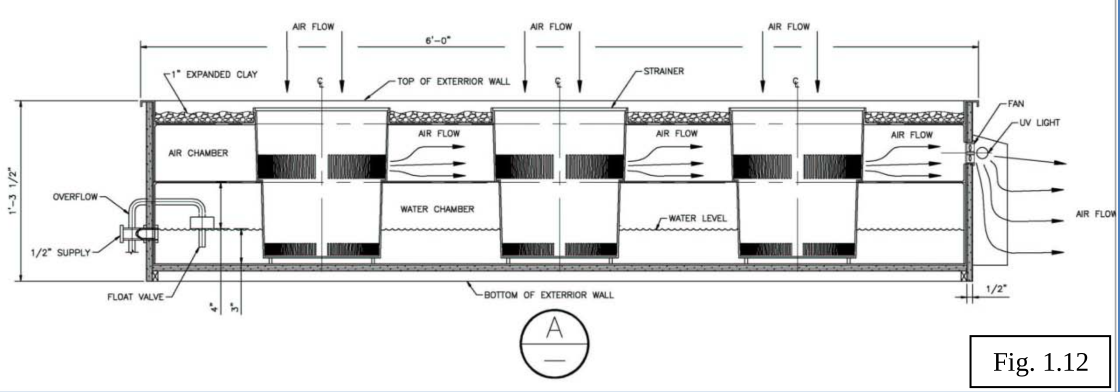

Fig. 1.12

Design Sketch

An artist concept for a rooftop system is shown in *Fig. 1.13*. Potential placement of modular systems is shown in the photo of an existing hotel atrium. *(Fig. 1.14)*

