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Study of the Influence of Indoor Plants as an Indicator of Biophilic Design on CO_2 Concentrations in a Classroom of Higher Education Institute

Ar. Anita K. Kavathekar*

Sinhgad College of Architecture, Pune - 411038 SP Pune University Maharashtra, India

Dr. Shaila Bantanur

BMS School of Architecture, Bangalore 560064, Visvesvaraya Technological University, Karnataka 590018, India

*Corresponding author: **kavathekar.anita@gmail.com**

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Abstract

Urbanization in Indian metropolitan cities deteriorating the outdoor environment by polluting water, soil, and air to a great extent. Some of the cities are at a fatal level of contamination affecting indoor environments. Many studies had reported the impact of a high level of CO_2 indoors on the occupants. Its effect depends upon the concentration of CO_2, the duration of exposure, and the concentration of oxygen (O_2). Still the effects range from increased respiratory rates to cardiac ailments and carcinoses. India is a developing country so the sustainable and affordable approaches will be more applicable in this context. This study tries to find a well-grounded way to improve indoor air quality. The current pilot study focuses on examining the effect of indoor plants on indoor air quality by measuring CO_2 levels. This study has used three different species of plants for three different classrooms of higher education institutes. The study was performed in an unsealed environment where air velocity and CO_2 were measured. Statistical analysis results show that indoor CO_2 concentration has been reduced by 11% than outdoors after placing the plants. This study also shows the correlation between CO_2 concentration and the distance from the plant using the Pearson correlation coefficient. Hence indoor vegetation can be considered a sustainable way of purifying the air and altering the microclimate of the classrooms for the well-being of the occupants.

Keywords: biophilic design, classroom, CO_2 concentration, indoor air quality, indoor plants.

Introduction

Globalization had a great impact on the entire world. It had increased urbanization to a great extent. Now it is projected that by 2050, 70 % of the population will live in the cities (Browning et al., 2014). For India, it is the most significant phenomenon of the 20th century that has affected all aspects of national life (Jaysawal & Saha, 2014). This urbanization is limiting access to open green spaces and people cannot explore the outdoors. The design of our physical surroundings, including landscapes and buildings, can have a meaningful impact on psychological states and wellbeing (Coburn et al., 2019). People spend almost 90% of their time indoors whether it is a residence or a workspace. Urban development is getting congested affecting ventilation around and across the buildings with reduced ventilation rates. Thus, urban areas are often associated with

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poor air quality. In India, pollution emerges from households and ambient air, thereby majority of the population is exposed to indoor and outdoor pollution (Bhargava et al., 2021). In the year 2017, the number of deaths due to air pollution (both indoor and outdoor) in India were about 1.2 million (Health Effects Institute 2019). A growing body of scientific study indicates that humans need daily contact with nature to be productive and healthy (Downton et al., 2017). So, bringing natural elements indoors (biophilic design) has received increased attention recently due to its potential health benefits, human fitness, and quality of life (Yin, 2019; Calabrese, 2015). Thus, indoor environmental quality and its comfort have an important role to play for the occupants in terms of their physical as well as psychological health. It was observed that the studies based on indoor plants and indoor environmental quality were from places like the Netherlands, Taiwan, United Arab Emirates (UAE), etc. (Mangone et al., 2014; Han, 2020; Jung & Awad, 2021), with significantly different climatic contexts than India. These studies were conducted in a sealed environment where doors and windows were closed and air conditioning was on mode. These sealed environments were representative of the conditions that would be normal for hot or cold regions.

The higher education sector in India is expanding at a great rate with 45000-degree colleges and diploma institutes having an enrollment of 25.9 million students (Higher Education Summit, & Ernst & Young, 2012). With this number, the design and comfort of the indoor environment of the classroom become very crucial. However, the classrooms in India rely majority on the natural light and ventilation. The studies about indoor plants and indoor environmental quality were hardly found in the Indian context. Hence understanding the impact of plants on the indoor environment in the natural condition where doors and windows were kept open and conducting the study, became important or relevant to the context. This research aims to evaluate the sphere of influence of indoor plants on indoor air quality for carbon dioxide (CO_2) concentration in a classroom. The objectives of the study were to develop a method of data collection and its validation through the experimental setup for documenting parameters of the indoor environment like CO_2 concentration and to explore the relationship between measured data of parameters and the position of plants. The hypotheses of this study were as follows:

Hypothesis 1: Plants at different distances and with the same green coverage ratio have different effects on the objective physical environment in terms of air quality such as CO_2 concentration, there is a correlation between CO_2 concentration and distance away from the plant.

