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Application Of Indoor Plants for Reduction of Formaldehyde Concentration in Interior Space

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Abstract
With an escalation in urbanization and increased standard of living, the jobs in service sector industries are growing at a prominent rate. This working space is usually dependent on artificial ventilation and air-conditioning. Several work so literature state numerous concerns about Indoor Air Quality(IAQ). The need to devote more care to interior environmental design has become necessary during designing—indoor environment results in diseases such as Cancer, Asthma which are silent killers. For research, the scope of purposes is narrowed to volatile organic compounds (VOC) emitted by the artificially processed material used in interior spaces, such as pressed wood products. Transmission of VOC can be one of the causes of sick building syndrome. The paper examines the use of pressed wood products and their effects on chemical emissions (formaldehyde). Phytoremediation is one method for chemical purification using plants to improve the air inside. The paper inspects phytoremediation as a process to control or diminish VOC in indoor office spaces. The objective is to establish the relation between indoor plants and the absorption of formaldehyde emitted from compressed materials used in making an office interior space.

Keywords: Formaldehyde Volatile organic compounds, Pressed wood products, Air-conditioned workspace, Foliage, Number of plants.

1 Introduction

Typology of interior spaces such as offices, hotels, and institutional facilities are becoming dependent on Heating, Ventilation, and Air Conditioning (HVAC) systems. Dependence on such systems allowed a parallel change in the plan depth of the building since the need for fenestration does not become a priority for outdoor use or lighting. These Interior spaces are more polluted than the surrounding outdoor ambient environment [29]. Relating this to the seriousness of the Indoor Environment, a look into the causes of world death rate analyzed by the Institute of Health Metrics and Evaluation (IHME) data, puts the cause of death numbers due to Indoor Air Pollution in, 8th position is 2.31 million. This is a serious matter as the effects of the same are not immediate and often go unnoticed. Also, according to the Confederation of Industry, the Indian Green Building Council (IGBC), in an updated addendum of 2019, states that 90 percent of the time people stay indoors. The health conditions associated with buildings are commonly classified as Sick Building Syndrome [37]. Poor and inappropriate lighting without sunlight, acoustic, economics, and humidity may contribute to sick building syndrome (SBS) and poor indoor air quality(IAQ) measures. Indoor pollutants are particles that are present at a scale of 100million numbers in comparison to outdoor pollutants which are a present maximum of 1 million numbers, as narrated by Dr. Arun Srivastava, in the consortium for educational communication (CEC) on Indoor Air [5]

The air quality is changing with different chemicals found, with change in material, technology as few reasons. Thus, factors contributing to IAQ are complex with connections to many essential fields. An attempt to cover three critical perspectives:

a. Chemical Properties related to pressed wood material are widely used in interior material applications.
b. Air-conditioned spaces and their relevant factors affecting interior spaces.
c. Quantification of indoor plants through a scientific approach.

These are relevant for the research. These three aspects are parallel framed for workspace interiors as to material usability, HVAC, and cost-effective approach through indoor plants. Quantifying the VOC emissions from the building materials and furnishings is both challenging and essential [29].

2 VOC in interior spaces

Over200types of VOC shave been identified in the indoor environment [30 &33]. VOCs have been associated with human health such as allergies, eye irritation, nose and throat malfunction, fatigue, lack of focus, vascular-nervous dysfunction, cancer, and acute, chronic health pathologies [23]. It can be determined that there is no effective system of classifying VOCs according to their physical-chemical properties. Hence, VOC in response to IAQ is assessed according to various factors such as Thermal, Visual [19], Acoustic comfort [15], and Pollutant concentration (such as benzenes and formaldehyde), gases, and odors [21]. Re-emission of sobbed VOCs can dramatically raise VOC concentrations in the Indoor Environment for months or years after a source event [35]. Thus, a material capable of depositing, adsorbing, and accumulating pollutant scan influence Indoor Air Quality (IAQ)during the entire service life of a building [20]. VOC emission factors have been stated in research promotion (RP)1097 by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), a globally approved code of ethics for HVAC. It was concluded through experimental data by the Linear Langmuir model. It indicates the following listed parameters as critical factors for sorption of VOC [35].