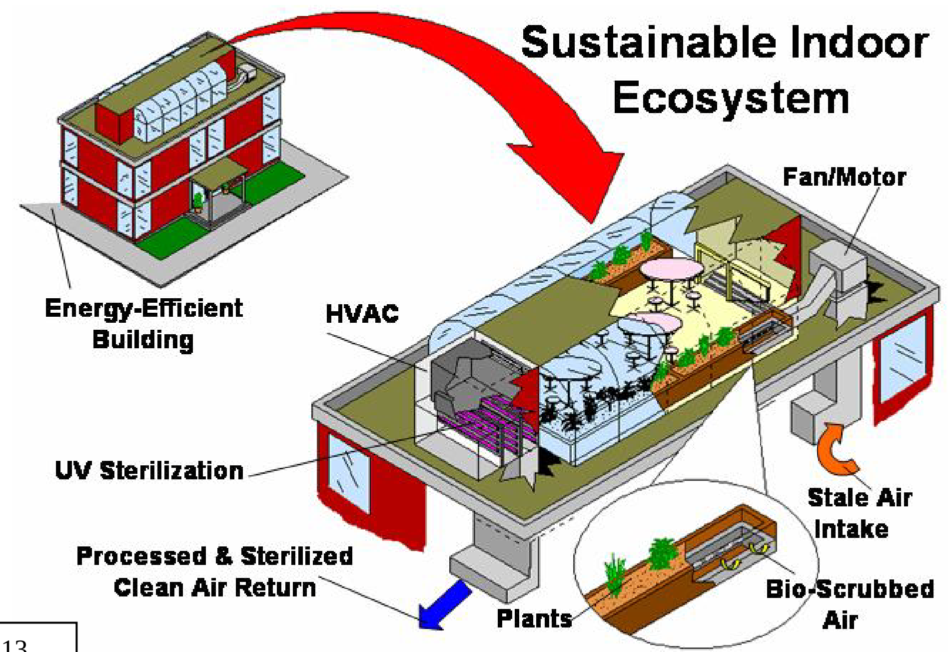

Fig. 1.13

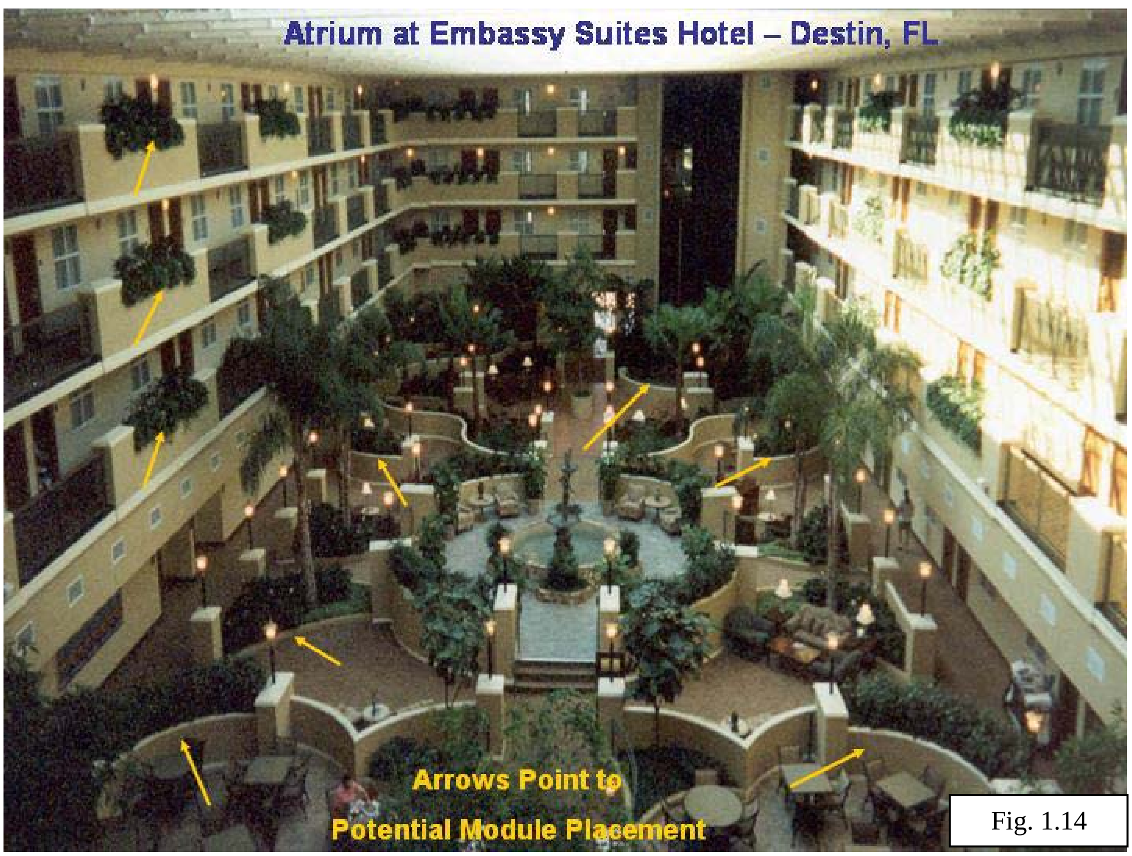

Fig. 1.14

With today's worldwide financial crisis, food shortages are a possibility. Weather patterns are also changing, causing crop failures in many food producing countries. As a result, scientists are beginning to look at the feasibility of growing food crops in environmentally controlled rooftop greenhouses. Fast growing food crops produce more oxygen and remove more carbon dioxide than slow-growing foliage plants. Therefore, the marriage of food production and indoor air purification in rooftop greenhouses could be an ideal combination. Space research has shown through the development of "closed ecological life support systems" for future long-term space habitation that this concept has great potential. In outer space, oxygen production is a primary goal. However, on earth our buildings are never sealed so tightly as to require oxygen production. Therefore, the concept for buildings is much easier to accomplish. Plants remove carbon dioxide during the process of photosynthesis. In fact, carbon dioxide enhances plant growth. So, any buildup of carbon dioxide within a tightly sealed building would serve as a valuable function in this concept as plants would effectively remove CO_2 from the indoor environment. Methods to increase photosynthesis and oxygen production by interior plants are currently in development by Takenaka Garden Afforestation, Inc. (Tokyo) with consultation by Dr. Wolverton. These methods may also prove to be very useful in further improving the air cleansing properties of interior plants.

Summary

Many people in industrialized nations spend as much as 90 percent of their time indoors. It is commonly understood that indoor air pollution is harmful to human health and may pose serious risk to the more vulnerable. Yet, the building industry has struggled for more than thirty years to find the dual solution of providing healthy indoor air quality while maintaining building energy efficiency.

As is often the case, NASA space application research has proven beneficial here on earth. Biotechnology that was originally developed by NASA has been improved and found practical application by WES, Takenaka Garden Afforestation and other researchers.

Built-in modular hydroculture systems and portable high-efficiency plant-based air filters are two of the more promising concepts for maintaining healthy air within energy-efficient buildings. These systems offer a more holistic, natural approach to improving indoor air quality and may have the added benefit of reducing energy use. As we enjoy the beauty and beneficial effects of placing plants indoors, it is comforting to know that they are also silently working to maintain a healthy indoor environment.

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