Hypothesis 2: Plants have affected indoor air quality by reducing indoor CO_2 concentrations than outdoor CO_2 concentrations in the classroom.

Hypothesis 3: All plant species used in the experiment has different ability to absorb the CO_2 concentration.

Literature Review

Biophilic design

Biophilia means the innate affection towards nature and natural elements. Innate means hereditary and hence part of ultimate human nature (Kellert, 2018). The term was coined by E.O. Wilson and further developed by researchers like S. Kellert, and Browning. These researchers have come up with different dimensions, and patterns of biophilic design. The 14 patterns identified by Browning et al. (2014) prioritize the most significant nature-health relationships in the built environment, which are supported by the WELL Building Standard rating system. The International WELL Building Institute is a public benefit corporation whose mission is to improve human health and wellbeing in buildings and communities across the world. Recent studies examining students' exposure to nature found the amount of vegetation and surroundings of campus significantly predicted school-wide student performance (i.e., standardized test scores, graduate rates) (Pan et al., 2014). During their time in classrooms, students are required to focus, absorb information, and actively reflect on this information. These tasks, call upon students' directed attention, and resources, which are susceptible to fatigue (van den Bogerd et al., 2020). One study proposes that the inclusion of biophilic elements such as plants, natural landscapes, light, and water in learning spaces, such as classrooms, supports the learning ability and can also generate a sustainable, inspiring, and innovative learning environment (Abdelaal, 2019). Many studies with different objectives were carried out and found that reduction in health complaints of students by 21% (Fjeld, 2000), stress reduction among the students (Li & Sullivan, 2016), reduction in blood pressure (Yin, 2019) when biophilic design attributes used in the classrooms. One study mentions that biophilic design requires repeated and sustained engagement with nature for its continuous benefits (Downton et al., 2017). It was found that there is an improvement in cognitive functions, creativity, short-term memory, and the attention capacity of occupants after introducing plants into the built environment (Kavathekar & Bantanur, 2021). Hence, plants were used indoors as one of the indicators of biophilic design for this study.

Benefits of indoor plants

From an evolutionary history aspect, plants were of crucial importance for survival. Humans were dependent on plants as a food resource, for shelter, and as an indicator of water. So, on the theoretical ground presence of plants was an integral part of the Human Environment of Evolutionary Adaptation (Grinde & Patil, 2009). Kellert argues that visual representations of nature, symbols of nature, nature views, indoor plants, and other natural objects and design elements appeal to this innate affinity and so can evoke positive experiences in the built environment. Plants are the most common element of nature and are also often regarded as the most representative of nature. Even within a manmade structure, it is true. (Hartig et al., 2008). Plants used for indoor environments have pleasing aesthetic features, and their associated microbiome has been greatly disregarded (Brilli et al., 2018). Plants used in workspaces show that the introduction of living plants in individual worktops & break- out has significantly changed perceived health & several performance metrics (attention, creativity, productivity) (Hähn et al., 2020). When potted plants were used in learning environments such as classrooms, it was reported that students had greater attention, more positive lecture evaluation (van den Bogerd et al., 2020), and good conduct as fewer punishments for misbehavior (Han, 2009) (Bringslimark et al., 2009).