- Chemical Properties
- Physical properties of building material
- VOC concentration
- Temperature
- Humidity

On an interior scale, these factors will significantly impact IAQ.

2.1 Formaldehyde VOC about pressed wood products used in the interior application.

Since the 1960s&1970s, interiors have been scrutinized for high concentrations of formaldehyde as a result of the hydrolysis of urea-formaldehyde resins. [31]. Formaldehyde concentrations are exceptionally high in buildings due to the presence of more formaldehyde-emitting materials and the relatively minor interior volumes of air. Pressed wood products used in interior furnishings are made of urea-formaldehyde resins capable of releasing formaldehyde, a type of VOC [26]. Table 1categorizesInteriormaterialsrelatedtot h e adsorption or desorption of Formaldehyde [8].

Table1: Interior material from pressed wood products

Interior Material	Emitted VOC's
Laminate	Formaldehyde and other chemicals
Varnish finished furniture	Formaldehyde and other chemicals
Particle Board	Formaldehyde and other chemicals
Plywood	Formaldehyde and other chemicals
MDF(medium density fiber)	Urea-formaldehyde resins

Indoor air quality and product emission studies reel the presence of formaldehyde and other VOC contamination. primarily resulting from furniture constructed of pressed wood products (formaldehyde source) and chemical deodorizers [5].

3 Method

Remediationtreatmentstoimproveindoorairqualityincludethreebasicstrategies as narrated by U. S. Environmental Protection Act (U.S. EPA) 2017[36] are:

I. Controlling the source of pollution
II. Building ventilation
III. Purifying the air

I Control the source of pollution.

Narrating these points in contact with to study undertaken are as follows:
pressed wood (product for the research) must be controlled to limit VOC emissions such as formaldehyde. The threshold units are measured in particles per billion(ppb), particles per million (ppb), and mg/m3. As the space is defined as length× width × height. The respective units are converted to mg/m3.

The threshold limit variation for the safety standard for formaldehyde varies on a large scale when compared between national and international certified organizations and other non-profit private organizations. The mean average of the certified organization is taken because the organizations are either world assembly forums or industrial experts, Thus, a mean can be helpful in further analysis, instead of taking one perspective reading only.

Organization	Formaldehyde (HCHO)		Time Duration
	Ppb & ppm	**mg/m3**	**Hours and minutes**
ASHRAE*	27 ppb	0.033	8 hours
OSHA*	0.75ppm	0.92	15 minutes
NIOSH*	0.016ppm	0.02	15 minutes
GREEN GUARD**	7.3ppb	≤0.5	Not mentioned
BIFMA**	---------	11	Not mentioned
BIFMA***	---------	17	Not mentioned
Mean average for study	**0.200 ppm**	**4.91**	**8 hours**

Table 2(a)Threshold units for formaldehyde

II Building ventilation

Building parameters are built along with threshold standards as analyzed for air-conditioned spaces. A series of protocols and methodologies have been enforced by national and international organizations to achieve common indoor air sampling strategies for quantitative analysis as in Table 2.

Table2(b)Threshold unit for air-conditioned workspace

Organization	Relative Humidity	Air supply rate	Temperature
	RH (%)	**ACH (change/hr)**	**temp**
ASHRAE	30-60	2-3*	19.40-27
WHO	50-70	4-6	19-23
Mean Average range (for study)	**40-65**	**3-4.5**	**19.20-25**

Source: ASHRAE: American Society of Heating, Refrigerating, and Air-conditioning Engineers. ASHRAE standard Inc. 55-2017
ASHRAE standard 62.1-2007
WHO: world health organization air quality guidelines global update 2005 and WHO guideline value for the ―classical‖ air pollutants (WHO 1999)

Purifying the air has physical, chemical, mechanical, and biological technologies such as self-regulating filters National and international organizations have enforced a series of protocols and methodology filtration, activated carbon absorption, and botanical purification. [12]. With the study of test chamber analysis done for temperature and relative humidity, it was seen that change in temperature or relative humidity did not have a significant effect on formaldehyde emissions for the particleboard or plywood [25].Many researchers have been experimenting to understand the indoor environment with material testing for press-wood products, particle board, plywood, and formaldehyde gaseous form. The relevant studies, by [10,14,16,22,25,34, & 35]; concludes that -temperature(T), relative humidity (RH), and Time(hours/days/months) factor are common parameters considered by all. While air

change rate, air flow rate, was not always considered in these chamber tests. Light is another parameter that influences the indoor workspace to a magnitude. But other influencing factors can override the effect of light. The effect of the light may be limited in indoor environments where light levels are typically around 9–14 μmol/m2 /s [7].

