

Natural Air Filtration: Potted Plants for Management of Sick Building Syndrome

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1 **Title : Natural Air Filtration: Potted Plants for Management of Sick**
2 **Building Syndrome**

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37 **Abstract:** Air pollution is a pressing issue that warrants attention. It is crucial to comprehend the impact of air pollution
38 on human health. With the rapid growth of industry and urbanization, the air we breathe has become hazardous to our well-being.
39 Moreover, because people spend most of their time indoors, the risk of exposure to toxic pollutants indoors is higher. Inorganic
40 gases and biological factors also contribute to indoor pollution, and these contaminants can cause Sick Building Syndrome, which
41 can result in symptoms that vanish once individuals leave the building. Sick Building Syndrome has a significant impact on the
42 health and productivity of occupants. In this study, NASA-proven natural air-purifying plant species, such as *Sansevieria Laurentii*,
43 were used to combat Sick Building Syndrome. The pollutants used for the study were Adhesive, Paint, Kerosene, Egg crate,
44 Cigarette, Varnish, Wood Shaving and Coconut Husk. It is best to use locally available plants that have a high potential for air
45 purification. The study aimed to determine the most effective phytoremediation methods using *Sansevieria Laurentii* to purify
46 indoor pollutants, and the results demonstrated a substantial reduction in indoor air pollution on increasing the number of potted
47 plants.

48 **Keywords :** Air pollution, Sick Building Syndrome, phytoremediation, *Sansevieria Laurentii*, potted plants
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1. Introduction

Sick Building Syndrome (SBS) is a group of symptoms that affect the health of occupants in a building. The environment is a significant concern for people worldwide, and outdoor air pollution resulting from burning fossil fuels, industrial emissions, vehicle movement, and volcanic eruptions can cause serious damage to human health. However, since 90% of people spend most of their time indoors, exposure to indoor pollutants is often higher than outdoor pollutants (Safaris et al., 2010). Indoor air pollution results from contaminated outdoor air that enters buildings through various means (Pettit et al., 2018). Carbon dioxide is a common indoor pollutant that can cause headaches, lethargy, and difficulty breathing in rooms with more people (Safaris et al., 2010). Research indicates that indoor air can be up to 12 times more polluted than outdoor air, with primary pollutants including carbon monoxide, particulate matter, nitrogen oxides, Sulphur oxides, arsenic, fluorine, volatile and semi-volatile organic compounds, ozone, radon, Trichloroethene (TCE), hydrocarbons, lead, asbestos, and aldehydes (Chauhan et al., 2017). Exposure to these toxic compounds can lead to serious problems such as cancer, developmental disorders, and acute and chronic illnesses. Volatile organic compounds (VOCs) are one of the most common indoor pollutants, primarily sourced from off-gassing from building materials and household products (Pettit et al., 2018). Every year, around 3 million people die due to indoor air pollution (Chauhan et al., 2017). ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers) provides permissible standards for indoor air quality to prevent discomfort to occupants caused by chemical compounds emitted into the air (Pettit et al., 2018). Pollutants can be organic or inorganic, solid, liquid or gas, and originate from both outside and within the indoor environment (Ozdamar, M et al., 2018). Sick Building Syndrome results from exposure to these pollutants, and symptoms include nose, eye and throat irritation, headaches, dizziness, anger, mood alteration, depression, fatigue, difficulty concentrating, non-asthmatic symptoms of asthma, itching, and red blotches on the skin (Safaris et al., 2010). These symptoms can significantly reduce work performance and productivity, but they usually disappear once the person leaves the building. Given that people spend most of their time indoors, it is vital to ensure indoor air quality to maintain a comfortable and productive environment.

2. Phytoremediation of Impurities by Indoor Plants

Air pollution has been becoming a significant concern with rapid modernization around the world, affecting the human health in numerous ways, such as ophthalmic, respiratory and cardiovascular diseases. (Yang and Yanju Liu, 2011). Whenever we come across air pollution the first thing that comes to our mind are vehicle or manufacturing exhaust, volcanic eruption, forest fires, burning fossil fuels, dry soil erosion, etc. All these are outdoor pollutants yet indoor air is also polluted as outdoor air or even 12 times more polluted than the outdoor air. Indoor air quality is significant to look into since it affects human health especially in developing countries where people spend 90% of their time indoors. (Chauhan et al., 2017). Phytoremediation is a process to stop environment pollutions, such as in air, water and soil pollution based on plants to extract and remove pollutants. Researchers have proved that this method is helpful to reduce pollutants in soil, water and air since it is energy-economizing and cost-effective compared with those physical or chemical methods giving people an aesthetic value (Chauhan et al., 2017). Various phytoremediation process involves phytostabilization, rhizodegradation, phytodegradation,

phytoextraction, phytovolatilization and phytofiltration (Yang and Liu, 2011).

Plants make a good bonus to the part of a room, be it a bedroom, schools, offices. People generally buy plants mostly for aesthetic purposes. Besides from their pleasant appearance which gives tranquillity to the occupants in buildings, green plants also play a great role in purifying indoor air from toxic pollutants (Bandeali et al.,2021). Green walls can be categorized into passive and active green wall and can also be used both indoors and outdoors. Besides plants, there are several air remediation methods used universally to improve the quality of indoor air. Air purifiers like HEPA (high efficiency particulate air filter) filter is helpful in capturing all the accumulated pollutants which is very effective for allergic people as it captures both biological and chemical pollutants which can cause allergies (Chauhan et al.,2017). Increasing the ventilation is another way to improve the quality of indoor air. Common household products like cleaning agent, spray, nail polish, smoke emission from kitchen while cooking release VOC which has a negative impact on human health. Ventilation helps in maintaining the flow of air and also helps in exchanging the stale air with the fresh outdoor air in areas where the outside pollution is less (Chauhan et al.,2017). Carbon filters are also the great air purifiers because of its adsorptive characteristics (Chauhan et al.,2017). Many of these methods are expensive and need technical expertise. Therefore, frequently using them hold a little chance. Due to the constraints stated above many researchers have conducted a study on bioremediation which uses organisms to purify the contaminated site. The removal of toxic pollutants from air by using chemical, biological and physical activities of green plants is termed as phytoremediation (Yang and Yanju Liu 2011).