Indoor plants are used for psychological as well as physiological well-being for their ability to clean air. During photosynthesis, plants take in more CO_2 through their stomata, they also absorb contaminants. A diverse range of indoor air pollutants can be Phyto-remediated with the help of potted plants. Absorption of CO_2 releasing of O_2 is also dependent on the amount of natural or artificial light, the leaf area of the plant (Park et al., 2010). Temperature influences the VOC emission from building materials along with air velocity and humidity. Similarly, relative humidity affects the emission of formaldehyde in particleboard. Hence plants not only clean air by the process of photosynthesis and phytoremediation but also can control temperature and relative humidity which can control the airborne pollutants (Aini Jasmin et al., 2012a). Some studies showed that after placing the plants indoors CO_2 levels were increased and got stabilized (Jung & Awad, 2021; H. Kim et al., 2016; Smith & Pitt, 2011) whereas few studies noted a continuous decreasing trend (Bhargava et al., 2021; Pamonpol et al., 2020; Pegas et al., 2012). Plants help achieve thermal comfort and it was observed that the effect of plants on thermal comfort was not reduced overtime or by season (Mangone et al., 2014). It was noticed that continuous reduction in Sick Building Syndrome (H. H. Kim et al., 2013) and ocular discomfort symptoms (H. Kim et al., 2016) with plant interventions. However, it was seen in the review paper (Han & Ruan, 2020) that, only 18.75% were field experiments conducted in living environments, whereas 76.04% were conducted using laboratory experiments, of which 66.34% were performed in small fumigation chambers. Therefore, whether the results of these studies can be directly generalized or applied to actual life situations is yet to be determined. For instance, pollutant concentrations and volatilization rates in fumigation chambers are typically higher than those in actual environments. However, such studies were hardly found in the unsealed environment in the Indian context. The study also states that the capacity of the indoor plants in removing air pollutants needs to be quantitatively assessed in realistic scenarios (Brilli et al., 2018). Hence the study is conducted in the actual classroom with live settings.

Indoor Air Quality (IAQ)

Indoor environmental comfort was categorized into visual, thermal, acoustical comfort, and air quality (Mujan et al., 2019). Whilst poor air quality remains a global issue (World Health Organization 2014). Indoor air pollution has become a major concern in India in recent past years. Numerous epidemiological studies have demonstrated associations between pollutants in outdoor air (primarily PM10, PM2.5, and ozone) and both morbidity (illness) and Mortality (death) (Sundell et al., 2011). Air composed of 21% O_2 and 0.033% CO_2 taken in by people from the normal atmosphere becomes 16-17% O_2 and 4% CO_2 content during discharge from the lungs. This change leads to a rapid rise in CO_2 content in environments like schools, shopping malls, and hospitals, where people tend to congregate. CO_2 concentration is currently adopted as a key parameter for ventilation and IAQ evaluation. Almeida (Almeida et al., 2017) explains through literature, how CO_2 is an important parameter while studying IAQ. CO_2 is the most used indicator of ventilation efficiency since it is a product of respiration and school and college buildings typically maintain high levels of occupancy during large periods of the day. CO_2 has been reported to cause breathing problems, inattentiveness, and headaches (Almeida et al., 2017). Although it does not harm the human body by itself, an increase in its concentration often indicates a deterioration in thermal conditions or an increase in other pollutants. Increased CO_2 levels were found to reduce short-term students' attention performance in experimental studies with 20 cluster-randomized classrooms in Germany and 51 primary schools in Portugal (Pulimeno et al., 2020). One study in Scotland has observed that an increase in CO_2 concentration of 100 ppm was associated with 0.4 days of missed school per child per year. The same study mentioned that despite of differences in climate and method of classroom ventilation, there was consistency in results for increased indoor CO_2 concentration in school was an important public health issue (Gaihre et al., 2014). How to sustain good IAQ with low energy consumption is an important aspect of designing the built environment (Pamonpol et al., 2020). Considering the exponential growth of higher education institutes in India, this study aimed to analyse the effect of indoor plants on improving the IAQ while focusing on CO_2 in the classroom.

Methods and Materials

To find out the effect of indoor plants on indoor air quality in terms of CO_2 concentration the field experiment was carried out in a classroom of an educational institute. A pilot study started in November 2021 and it still going on as a long-term research project for the author.

Experiment methodology design assumptions and limitations

The selection of instruments was based on literature study, accuracy limits, Indian Society of Heating, Refrigerating, and Air Conditioning Engineers (ISHARE) standards, and economical constraints. The study presented in the paper was a pilot study so the experiment was focused on the CO_2 concentration of three classrooms with three types of species. It was assumed that the quality of air due to the plant effect will be changing as pollutants in actual space in natural ventilation mode do not maintain constant concentration. Similarly, the study has considered the plants, potting soil, and container as a whole unit. So, the influence of plants, potting soil, and the container was not seen differently.

