ALTERNATIVE TECHNIQUES TO IMPROVE INDOOR ENVIRONMENTAL QUALITY

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ABSTRACT

Most of the time people stay in confined environments and thus are highly exposed to accumulated indoor pollutants. Indoor environmental pollution has been identified as one of the most prevalent causes for health problems, such as sick building syndrome. These health problems have been magnified with the introduction of energy efficient building concepts, coupled with limited fresh air supply, which has compromised the effective means of air purification. Further, the frequent use of chemical substances for numerous purposes contributes to indoor air pollution. Therefore, investigation of alternative techniques to improve indoor environmental quality has been extensively studied in the last two decades. In Sri Lanka, there is a potential for studying indigenous techniques to improve indoor air quality. However, verification of such techniques and quantification of their impacts has not been given much attention. The research focus of this paper is to identify those material substances that can be used to absorb pollutants and lessen their harmful impacts and thereby improve air purification. A chamber study was used to quantify air purification using different material substances and considering the following parameters: total volatile organic compound (TVOC) and Carbon Monoxide (CO) levels. Further, the results obtained in the chamber study were assessed for its projection to real applications by comparison with a study conducted in an actual indoor space. The outcome of the study has revealed that the indigenous knowledge of Sri Lanka can be used to improve indoor air quality.

KEYWORDS

indoor air quality, material substances, indigenous knowledge, TVOC

1. INTRODUCTION

Adverse health effects can be caused by over exposure to air pollutants (Klepeis, et al., 2001; WHO, 2010). Threshold values for different pollutants have been published by organizations like the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE, 2016) and the United States Environmental Protection Agency (EPA, 2016). The U.S. EPA ranks indoor air pollution as one of the top five threats affecting public health. Studies from the Environmental Protection Agency on human exposure to air pollutants show that

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indoor pollutant levels may be two to five times, sometimes more than 100 times, higher than outdoor levels.

Sick Building Syndrome (SBS) is the most common adverse outcome of poor indoor environmental quality (IEQ). The associated discomforts include allergic reactions, lethargy, dizziness, nausea, sensory irritation of the eyes, nose and throat, headache etc. A considerable number of research studies have been carried out to evaluate the effects of SBS on the productivity of office workers (Gupta, et al., 2007; Norhidayah, et al., 2013; Wargocki, et al., 2000; Wolkoff, 2013). A range of indoor environmental factors, such as thermal, visual, acoustic and chemical can create an impact on the wellbeing of occupants. Lower ventilation rates aggravate poor air quality indoors and causes SBS (Al horr, et al., 2016; Apte & Erdmann, 2002; Sarafis, et al., 2010).

In a naturally ventilated building, outdoor air directly penetrates inside, whereas in a mechanically ventilated building, outdoor air is supplied to the indoors through ducts and vents. The energy demand required to maintain indoor thermal comfort varies with the outdoor air temperature (Blondeau, et al., 2005; Koponen, et al., 2001).

Most of the studies on indoor air quality have identified Volatile Organic Compounds as a key pollutant in the indoor environment. In a study carried out in two cities of Korea, it had been found that majority of VOCs measured in both indoor and outdoor environments were derived from outdoor sources and a very strong correlation had been found between indoor and outdoor levels of vehicle-related pollutants (Baek, et al., 1997).

Source control, proper ventilation systems to extract contaminated air, and purifying the indoor air are three common ways to improve indoor air quality. The use of indoor plants has gained popularity because of plants' advantages like low cost and reduction of CO_2 levels. Plants generally utilize CO_2 for photosynthesis and studies show that plants have the ability to absorb several other pollutants, like VOCs (Irga, et al., 2013; Lambers, et al., 2008; Liu, et al., 2007; Raza, et al., 1995; Wolverton, et al., 1989; Yang, et al., 2009). These studies can be categorized into two types: 1) laboratory scale chamber studies and 2) actual scale studies. The chamber studies were carried out under controlled conditions. Therefore, it is difficult to project these findings to actual environments (Lin, et al., 2013). The studies have shown that certain plants have the capability of absorbing and adsorbing indoor air pollutants (Cornejo, et al., 1999; Wolverton, et al., 1989).

Several other studies have considered alternative substances as indoor air purifying agents. Activated charcoal and activated carbon fibre are considered to be some of the most promising adsorbents. Also, it has been found that activated carbon has a high affinity to polar compounds, and in the presence of humid conditions, they tend to get attached to water molecules, decreasing their pollutant absorption ability. The adsorption capability of activated carbon due to its porous surface nature also improves the ability to entrap the pollutants (Lee, et al., 2013; Mangun, et al., 2001). Another study shows that activated carbon can remove VOCs like toluene, ethylbenzene and xylene emitted from the surfaces of coating materials. Once the pollutants have been absorbed and activated carbon is fully saturated, it can be used as a fuel due to the entrapped inflammable VOC (Dinh, et al., 2016).