Researchers have also proved that phytoremediation is effective in reducing air pollutants it is also cost-effective compared with those advanced methods like air purifiers. Furthermore, it also creates calm and exquisite atmosphere within the building (Yang and Yanju Liu 2011)

3. Objectives of the Study

There is a gap in the research on the reduction of multiple sources of indoor air pollutants. Additionally, no research has been conducted on managing Sick Building Syndrome in the North East region of India using indoor air, despite its high potential.

The objectives of this project work include selecting an indigenous local plant with high potential for phytoremediation of indoor air pollution. The project also aims to compare the phytoremediation of indoor air pollutants by potted plants, passive and active green wall mechanisms. Finally, the project seeks to design a low-cost self-sustaining and self-maintaining active green wall to manage Sick Building Syndrome.

4. Motivation

Since India is a developing country and less hygiene is maintained in almost every part of the country, it is true that the air we breathe in is contaminated due to various outdoor activities. Due to which the indoor air quality is also affected and that affects our well-being too. It is also a fact that we are surrounded by toxic pollutants in our lives. The very buildings where we live in, the household products that we utilize all these things have chemical

compounds which are extremely toxic to our health. Retired people, school children, infants and physically challenged people spend most of their time indoors. Therefore it is captivating and demanding to understand the important of plants which can fight against sickness and diseases and also provide relaxation to our mind and body. Although the world has been advanced technologically and air filters can easily be bought, it remains a question for poor people concerning the money.

As we know that the Air Quality Index is very poor to the guwahati city so it's necessary to improve the Air Quality Index to live a sustainable life. The scope of this project includes the selection of indigenous plants and a highly potential phytoremediation method. It also involves determining the number of pots required.

Table i: Effects on human health and its sources

Ill effects	Causes/sources	References
Changes in personality, anger, headaches, nausea and light dizziness, fatigue & lethargy.	Insufficient ventilation, unbalanced humidity, airborne chemical pollution, computer screens, formaldehyde (HCHO), carbon monoxide (CO), carbon dioxide (CO ₂), Cigarettes,	Burge, P. S. (2004). Sickbuilding syndrome. <i>Occupational and environmental medicine</i> , 61(2), 185-190.
Acute and chronic illness reproductive, developmental disorders and diseases May even lead to cancer	Building products, emission of human activities inside the building, carbon monoxide, particulate matter Improper ventilation condition, nitrogen oxides, Sulphur oxides, arsenic, fluorine, volatile and semi-volatile organic	Chauhan et al., (2017).. "Role of Plants in Indoor Air Remediation." <i>Int. J. Eng. Tech. Sci. Res</i> 4.9 (2017): 749-756..
Psychological and physical effect working environments where they are present, stress, poor task performance	Synthetic products such as furniture, antimicrobial filters that are used in air cleaners VOCs.	Hong et al., (2017). Study of the removal difference in indoor particulate matter and volatile organic compounds through the application of plants. <i>Environmental health and toxicology</i> , 32.
Ear, nose, and throat, irritation, coughing, itching, dizziness and nausea, lack of concentration, fatigue even chest tightness, muscle aches, asthma symptoms,	TVOC	Pettit et al., (2018). Towards practical indoor air phytoremediation: a review. <i>Chemosphere</i> , 208, 960-974.

5. Indoor Airborne Impurities

Many researchers have stated that air quality inside buildings may be worse than outdoors and since the modern person spends more than the 90% of his time in buildings the quality of indoor air shows a major public health concern(Mallany,2000). Indoor airborne impurities come in many forms: gases, liquids, and/or particulates suspended in air. (Kai Wilkinson, 2013). Researches have also been reported that indoorair is 12 times more polluted than the outdoor air (Chauhan et al., 2017). According to Environmental Protection Agency (EPA) Spread of COVID-19 occurs through the droplets and particles. People who are infected are likely to spread the droplets to other person through sneezing, coughing, talking etc. Airborne impurities can also occur through carbon monoxide, particulate matter, nitrogen oxides, Sulphur oxides, arsenic, fluorine, volatile and semi-volatile organic compounds etc(Chauhanet al., 2017).

Table ii: Sources of Indoor Air Impurities

Sl. No.	Air impurities	Sources	Referenrces
1.	Carbon monoxide	Fuel,wood burning, cigarette	Burge, P. S. (2004). Sick buildingsyndrome. <i>Occupational and environmental medicine</i> , 61(2), 185-190.
2.	Formaldehyde	indoor wooden furniture with formaldehyde resin paints, building materials, adhesives,	Bandehali et al.,(2021). Current state of indoor air phytoremediation using potted plants and green walls. <i>Atmosphere</i> , 12(4), 473.
3.	VOC	antimicrobial filters that are used in air cleaners,common household and office materials	Sokhal et al.,(2020). Plants are More Effective in Absorbing Volatile Organic Compounds from the Atmosphere Than Air Purifiers. <i>Journal of Student Research</i> , 9(2) and Hong, S. H.,
4.	Benzene.	garage, heatingand cooking systems, solvents, varnishes, office equipments, cigarettes	Özdamar, M., & Umaroğullari, F. (2018). Thermal comfort and indoor air quality. <i>International journal of scientific research and innovative technology</i> , 5(3), 90-109.
5.	Carbondioxide	can be found in the atmosphere in low concentrations of approximately 0.03%, people	Burge, P. S. (2004). Sick building syndrome. <i>Occupational and environmental medicine</i> , 61(2), 185-190.
6.	Hydrocarbons	floor detergents and furniture	Burge, P. S. (2004). Sick building syndrome. <i>Occupational and environmental medicine</i> , 61(2), 185-190.
7	Insecticides and pesticides	Consumer products	Burge, P. S. (2004). Sick building syndrome. <i>Occupational and environmental medicine</i> , 61(2), 185-190.