Pilot case experiment building description

The chosen institutional building is established in the mid-nineties and is situated in the core city. The building was abutting a busy road. Building construction material was an RCC structure with 0.23 m partition walls of burnt bricks, flooring of mosaic tiles, door and windows were of teak wood with paint finish. Surface finishes were cement plaster, and walls and ceiling were painted with distemper paints one decade back. The classroom has furniture like student tables (Mild steel), stools (wood (varnished) and Mild steel (oil painted)), teacher tables (wood and laminated ply), and soft boards with jute-based fabric covering. Tabletops for students were of pinewood and three years old, storage cabinets were kept of oil painted mild steel.

Environmental parameter measurement methodology

The selected classrooms were of the same area and volume. The area of the classrooms was a 76 sq.m. area. The rooms were divided into a ten-point grid to form approximately equal ten parts of the room. Now, the centre of each part is a measuring point for data collection. Air velocity and CO_2 concentration were measured at all these points with the instruments mentioned in Table 1. This study was conducted in the winter season (November and December). The outdoor temperature was 23-24 °C, so the indoor temperature was within comfort conditions as per mentioned by the (ISHARE). Few research studies mentioned data collection point one, readings were taken at the centre (Shree et al., 2019a; Shree et al., 2019b; Jung & Awad, 2021) or only two points depending upon occupancy and plant position (Kim et al., 2013; Han, 2019; 2020) but the current study had collected data uniformly throughout the classroom. Similarly, the study by Bhargava et al. (2021) mentioned the readings taken by moving the instrument around the room (Bhargava et al., 2021). Whereas the current study mentioned systematic arrangements of data collection points. The literature study documented the frequency of reading thrice a week (Kim et al., 2013) with nine readings, and the second was with continuous reading with data loggers, the frequency was every 6 min., 30 data points were recorded (Han, 2019). For this study frequency of reading was one per week and a total of six readings were measured. As this was a pilot project, methods tested in this experiment will be applied to a greater extent in the form of a long-term project. During the data collection, all the windows and doors were

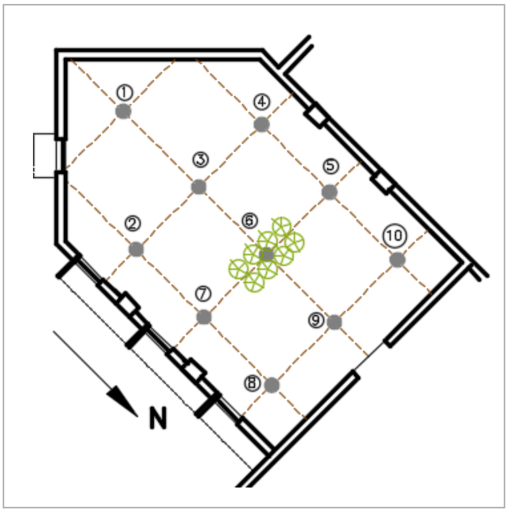


Fig. 1

Sketch and image of the classroom showing plants at the center

Table 1

List of instruments used for experiments for different parameters

Sr. No.	Environmental parameter	Instrument	Specification	Cronbach alpha (Reliability test of the instruments)
1	Carbon dioxide	Lutron CO_2 meter GCH - 2018	Range - 0 - 4000 ppm Resolution - 1ppm Accuracy - ± 40 ppm ≤ 1000 ppm	0.999
2	Air velocity	Hotwire anemometer Lutron - AM-4204	Measurement: m/s Range - 0.2 - 20.0m/s Resolution - 0.1 m/s Accuracy - ± 5% +1d	0.972

open whereas artificial lights and fans were switched off. For the study duration growth of the plants was not considered as these plants were slow-growing plants. For the long duration study, the growth of the plant would be considered as one of the parameters. Readings were taken in the non-occupancy mode because of pandemic conditions (lockdown due to COVID-19 restriction). An equal number of plants were kept in three classrooms referring to Table 2.

Table 2

Shows the green coverage ratio and number of plants

Green Coverage ratio	Diameter of plant/pot	No. of plants
6	0.45 - 0.6 m	14
5	0.45 - 0.6 m	11
4	0.45 - 0.6 m	9
3	0.45 - 0.6 m	7
2	0.45 - 0.6 m	5

A previous study by Han (2019) states that installing one large potted plant and one small potted plant per 6 m^2 floor area in a room whereas US studies have also recommended placing at least one (15.24 cm) potted plant per 9 m^2 floor area in a room was sufficient to clean air (Han, 2019). The green coverage ratio was derived from the literature study (Han, 2009; 2019; 2020). Based on the literature study, plant requirement for air quality was developed for a 100 sq.m. area which is dependent upon the diameter of the plant. Whereas the study by Bhargava et al. (2021) had not mentioned the relation between room area and the number of plants placed for the experiments (Bhargava et al., 2021).