III Purifying the air.

Phytoremediation, using plants with their associated microorganisms to remove pollutants from soil, water, and the air, is cost-effective and quick on hand. Phytoremediation can develop as an air-cleaning technology and an aesthetic-enhancing tool in Interior Planning. Phytore mediation can be stated as a method, system, or cure where plants are involved in air purification. It is an amalgam of the Greek "Phyto" (plant) and Latin "mediation" as (restoring balance) [24]. Whole or part of the plant as roots, stomata, soil containment, water containment, surface area, foliage, etc., are in volved directly or indirectly [9]as seeninFig-1. This technology can emerge as a cost- effective and publicly acceptable way to address the removal of toxicity of Indoor Air. Exploration of the Potential of plants to purify the air from pollutants started in the early 1980s. The phytoremediation technique can be used for indoor environmental cleanup [14].

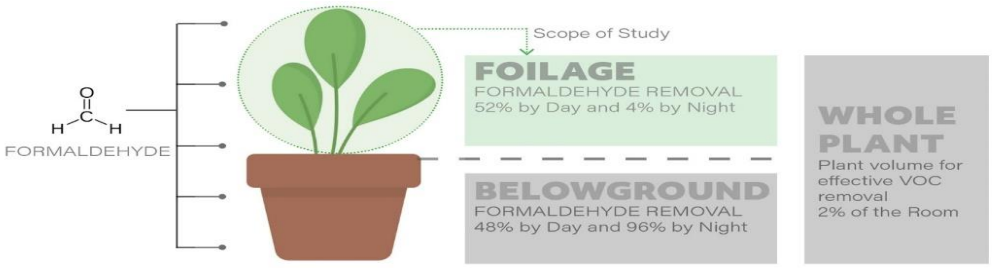

Fig-1: Understanding phytore mediation in plants. Source:(KwangJinKim,2018) [Illustration by Deeksha Somaiya]

For conducting the study, the guideline for formaldehyde removal from plants is selected from the seal experiment Wolver to and the National Aeronautic sand Space Administration (NASA)in1989, to derive one plant type and its quantification [34]. Fig. 2 and Fig. 3 states the data of 14 plant typology listed by Wolverton, seen in removing formaldehyde. Fig. 2 shows the total microgram removed by the respective plant and Fig. 3 graphs the total surface area per plant.

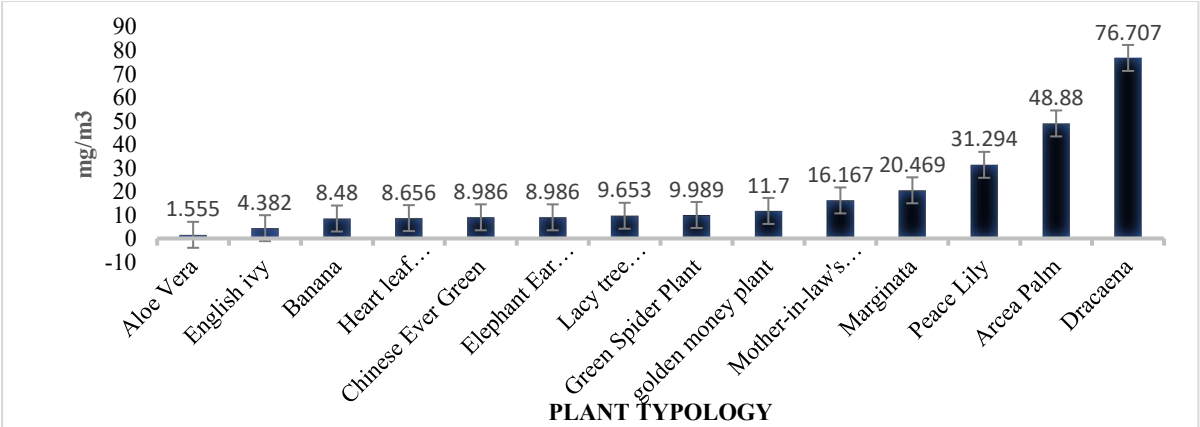

Fig. 2 Total formaldehyde as microgram(mg) removed per plant

One plant removal of formaldehyde varies from 1.55mg/m^3 to 76.70mg/m^3 in an observation undertaken after 24 hours.