180 **Table iii:** Indoor air pollutants and air purifying plants

Impurities	Plants	References
BENZENE	Spathiphyllum wallisii (peace lily), Chamaedorea Seifrizii (Bamboo Palm), Hedera helix (English ivy), Sansevieria laurentii (Mother-in-law tongue) , Aloe vera, (Aloe vera), Dracaena Marginata, (Red-edged dracaena)	Chauhan et al., (2017) Role of Plants in Indoor Air Remediation. <i>Int. J. Eng. Tech. Sci. Res</i> , 4(9), 749-756. & de Visser, P. (2017). Air purification by houseplants: a literature survey.
OZONE	Chlorophytum comosum (Spider plant), Sansevieria laurentii (Mother-in-law tongue) ,	Chauhan et al., (2017) Role of Plants in Indoor Air Remediation. <i>Int. J. Eng. Tech. Sci. Res</i> , 4(9), 749-756.
TOULENE AND XYLENE	Phoenix roebelenii (Dwarf date palm), Dyspis Lutescens (Areca Palm), Nephrolepis exaltata (Boston fern), Hedera helix (English ivy), Chlorophytum Comosum (Spider plant), Epipremnum aureum (money plant), Spathiphyllum wallisii (peace lily), Chamaedorea seifrizii (Bamboo Palm), Rhaps Excelsa (Broadleaf lady palm), Sansevieria laurentii (Mother-in-law tongue) , Dracaena marginata (Red-edged dracaena), Ficus Benjamina (Weeping Fig), Ficus Elastica (Rubber plant)	Chauhan et al., (2017) Role of Plants in Indoor Air Remediation. <i>Int. J. Eng. Tech. Sci. Res</i> , 4(9), 749-756.
FORMALDEHYDE	Phoenix roebelenii (Dwarf date palm), Dyspis Lutescens (Areca Palm), Nephrolepis exaltata (Boston fern), Hedera helix (English ivy), Chlorophytum Comosum (Spider plant), Epipremnum aureum (money plant), Spathiphyllum wallisii (peace lily), Chamaedorea seifrizii (Bamboo Palm), Rhaps Excelsa (Broadleaf lady palm), Sansevieria laurentii (Mother-in-law tongue) , Dracaena marginata (Red-edged dracaena), Ficus Benjamina (Weeping Fig), Ficus Elastica (Rubber plant), Aglaonema modestum (Chinese Evergreen), Musa Oriana (Banana), Aloe vera (Aloe vera), Gerbera jamesonii (Barberton daisy)	Chauhan et al., (2017) Role of Plants in Indoor Air Remediation. <i>Int. J. Eng. Tech. Sci. Res</i> , 4(9), 749-756.
TRICHLOROETHYLENE	Spathiphyllum wallisii (peace lily), Dracaena marginata (Red-edged dracaena), Chrysanthemum Morifolium (Florist's Chrysanthemum)	Chauhan et al., (2017). Role of Plants in Indoor Air Remediation. <i>Int. J. Eng. Tech. Sci. Res</i> , 4(9), 749-756.

AMMONIA	Hedera helix (Englishivy), Rhaps Excelsa(Broadleaf lady palm), Ficus Elastica (Rubberplant), Dieffenbachia spp.(Dumb Canes)	Chauhan et al., (2017) Role of Plants in Indoor Air Remediation. Int. J. Eng. Tech. Sci. Res,4(9), 749-756.
HYDROCARBON	Hedera helix (English ivy), Chlorophytum comosum (Spider plant), Anthurium Andraeanum (Flamingo lily),Philodendron Cordatum (Heartleaf Philodendron, Philodendron domesticum (Elephantear philodendron), FicusBenjamina (Weeping Fig), Dieffenbachia spp. (Dumb Canes),	Chauhan et al., (2017) Role of Plants in Indoor Air Remediation. Int. J. Eng. Tech. Sci. Res,4(9), 749-756.
CARBON DIOXIDE	Sansevieria laurentii (Mother-in-law tongue) , Dracaena marginata	Thongsanit, Pajaree, et al (2015)"Efficiency of Snake Plants Absorb Carbon Dioxide inOffices."
CARBON MONOXIDE	Sansevieria laurentii (Mother-in-law tongue) , Epipremnum aureum (Scindapsus Aureus)	Janah et al (2020). Absorption Pollutants Carbon Monoxide (CO) in the Air UsingSansevieria and Scindapsus Aureus.

6. Indoor Air Phytoremediation Methods

Potted plants: Thongsanit et al (2015) proved the efficiency of potted plants to reduce the amount of carbon dioxide. They conducted a test to measure the concentration of carbon dioxide in offices using snake plants. Sowa et al (2019) also proved the ability of potted plants to purify Indoor Air Quality. They found that VOC, formaldehyde were reduced to higher extend as compared to the same procedure performed without plants. The plants species used were *Sansevieria trifasciata* ,*Epipremnum aureum*, *Dieffenbachia seguine*. It is important to consider the fact that working in offices where cooling and heating system are fitted create stress and gradually affect the working performances of the occupants. Many researchers proved that plants have the special ability to reduce the fatigues, stress, mood alterations. Another significant advantage of the plant is the ability to provide cooling effect due to evaporation. Potted plants have also the ability to remove VOCs and formaldehyde (Sowa et al., 2019). The above-ground part of the plant, roots and microorganisms found in the substrate are important mechanisms which help to reduce the concentration of indoor pollutions. Plant organisms are very much helpful in removing the pollutants specially VOCs. Other pathways are: Plants absorb gaseous pollution by stomata. The idea of mitigating to remove indoor pollutions was brought by Wolverton and his associates in 1989 (Samaneh et al., 2021).