The selection of the plant species was based on pollutants that can be removed, dimension, daylight/ shade tolerant, sustained to temperature variation, vulnerability to pests & diseases, and maintenance (Han, 2009). Plants were selected as per Table 3. Ten numbers of each, Rhapis excelsa (Lady palm), Areca Palm, and Dracaena reflexa (Song of India) were placed in three different classrooms. The plants were kept in the centre of the classrooms which coincides with one of the data collection points. Plants were of 0.45-0.50 m diameter mean foliage and 1.1 m in height. The plants kept in the class were in healthy condition and were in nursery bags only. Soil is nursey red soil and during the entire experiment, no fertilizers and pesticides were applied to the plants.

Table 3

Details of selected plant species

Image			
Name	Rhapis excelsa (Lady palm)	Areca Palm	Dracaena reflexa (Song of India)
Plant Dimension	Dia.- 0.55 Ht.- 1.1	Dia.- 0.45 Ht.- 0.9	Dia.- 0.55 Ht.- 1.0m
Daylight/ Shade tolerant	very tolerant of shade and dry air	prefer a part-shade setting	Need indirect light and warm temperatures
Sustained temperature variation	16-27 °C	18-25°C	19-24°C
Maintenance	Only feed the plant once a year	Easy to grow and maintain	It is relatively easy to care
Pollutants that can be removed	formaldehyde, ammonia, and xylene	benzene, carbon monoxide, formaldehyde, trichloroethylene, xylene	xylene, trichloroethylene, and formaldehyde

(Green Planner, n.d.)

Empirical readings

Readings were taken before placing the plants. The next sets were done after one week and the frequency of the readings was per week. Data was collected to each grid point at the 0.9 m level. This was the breathing zone when students were in the seating position. As mentioned above, while taking measurements doors and windows were kept open. Readings of the immediate outdoor were also taken at the same time to have parity. While taking the reading average indoor air velocity was ranging from 0.00 to 0.07 m/s.

Statistical Analysis

The purpose of the study was to understand the sphere of the influence of the plant on the quality of air. So, the data has been compiled for six weeks. The collected data passed the normality test and then the mean was taken for each data point. To find out the correlation, the point where plants were kept was considered as the reference point. Considering that as a reference, the CO_2 concentration of all other points was plotted against the distance and was arranged in an increased order. The statistical analyses were conducted using IBM SPSS 28.0. To understand the correlation between CO_2 concentration and the distance from the plant, Pearson Correlation Coefficient was used. To find out the difference between the indoor and outdoor CO_2 concentrations, an independent t-test was used as the samples were independent. One-way ANOVA was used to compare the CO_2 concentration absorption ability of three species.

Results

Plant effect on indoor CO_2 concentration with respect to distance

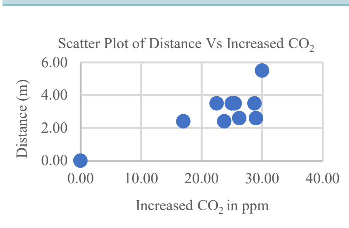
Hypothesis 1: There is a correlation between CO_2 concentration and the distance away from the plant.

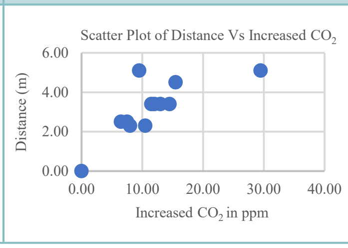
The scatter plots of three plants in Table 4 show the relation between distance and increased CO_2 concentration still, statistical tests were performed to find the level of significance for the same. To test the first hypothesis, Pearson's correlation coefficient was found for three species shown in Table 5.