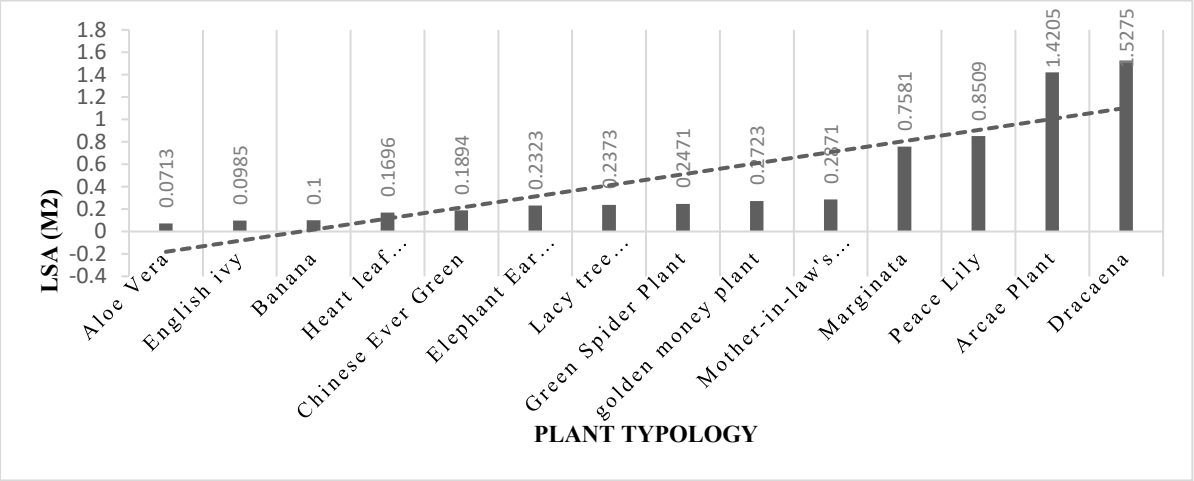

Fig-3 Plant relation to its aesthetic part of the foliage, which is considered as leaf surface area (LSA)The LSA for plant varies from 0.07 m^2 to 1.5 m^2