Fig 1: Resting area arranged with potted plants in pilot office building in Gdańsk
(Sowa et al., 2019)

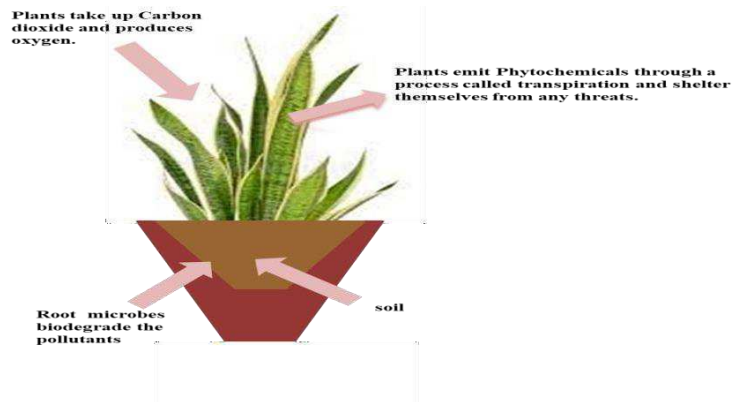


Fig 2: Snake plant (*Sansevieratrifasciata*) adopted from <https://planterra.com/how-can-plants-improve-air-quality/>

7. Selection of Indoor Plant for Pythoremediation:

Many researchers have proved the efficiency of indoor plants for purifying indoor air as well as managing psychological and physical benefits and reducing the symptoms of ill effects (Seung-Han Hong et al., 2017). Many researchers have also done experimentation on different indoor plants. Tatiana Armijos Moya et al (2017) reported that *Nephrolepis exaltata* (Boston fern) was able to remove VOCs from the air among the species. There are many species which are effective in cleaning the air as shown in Table iii. However this project aims to serve with self-sustaining, cost effective and native plant species *Sansevieria laurentii* (Mother-in-law tongue) stands at top . *Sansevieria trifasciata* belongs to the family Asparagaceae, native to tropical West Africa from Nigeria east to the Congo commonly known as the snake plant, mother-in-law's tongue, and other names (Hayk S et al., 2015). There are many health benefits associated with this indoor plant as discussed above. The most captivating part of snake plant is it converts CO₂ into oxygen at night while other indoor plants release oxygen during photosynthetic activity ([Snake Plant: Everything You Need To Know – RollingNature](#)) (Pachauri et al., 2017). Research conducted by NASA reported that ***Sansevieria laurentii* (Mother-in-law tongue)** is able to purify air which leads to SBS which again makes this the best indoor plant (Janah et al., 2020). Table iii represents the plants which can combat some of the pollutants.

Following are the brief discussions on **Sansevieria laurentii (Mother-in-law tongue)**.

- Snake plant releases moisture into the air and gets rid of airborne allergens. Thus lessening the symptoms involved with SBS (Pachauri et al., 2017).
- Snake plant helps in absorbing carbondioxide, carbon monoxide, xylene, toluene and also removes formaldehyde. Exposure to such chemical compounds have great ill effects on human health and suffers developmental problems as well as reproductive problems in female (Hayk S et al., 2015).
- Snake plant also helps in eliminating bad odour besides absorbing indoor pollutants (Pachauri et al., 017).
- Snake plant is a versatile plant because it can withstand any condition (Pachauri et al., 2017).
- Snake plant is one of the most recommended plants for improving air quality as it releases more oxygen at night making an ideal indoor plant in the bedroom (Pachauri et al., 2017).
- Snake plant is also self-sustaining indoor plant as it doesn't require constant watering(Pachauri et al., 2017)

8. Standard Units as Per WHO and ISHRAE (Recommended by GRIHA)Table 4

Permissible exposure limits.

WHO; World Health Organisation

ISHRAE; Indian Society of Heating Refrigerating and Air Conditioning Engineers

GRIHA; Green Rating for Integrated Habitat Assessment

Table iv Types of parameters and their permissible limits

Parameters	Units	PERMISIIBLE LIMITS		
		WHO	ISHRAE	DEVICE MANUAL
CO	PPM	50	<9	0-50(excellent), 51-100(good) ,801-2400(serious)
CO ₂	PPM		0-450	0-450(excellent), 451-1000(good),3001-5000(serious)
HCHO	mg/m ³	0.1		0-0.08(excellent), 0.081-0.1(good),1.001-999(serious)
TVOC	mg/m ³	0.3-0.5		0-0.5(excellent), 0.5-0.6(good), 6.0-12(serious)

Air Pollution Measurement: Selected sources were used to emit the pollutions. Three different types of phytoremediation methods were tested for each pollutant sources in the room to check on their capacity to filter the pollutants.

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Table v Types of pollutants and their sources of formation.

Chemical compounds	Emissions
Total Volatile Organic compound (TVOC)	1. Paint (Özdamar, M et al., 2018) 2. varnish (Özdamar, M et al., 2018)
Formaldehyde (HCHO)	1. Adhesive (https://www.molhr.gov.bt/molhr/wp-content/uploads/2020/07/Fevicol-Type-Adhesive.pdf) 2. Kerosene (N. L et al., 2012)
(carbon dioxide) CO ₂	1. Coconut husk (Simanjuntak, W et al., 2014) 2. Egg crate (Zabaniotou, A & Kassidi, E.(2003).
(carbon monoxide) CO	1. Cigarettes (Sarafis et al., 2010). 2. Wood shavings (Özdamar, M et al., 2018)

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9. **Methodology:** In this experiment total of 6 days were required in order to perform the experiment for each pollutant. 5 shoots of snake plants were planted in each pot. Following are the procedures that had been followed throughout:
- Potted plants were placed increasingly on each day starting from 1 pot till 6 pots.
 - For TVOC and HCHO sources were spread on a chart paper and wood.
 - For CO₂ and CO sources were burned on metal base.
 - For all the chemical parameters the sources taken had been emitted beyond the permissible limits.
 - Observation time was taken in hours except for the cigarettes.
 - For cigarettes 15 minute was considered because the nature of smoke is thin.
 - 1st Observation was recorded after 2 hours of diffusion. This was followed by two consequent observations at two hour intervals each).
 - Experimentations were also conducted in absence of plants.
 - The test observation performed in the presence and absence of plants was done to compare the outcomes / the reduction of the pollutants concentration.

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The outcomes of the experimentation are summarized in the tables below.

It is observed from the tables below that the maximum number of 6 pots were most effective in removing the emitted sources for all the chemical compounds. While lesser number of pots showed a lower reduction.