Table 4

The Scatter plot shows the relationship between Distance Vs CO_2 Concentration

Rhapis	Areca	Song of India





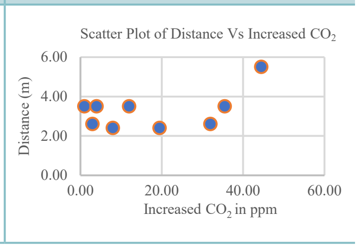


Table 5

Pearson Correlation coefficient for three species

Rhapis			Areca			Song of India		
Correlations								
	Distance	Increased CO_2 (ppm)		Distance	Increased CO_2 (ppm)		Distance	Increased CO_2 (ppm)
Pearson Correlation	1	.823**	Pearson Correlation	1	.769**	Pearson Correlation	1	.573
Sig. (2-tailed)		.003	Sig. (2-tailed)		.003	Sig. (2-tailed)		.084
**. Correlation is significant at the 0.01 level (2-tailed).			**. Correlation is significant at the 0.01 level (2-tailed).					

To find out the correlation between CO_2 concentration and distance from the plant, Pearson correlation was used after performing a normality test on data. The Pearson Correlation coefficient shown in **Table 5** between distance and increased CO_2 concentration is 0.823, 0.769 significance at the 0.01 level, for Rhapis and Areca respectively. For Song of India plants, it was 0.573.

Data were analysed for linear regression to find out the strength of the model as shown in **Table 6**. The values of R and squared R were promising for Rhapis and Areca, 0.823, 0.839 (R^2), and 0.677, 0.704 (R^2) with a p-value of 0.003 and 0.001 respectively. While Song of India shows a low R-value with no statistical significance.

The unstandardised predicted value was found in linear regression and plotted on a scatter plot along with the original values. The model was checked for its goodness of fit.

Scatter plots in **Fig. 2** show that the observed values and unstructured values were coincides closely with Rhapis, Areca, and Song of India. While for Rhapis, and Song of India it was getting apart after 5.5m. Whereas for Areca data points coincide with predicated values even after 6.0m.

Table 6

Linear regression data analysis to find out the strength of the model

Plant	R	R^2	Durbin-Watson	F	Sig.
Rhapis	0.823	0.677	1.12	16.77	0.003
Areca	0.839	0.704	1.964	21.407	0.001
Song of India	0.593	0.352	0.623	4.345	0.710