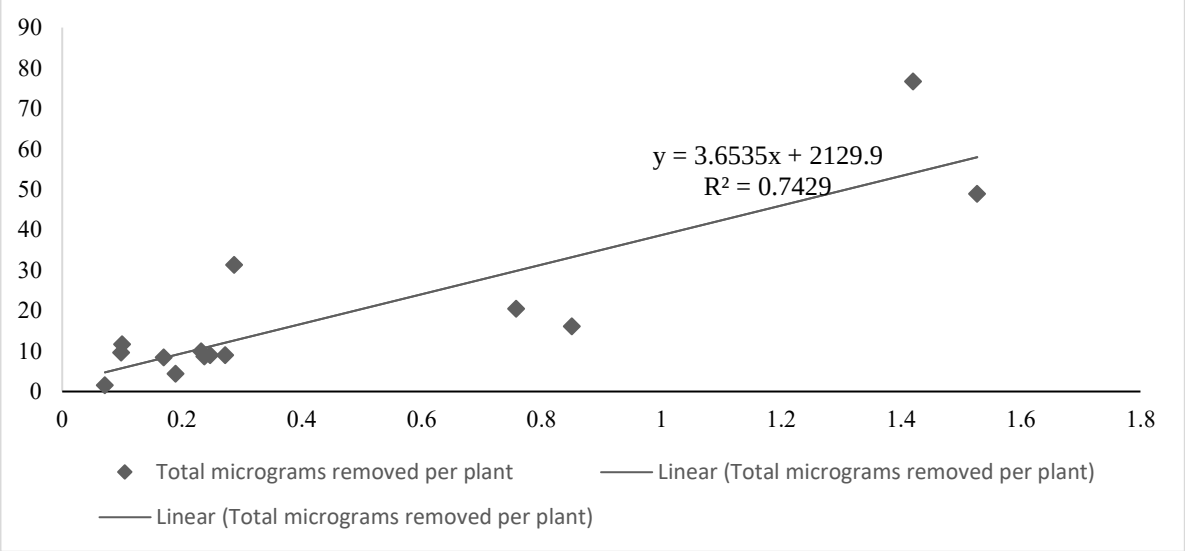

Fig-4: Regression analysis for micrograms removed per plant in relation to Leaf Surface Area

With linear regression analysis, it can be concluded that among the most common indoor plants, the total mg/m3 removed per plant is in direct proportion to their leaf surface area(LSA) 74% is the absorption of micrograms through LSA, as shown in Fig. 4. From Table 2(a) & Table 2(b), the following parameters are considered constant for the workspace's ambient conditions under which phytoremediation occurs.

The ambient temperature of the room = 19.20-25 ◦c *(a*)*
The relative humidity=40-65*(b*)*
Time factor= 8hours *(c*)*
Mean average of safety limit for HCHO=4.91 mg/m^3
Space volume= L x B XH as of the same dimension

Emission of formaldehyde =€
Emission (€) < safety limit
(1)
Emission € = *a**+ *b**+ *c**+ …+ *e, wheree= any other constant required.*

For phytoremediation, leaf surface area (LSA), derived from fig-3 derives to following equation-2,
where α= Total micrograms removed per plant
α=(LSA x 3.6535)+2.2129.9 (2)
Thus, about equations 1 and 2, if we want to conclude the number of plants to be placed in office interior space, we need to derive Equation 3. For the same,
Number of plants=N
Leaf surface area of a single plant =LSA
Total leaf surface area of N plants= TSA
Ω = total formaldehyde(HCHO) absorbed
Ω=N x α → (1 plant type) (3.1)
For one type of plant equation 3.1
Ω= N x (LSA x 3.6535) +2.2129.9
Ω-2.2129.9= (N x LSAx3.6535)
N= Ω-2.129.9÷LSAX3.6535
For more than one type of plant equation 3.2:
Ω=N1α1+N2α2+ N3α3 (2 or more plant types)
(3.2)
Ω= [N1 x (LSA1 x 3.6535) +2.2129.9] + [N2 x (LSA2 x 3.6535) +2.2129.9] + ….
Where N1=plant type1, N2 =plant type 2
Consequently, equation-1 will be balanced as with equation 3.1 & 3.2 as:
Emission (€) < safety limits = Ω=N x α → (1 plant type)
or
Emission (€) < safety limits= Ω= N1α1+N2α2+ N3α3 (2 or more plant types)

4 Analysis

The removal of formaldehyde from indoor air by the plant can be directly proportional to the Leaf surface area. Phytoremediation techniques from plants and their associated parts have proved to be a significant betterment of IAQ. This phytoremediation technique can be experimented with (1) a single variety and quantifying it or (2) different typologies of plants. (1) or (2) can be opted forbest suited for retaining the needed VOC &formaldehyde levels. This can be done considering the aesthetics of plant surface area and color variations suitable for the office space requirement as desk area or workstations, cubicles to name a few. Thus, enhancing the interiors of the workspace better with a methodological approach. The study here is limited to the quantification of plants with leaf surface area absorption.

5 Conclusion

The research paper has come to conclusion that random placements of plants in interiors can be justified further with a scientific understanding. *"Interior Plant-o-placement* "can be a new approach to streamline with aesthetics of foliage plants to its absorption of VOC harmful for human breathing.

6 Further Scope of research

The paper here only analyzed the current data available through Literature study undertaken. Further, chamber Test needs to be undertaken, on the basis of the mathematical methodology described. This further will derive to the pattern of foliage of plants and numbers adding to the aesthetics of Interior Spaces, in scientific method.

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