Table vi:Reduction of TVOC concentration (with plants)

Using paint						
Days	No. of potted snake plants		Time	12:30pm	2:30pm	4:30pm
			10:30am (Initiated TVOC in (mg/m ³))	Reduced TVOC in 2 hrs. of intervals (mg/m ³)		
Monday			11	10	10	9.8
Tuesday			12	10	9.1	9.0
Wednesday			11	9.9	9.1	8.1
Thursday			12	8.2	7.9	6.4
Friday			12	8.1	7.5	6.2
Saturday			12	7.1	7.3	6.0
REDUCTION % of 6 pots of plants	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	10%	25%	26	46	48	50%

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Table vii. Reduction of TVOC concentration (without plants)

Using paint				
Days	Time 10:30am (Initiated TVOC in ppm)	12:30pm	2:30pm	4:30
		Reduced TVOC in 2 hrs. of intervals (ppm)		
Any Day	12	11.7	11.5	11
REDUCTION % of NP	10%			

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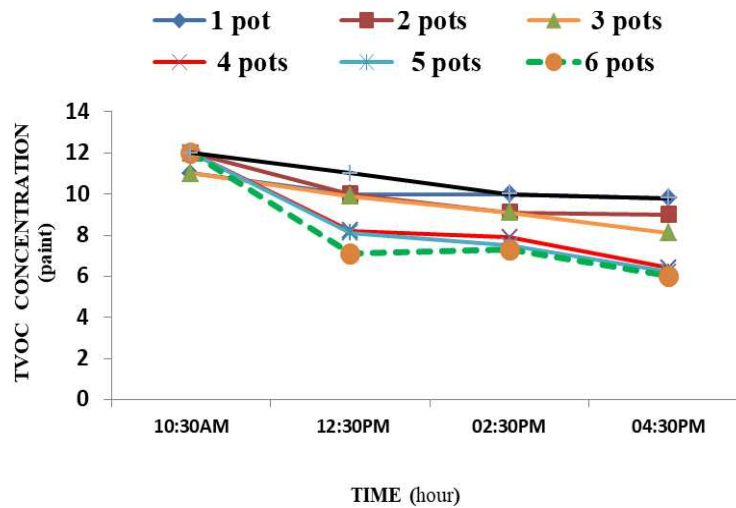


Fig 3:TVOC (paint) removed by potted plants.

From the Figure 3 it is observed that the no. of six potted plants give the highest reduction capacity in TVOC concentration using paint. The graph showing the highest curve indicates the removal of TVOC emission using *Sansevieria laurentii* (Mother-in-law tongue). The percentage reduction of TVOC (paint) is 50% in presence of plants and 18% in absence of plant.

Linear Regression Analysis in Python

Linear Regression Analysis was performed where Y = Reduction and X = No of plants and the following equation was derived

$$Y = 7.75 * X + 7.46$$

Source Code for Python is as follows:

```
%matplotlib inline
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
plt.rcParams['figure.figsize']=(20.0,10.0)

#Reading Data
data = pd.read_csv('Cherike8.csv')
print(data.shape)
data.head()

# Collecting x and y
X = data['No'].values
Y = data['Reduction'].values

# Mean X and Y
mean_x = np.mean(X)
mean_y = np.mean(Y)

# Total number of values
m = len(X)
```

```

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350 # Using the formula to calculate b1 and b2
351
352 numer = 0
353 denom = 0
354 for i in range(m):
355     numer += (X[i] - mean_x)*(Y[i] - mean_y)
356     denom += (X[i] - mean_x)**2
357 b1 = numer/denom
358 b0 = mean_y - (b1*mean_x)
359
360 # Print coefficients
361 print(b1,b0)
362 # Plotting values and Regression line
363
364 max_x = np.max(X) + 100
365 min_x = np.min(X) - 100
366
367 # Calculating line values x and y
368 x = np.linspace(min_x,max_x,1000)
369 y = b0 + b1*x
370
371 # Plotting line
372 plt.plot(x, y, color='#58b970',label = 'Regression Line')
373
374 #Plotting scatter points
375 plt.scatter(X,Y, c='#ef5423', label='Scatter Plot')
376
377 plt.xlabel('No')
378 plt.ylabel('Reduction')
379 plt.legend()
380 plt.show()
381 ss_t = 0
382 ss_r = 0
383 for i in range(m):
384     y_pred = b0 + b1*X[i]
385     ss_t += (Y[i] - mean_y)**2
386     ss_r += (Y[i] - y_pred)**2
387 r2 = 1 - (ss_r/ss_t)
388 print(r2)
389 from sklearn.linear_model import LinearRegression
390 from sklearn.metrics import mean_squared_error
391
392 # Cannot use Rank 1 matrix in scikit learn
393
394 X = X.reshape((m,1))
395 # Creating model
396 reg = LinearRegression()
397 # Fitting training data
398 reg = reg.fit(X,Y)
399 # Y Prediction
400 Y_pred = reg.predict(X)
401 #Calculating RMSE and R2 score
402 mse = mean_squared_error(Y, Y_pred)
403 rmse = np.sqrt(mse)

```

```
r2_score = reg.score(X,Y)
```

```
print(np.sqrt(mse))
```

```
print(r2_score)
```

Table viii: Reduction of TVOC concentrations (with plants)

Using varnish						
Days	No. of potted snake plant		Time 10:30 am (Initiated TVOCin mg/m ³)	12:30 pm	2:30 pm	4:30 pm
				Reduced VOC in 2 hrs. of intervals (mg/m ³)		
Monday			12	10	10	9
Tuesday			12	10	9	9
Wednesday			11	8.0	7.5	7.2
Thursday			12	5.3	4.9	4.6
Friday			12	5.2	4.1	4.2
Saturday			12	5.1	3.9	3.0
REDUCTION % of 6 pots of plants	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	10%	25%	26%	39%	40%	75%

Table ix:Reduction of TVOC concentrations (without plants)

Using varnish				
Day	Time 10 :30am (InitiatedTVOC inppm)	12:30p m	2:30 pm	4:30p m
		Reduced TVOC in 2 hrs. of intervals (ppm)		
Any day	12	11	9.6	9.8
REDUCTION % of NP	10%			