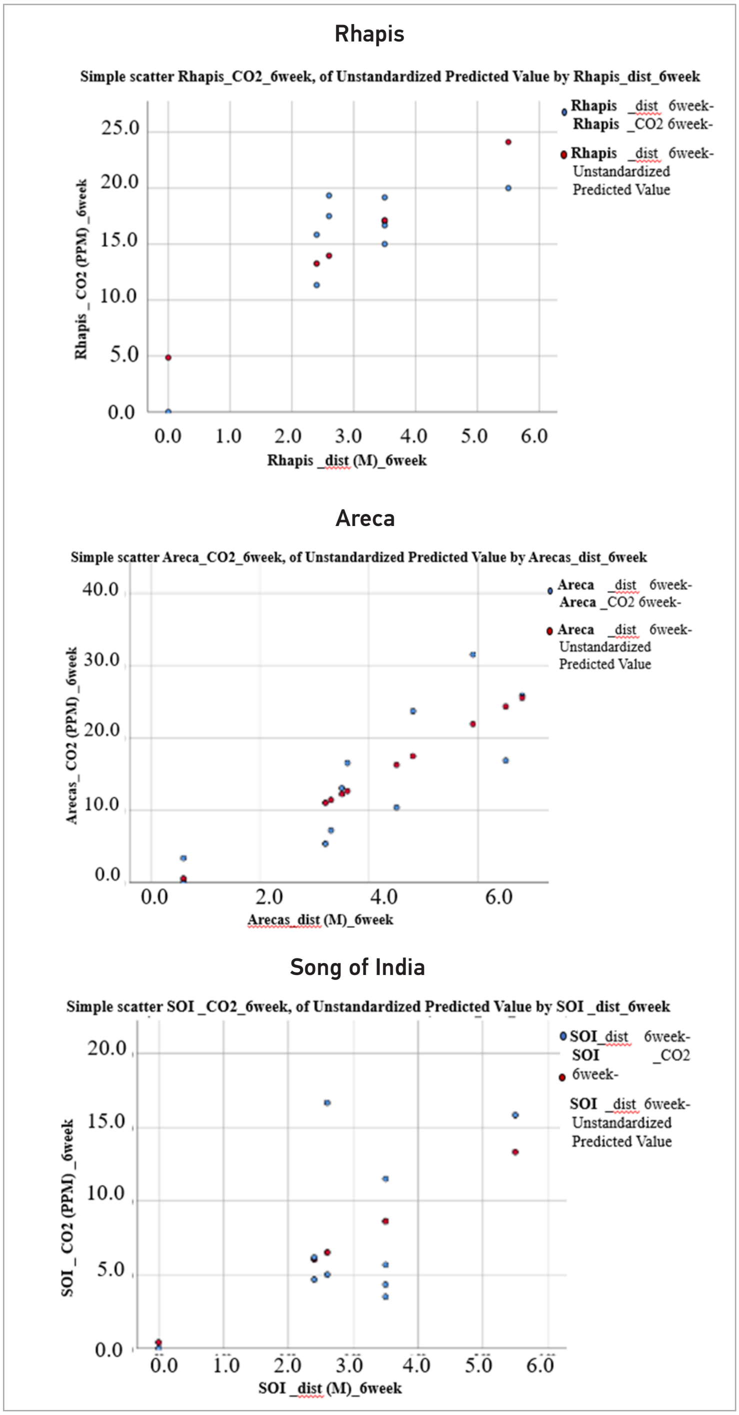


Fig. 2

Scatter plot of the predicted value of increased CO_2 concentration by distance

Comparison of indoor and outdoor CO_2 concentration

Hypothesis 2: Plants have affected indoor air quality by reducing indoor CO_2 concentrations than outdoor CO_2 concentrations in the classroom.

The performance of the mentioned three species was compared to how much indoor CO_2 concentration is less than outdoors. Data were tested for their normality and an independent t-test was used to compare. As the data was not paired and the comparison was between two sets, an independent t-test was used. As the difference was checked for either more or less hence significance of one-sided p was considered. One-Sided p values for Rhapis (0.004) and song of India (0.022) were less than 0.05 whereas for Areca it is 0.05 as per Table 7.

Table 7

Results Independent t-test of three species comparing indoor and outdoor CO_2 concentrations

	Sig.	t	df	Significance	
				One-Sided p	Two-Sided p
AVG_102_ Rhapis	.012	-3.357	10	.004	.007
Avg.CO_2_203_Areca	.014	-1.807	10	.050	.101
AVG_202_ Song of India	.236	-2.304	10	.022	.044

Comparison of ability to absorb CO_2 of three species

Hypothesis 3: All plant species used in the experiment has different ability to absorb the CO_2.

Three species were compared for their ability to absorb carbon dioxide. As data had passed the statistical normality test, one way ANOVA test was used as the data was not paired and there were more than two data sets. Results were shown in Table 8. It was found that all p - values were greater than 0.05.

Table 8

Result of One-way ANOVA comparing performance in terms of absorbing CO_2 concentration of three species

(I) VAR00013	(J) VAR00013	Mean Difference (I-J)	Sig.
Rhapis	Areca	-12.27500	.575
	Song of India	.35000	1.000
Areca	Rhapis	12.27500	.575
	Song of India	12.62500	.553
Song of India	Rhapis	-.35000	1.000
	Areca	-12.62500	.553

Discussion

Hypothesis 1(There is a correlation between CO_2 concentration and the distance away from the plant) gets supported for Rhapis and Areca plants. Rhapis and Areca plants indicate a positive correlation between distance and increased CO_2 concentration is significant at a 1% level. Whereas the third plant Song of India did not show the significance level. So, hypothesis 1 was partially supported. It shows that as one moves away from the plants, the CO_2 concentration was increasing. While studying the plants and air quality, Han (Han, 2019) observed that the CO_2 concentration was higher near the plant regardless of the number of plants. In the current study, the green coverage ratio is constant but the correlation with distance is significant for the two species. CO_2 concentration has increased away from the plant which contradicts to literature. Han experimented with almost sealed environments hence direct comparison may not be appropriate. Even Han (Han, 2019) had also checked the effect of plants at 1.5 and 3.0 m distances. Table 6 showed the R-value measures the degree of relationship between the actual values and the predicted values of the increased CO_2 concentrations. The coefficient value (R) of 0.823, 0.839 for Rhapis and Areca, indicates that the relationship between distance and the increased CO_2 concentrations is quite strong and positive. Thus, the value of R square is 0.677, 0.704 means that about 67.70% and 70.4% of the variation in CO_2 concentrations is explained by the estimated simple regression that uses distance as the independent variable and the R square value is significant at 3% and 1 % level for Rhapis and Areca respectively. The scatter plots in Fig. 2 showed that the model was working efficiently till 5.5m for Rhapis and Song of India plants while for Areca it would work for more than 6.0m. This means the influence of these plants could work 5.0-6.0 m range. So, in a classroom plant can be placed at the mentioned distance for improved air quality. However, the study by the researcher mentioned that irrespective of the green coverage ratio and distance from the plant, CO_2 was significantly greater in the presence of indoor plants than in the absence of indoor plants (Han, 2019).

Hypothesis 2 (Plants have affected indoor air quality by reducing indoor CO_2 concentrations than outdoor CO_2 concentrations in the classroom) gets supported. The results of Table 7 indicate that the absorbing capacity of Rhapis, Areca, and Song of India is significant concerning outdoor CO_2 concentration with a one-sided p-value of 0.004, 0.050, and 0.022 respectively. Hence the hypothesis got accepted. The indoor CO_2 is significantly less than outdoor. For the Areca plant, a one-sided p-value is 0.005 which is on the border. So, it needed further investigation to confirm the results. While the study by Bhargava et al. (2021) found that with the increase of Areca palm plants from three to nine, a reduction in the CO_2 level was recorded from 10.2% to 44.76% in respective experimental rooms (Bhargava et al., 2021).

Hypothesis 3 (All plant species used in the experiment has different ability to absorb the) is tested with the ANOVA test. While comparing these three species as shown in Table 8, in terms of absorbing the capacity of CO_2 amongst these three, the p-value for all these species was more than 0.05. So, the hypothesis gets rejected. It has been noted that all three species perform equally. The results of the current study corroborate with the study by Aini Jasmin et al. (2012) where Rhapis and Dracaena species were used in a similar experimental room as mentioned here. As per the current study, the CO_2 absorption ability of the Rhapis plant was better than Song of India, and Song of India was better than Areca. The results coincide with the other studies for Rhapis but not for the Areca plant for CO_2 absorption ability. The study observed that the Areca palm had a better CO_2 absorption capacity (Jung & Awad, 2021; Kulkarni & Zambare, 2018).

Conclusion

The study explains the effect of the indoor plant on the physical environment. This research has also observed the CO_2 absorption ability of different plant species although the classrooms have the same area and volume and the number of plants was also the same. From the current study, it can be inferred that for improved air quality, plants can be kept at a 5.0-6.0 m distance. The findings of this study have bridged the gap in research regarding the conducting unsealed environment instead of enclosed fumigation chambers and sealed environments. The study has contributed to finding the correlation of change in CO_2 concentration with respect to distance away from the plant. The findings will be applicable in terms of quantification of green coverage ratio to distance for improving the air quality of the classrooms where the occupancy is high for a longer time. In the Indian context, such a method has not yet been used for unsealed rooms. This is an energy-free method for regulating indoor air quality and immediate surroundings.

Future Scope

As the current study is a pilot study, further investigation will help to find more robust findings. Further study could be conducted in a regular working classroom by placing indoor plants in a classroom and studying objective thermal comfort and subjective visual comfort.

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About the Authors

AR. ANITA K. KAVATHEKAR

Associate Professor

Sinhgad College of Architecture, Pune- 411038
SP Pune University Maharashtra, India

Main research area

Biophilic Design, Indoor environmental quality, built environment, Architectural design Theory.

Address

Pune, Maharashtra
Tel.: 9881720569
E-mail: kavathekar.anita@gmail.com

Dr. SHAILA BANTANUR

Director and Professor

BMS School of Architecture, Bangalore 560064

Main research area

Sustainability practices and awareness in rural areas, Lighting analysis in rural areas, Sustainability and green buildings.

Address

Avalahalli, Doddaballapur Main Road,
Yelahanka, Bengaluru – 560064
Tel.: 8978577592
E-mail: shailabunty@gmail.com