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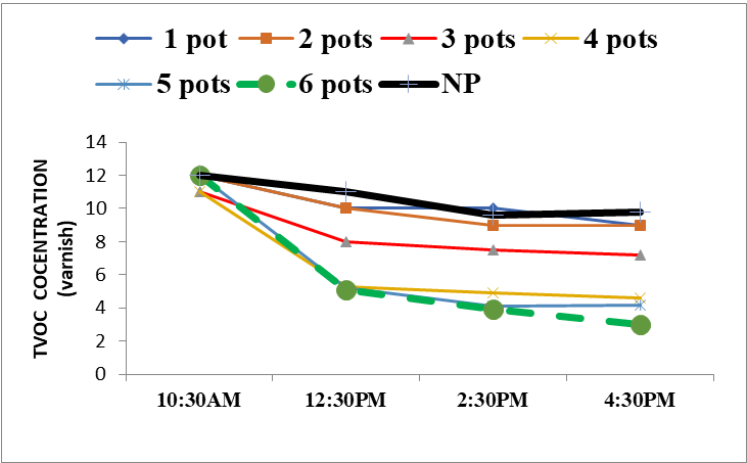


Fig 4:TVOC (varnish) removed by potted plants.

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From the Figure 4 it is observed that the no. of six potted plants give the highest reduction capacity in TVOC concentration using varnish. The graph showing the highest curve indicates the removal of TVOC emission using *Sansevieria laurentii* (Mother-in-law tongue). Thepercentage reduction of TVOC (varnish) is 75% in presence of plants and 10% in absence of plant.

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Linear Regression Analysis in Python

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Linear Regression Analysis was performed where Y = Reduction and X = No of plants and the following equation was derived

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$Y = 9.6 * X + 3.32$

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Table x: Reduction of HCHO concentrations (with plants)

Using kerosene					
Days		Time 10:30a m (Initiated HCHO in mg/m ³)	12:30p m	2:30p m	4:30pm
			Reduced HCHO in 2 hrs. of intervals (mg/m ³)		
Monday		0.590	0.544	0.541	0.539
Tuesday		0.614	0.581	0.579	0.56
Wednesday		0.618	0.582	0.544	0.522

Thursday			0.610	0.440	0.365	0.333
Friday			0.598	0.320	0.299	0.279
Saturday			0.612	0.266	0.243	0.224
REDUCTION % of 6 pots of plants	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	8%	8%	14%	45%	53%	63%

Table xi. Reduction of HCHO concentrations (without plants)

Using kerosene				
Day	Time 10 :30am (Initiate dHCHO in ppm)	12:30p m	2:30 pm	4:30p m
		Reduced HCHO in 2 hrs. of intervals (ppm)		
Any day	0.611	0.599	0.588	0.575
REDUCTION % of NP	6%			

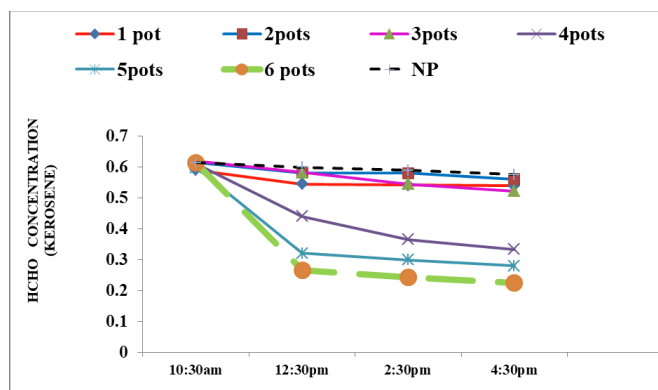


Fig 5:HCHO (kerosene) removed by potted plants.

From the Figure 5 it is observed that the no. of six potted plants give the highest reduction capacity in HCHO concentration using kerosene. The graph showing the highest curve indicates the removal of HCHO emission using *Sansevieria laurentii* (Mother-in-law tongue).The percentage reduction of HCHO (kerosene) is 63% in presence of plants and 6% in absence of plant.

Linear Regression Analysis was performed where Y = Reduction and X = No of plants and the following equation was derived

$$Y = 10.64 * X - 3.7$$

Table xii. Reduction of HCHO concentrations (withplants)

Using adhesive						
Days	No. of potted snake plants		Time 10:30a m (Initiated HCHO in mg/m ³)	12:30pm	2:30pm	4:30pm
				Reduced HCHO in 2 hrs. of intervals (mg/m ³)		
Monday			0.611	0.589	0.583	0.578
Tuesday			0.613	0.564	0.551	0.546
Wednesday			0.618	0.561	0.552	0.532
Thursday			0.61	0.452	0.396	0.434
Friday			0.598	0.33	0.326	0.314
Saturday			0.612	0.289	0.272	0.262
REDUCTION % of 6pots of plants	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	5%	10%	13%	28%	47%	57%

Table xiii. Reduction of HCHO concentrations (without plants)

Using adhesive				
Day	Time 10 :30am inmg/m³) (Initiated HCHO	12:30pm	2:30 pm	4:30pm
		Reduced HCHO in 2 hrs. of intervals		
Any day	0.61 0	0.591	0.587	0.581
REDUCTION % ofNP	4%			

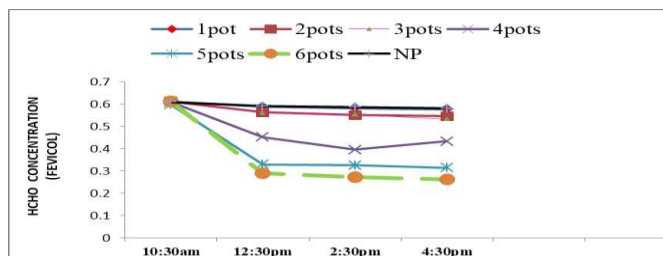


Fig 6:HCHO (adhesive) removed by potted plants.

From the Figure 6 it is observed that the no. of six potted plants give the highest reduction capacity in HCHO concentration using adhesive. The graph showing the highest curve indicates the removal of HCHO emission using *Sansevieria laurentii* (Mother-in-law tongue). The percentage reduction of HCHO (adhesive) is 57% in presence of plants and 4% in absence of plant.

Linear Regression Analysis in Python

Linear Regression Analysis was performed where Y = Reduction and X = No of plants and the following equation was derived

$$Y = 9.32 * X - 4.53$$

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Table xiv. Reduction of CO₂ concentrations (with plants)

Using coconut husk						
Days	No. of potted snake plants	Time		12:30p m	2:30p m	4:30pm
		10:30a m		Reduced CO ₂ in 2 hrs. of intervals (mg/m ³)		
		(Initiated CO ₂ in mg/m ³)				
Monday		2888		2886	2809	2788
Tuesday		2776		2737	2750	2678
Wednesday		2799		2666	2590	2586
Thursday		2800		2547	2542	2521
Friday		2792		2512	2432	2345
Saturday		2790		2412	2399	2277
REDUCTION % of 6 pots of plants	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	3%	3%	7%	9%	16%	18%

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Table xv. Reduction of CO₂ concentrations (without plants)

Using coconut husk				
Day	Time 10 :30am	12:30p m	2:30 pm	4:30pm
	(Initiated CO ₂ in ppm)	Reduced CO ₂ in 2 hrs. of intervals (ppm)		
Any day	2884	2881	2887	2779
REDUCTION % of NP	3%			

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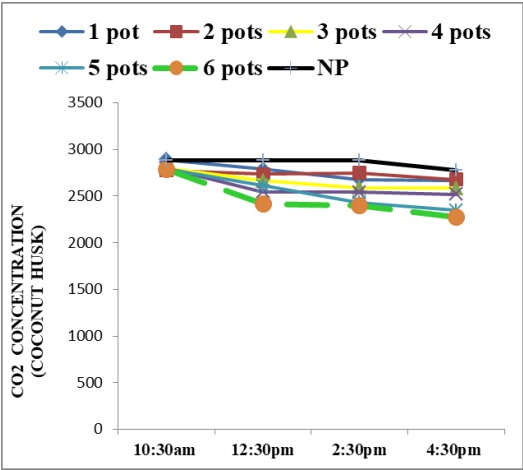


Fig 7:CO₂(Using coconut husk) removed by potted plants.

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From the figure 7 it is observed that the no. of six potted plants give the highest reduction capacity in CO₂concentration using coconut husk. The graph showing the highest curve indicates the removal of CO₂emission using *Sansevieria laurentii* (Mother-in-law tongue). Thepercentage reduction of CO₂(using coconut husk) is 18% in presence of plants and 3% in absence of plant.

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Linear Regression Analysis in Python

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Linear Regression Analysis was performed where Y = Reduction and X = No of plants and the following equation was derived

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$$Y = 2.75 * X + 0.17$$

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Table xvi : Reduction of CO₂concentrations (with plants)

Using egg crate						
Days	No. of potted snake plant		Time 10:30 am (Initiated CO ₂ in ppm)	12:30pm	2:30pm	4:30pm
				Reduced CO ₂ in 2 hrs. of intervals (PPM)		
Monday			2884	2879	2865	2859
Tuesday			2776	2770	2698	2689
Wednesday			2774	2753	2732	2600
Thursday			2800	2653	2553	2457
Friday			2799	2452	2400	2339
Saturday			2794	2331	2298	2278
REDUCTION % of 6 pots of plants	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1%	3%	6%	12%	16%	18%

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Table xvii. Reduction of CO₂concentrations (without plants)

Using egg crate				
Day	Time 10 :30am (Initiated CO ₂ in ppm)	12:30pm	2:30 pm	4:30pm
		Reduced CO ₂ in 2 hrs. of intervals (ppm)		
Any Day	2899	2885	2881	2870
REDUCTION % of NP	1%			

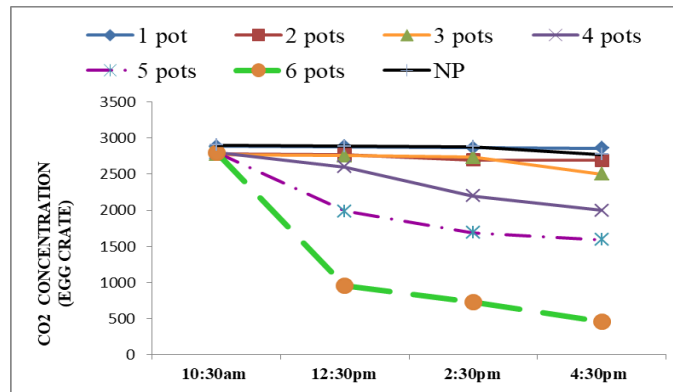


Fig 8: CO₂ (Egg crate) removed by potted plants

From the figure 8 it is observed that the no. of six potted plants give the highest reduction capacity in CO₂ concentration using Egg crate. The graph showing the highest curve indicates the removal of CO₂ emission using *Sansevieria laurentii* (Mother-in-law tongue). The percentage reduction of CO₂ (Egg crate) is 18% in presence of plants and 4% in absence of plant

Linear Regression Analysis in Python

Linear Regression Analysis was performed where Y = Reduction and X = No of plants and the following equation was derived

$$Y = 3.21 * X - 1.5$$

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Table xviii: Reduction of CO concentrations (with plants)

Using Cigarretes						
Days	No. of potted snake plant		Time 10:30a m (Initiated CO in ppm)	10:45 am	11:00 am	11:15a m
				Reduced CO in 2 hrs. of intervals (ppm)		
Monday			678	671	669	664
Tuesday			673	598	545	519
Wednesday			675	476	450	430
Thursday			673	392	388	375
Friday			674	364	291	284
Saturday			671	201	192	150
REDUCTION % of 6 pots of plants	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	2%	22%	36%	44%	58%	77%

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Table xix: Reduction of CO concentrations (without plants)

Using Cigarettes				
Day	Time	10:45 am	11:00 am	11:15am
		Reduced CO in 2 hrs. of intervals (ppm)		
	10 :30am			
	(Initiated			
	CO			
	in ppm)			
Any Day	669	674	669	661
REDUCTION % of NP	1.2 %			

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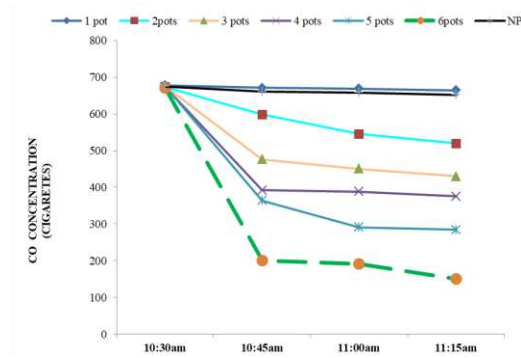


Fig 9:CO (Cigarettes) removed by potted plants

From the Figure 9 it is observed that the no. of six potted plants give the highest reduction capacity in CO concentration using cigarettes. The graph showing the highest curve indicates the removal of CO emission using *Sansevieria laurentii* (Mother-in-law tongue). The percentage reduction of CO (cigarettes) is 77% in presence of plants and 3% in absence of plant

Linear Regression Analysis in Python

Linear Regression Analysis was performed where Y = Reduction and X = No of plants and the following equation was derived

$$Y = 12.9 * X - 4.4$$

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Table xx: Reduction of CO concentrations (with plants)

Using wood shavings						
Days	No. of potted snake plant	Time 10 :30am (Initiate dCO in ppm)	12:30 pm		2:30 pm	4:30 pm
			Reduced CO in 2 hrs. of intervals (ppm)			
Monday		661	656	641		640
Tuesday		659	650	634		623
Wednesday		660	594	584		541
Thursday		657	558	535		519
Friday		658	546	501		512
Saturday		657	498	486		476
REDUCTI O N % of 6 potsof plants	Monda y	Tuesday	Wedne s day	Thursd ay	Friday	Saturday
	3%	5%	18%	21%	22%	27%

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Table xxi: Reduction of CO concentrations (without plants)

Using wood shaving				
Day	Time 10 :30am (Initiated TVOC in ppm)	12:30pm	2:30 pm	4:30pm
		Reduced CO in 2 hrs. of intervals (ppm)		
Any Day	675	664	659	653
REDUCTION % of NP		3%		

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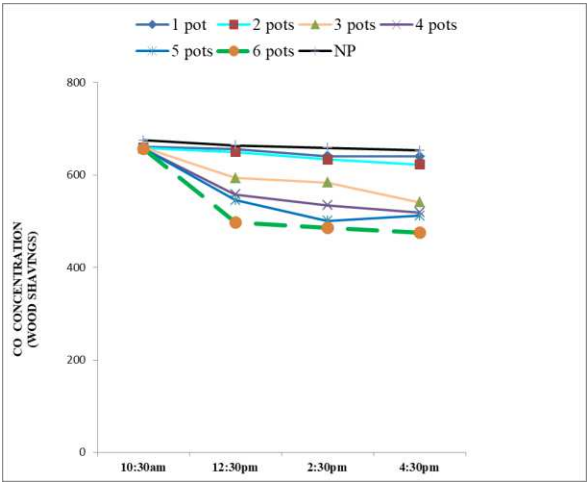


Fig 10:CO(wood shavings) removed by potted plants

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From the figure 10 it is observed that the no. of six potted plants give the highest reduction capacity in CO concentration using wood shavings. The graph showing the highest curve indicates the removal of CO emission using *Sansevieria laurentii* (Mother-in-law tongue). The percentage reduction of CO (wood shavings) is 27% in presence of plants and 3% in absence of plant.

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Linear Regression Analysis in Python

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Linear Regression Analysis was performed where Y = Reduction and X = No of plants and the following equation was derived

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$$Y = 4.5 * X + 0.64$$

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10. Conclusion:

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The highest no. of potted plants has been maintained as six throughout the potted plants experiment. It is observed that the potted plants and passive green wall does not produce much reduction comparing to Active green wall. The reduction of TVOC concentration using paint in presence of snake plant is 50% while in absence of plant is 10%. Another reduction of concentration using varnish in the presence of snake plant is 75% while in absence of plant is 10%. The reduction percentage of HCHO concentration using kerosene in presence of plant is 63% while in the absence of plant is 6%. Another reduction percentage using adhesive is 57% while in the absence of plant is 4%. CO₂ reduction of concentration using coconut husk in presence of plants is 18% while in absence of plant is 3%. Another reduction of concentration using egg crate is 18% in presence of plant while in absence of plant is 1%. The reduction of CO concentration using cigarettes is 77% in presence of plants while in the absence of plants is 1.2%. Another reduction using wood shaving is 27% in presence of plants while in absence of plants is 3%.

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710 **12. Statements & Declarations**

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713 **Consent to Participate and Consent to Publish**

714 We certify that we have participated sufficiently in the intellectual content, conception, design, analysis and interpretation
715 of the data in this article, as well as the writing of the manuscript, to take public responsibility for it and have agreed to
716 have my (or our) name(s) listed as the author(s). I (or we) believe that the manuscript represents valid work. Neither this
717 manuscript nor one with substantially similar content under my (or our) authorship has been published or is being
718 considered for publication elsewhere, except as described in the covering letter. Furthermore, all ethical guidelines have
719 been followed in the conduct and reporting of this research, and I (or we) have obtained necessary permissions and
720 approvals from the appropriate authorities.

721 **Competing Interests**

722 The authors have no relevant financial or non-financial interests to disclose.

723 **Author Contributions**

724 All authors contributed to the study conception and design. Material preparation, data collection and analysis were
725 performed by Cherike Marak, Pori Das and Gitartha Kalita. The first draft of the manuscript was written by Gitartha
726 Kalita and all authors commented on previous versions of the manuscript. All authors read and approved the final
727 manuscript.

728 **Data Availability**

729 The datasets generated during and/or analysed during the current study are available in the manuscript.

730 **Ethics approval**

731 This study did not require ethics approval

732 The research did not involve human subjects