For purification and deodorization of ambient air, photo-catalysis (a photo reaction process which is accelerated by the presence of a catalyst) can be used. Titanium Dioxide (TiO_2) reactors can be used in air conditioners which have to be specifically designed to the relevant environmental conditions (Agrios & Pichat, 2005; Chin, et al., 2006). As a solution for air pollution by traffic, TiO_2 photo-catalytic materials can be added to the surface of pavements and building materials (e.g., concrete pavement blocks). In combination with light, when the pollutants are oxidized and precipitated on the surface of the material, they can easily be removed from the surface when it rains. Also, TiO_2 can be used in the weather coating of walls so that the indoor environment can be protected from external pollution getting in. It has been found that these substances give good results in air purification, measured in terms of $NO_{x,}$ indicating the reduction in concentration in the presence of high temperature (25°C), low relative humidity, higher light intensities and long contact times (Beeldens, 2017).

Though several studies have been carried out on various techniques to improve IEQ, the use of pollutant absorbent material substances based on indigenous knowledge have not been properly assessed for their performance. Therefore, it is worth testing these materials derived from indigenous knowledge and assess these substances use for indoor air purification.

2. OBJECTIVES

The research presented in this paper was aimed at the following objectives:

- To identify different material substances that can purify indoor air
- To quantify the effectiveness of such substances in air purification

3. METHODOLOGY

A detailed literature review was followed by a questionnaire survey to gather information on indigenous knowledge by selecting a sample of indigenous medical practitioners. Based on the results of the survey, several material substances were selected to test their ability to improve air purification. In order to create controlled conditions, a chamber was fabricated for the experimental program. All the selected substances were tested for the effects of air purification. In order to project the findings to the real indoor environment, the experimental program was extended to an actual room.

3.1 Questionnaire Survey

Based on a detailed literature review, it was found that certain material substances used in a day-to-day domestic environment can be simply used to purify indoor air. This was also verified by one-on-one interviews with a selected sample of indigenous medical practitioners. In order to get more information from a larger sample, a structured questionnaire survey was conducted among indigenous medical practitioners in Sri Lanka. The questionnaire survey was carried out on a convenient sample, which included twenty qualified doctors engaged in indigenous medical practice.

3.1.1 Results and Analysis of Questionnaire Survey

It was revealed that in indigenous medical practice there are different techniques that can be used to improve indoor air quality. Error! Reference source not found. presents the responses of indigenous medical practitioners indicating their preferences for various materials such as lime slices soaked in water, straw soaked in water, baking soda, apple cider vinegar, coffee powder, and coal. Also, in the opinion of the respondents, these materials have different capacities to remove pollutants.

Out of 20 respondents, 17 have used or heard of using lime slices soaked in water for improving indoor air quality which accounts for 85% of the population and therefore represents the experience of the majority. About 50% of the sample had experience with straw soaked in water and baking soda usage. Additionally, 45% of the sample had used or heard of using apple cider vinegar for indoor air purification. A proportion of 35% of the sample and 25% of the sample have had experience with coffee powder and coal used for indoor air purification respectively.

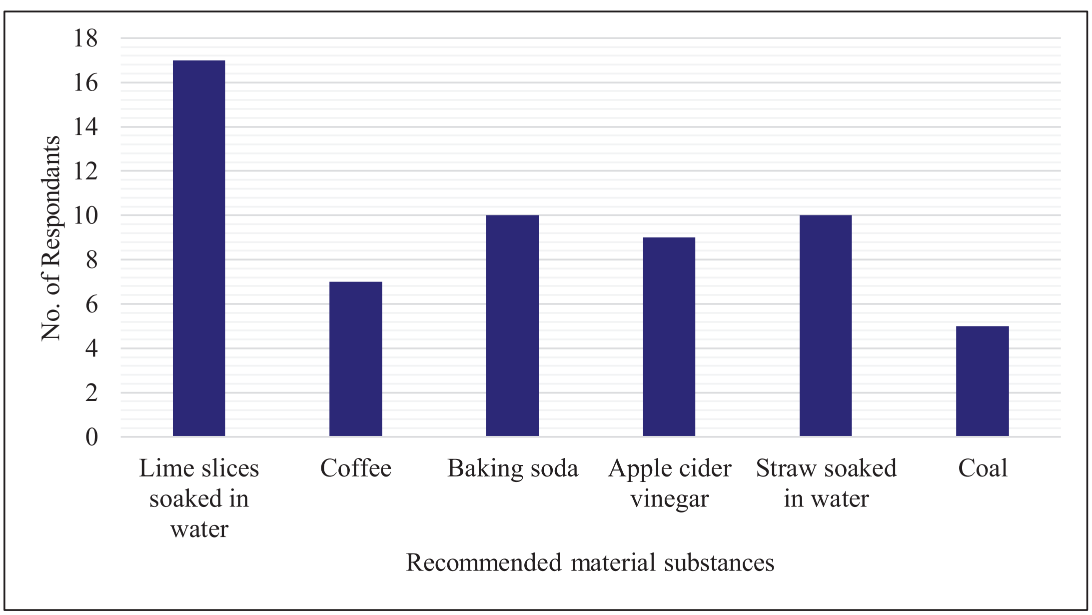
From the material substances identified through the questionnaire survey, it was decided to carry out an experimental program to validate existing practices and to quantify their effectiveness. Since the research focuses on the use of sustainable materials, coal was omitted from the experimental process. Activated carbon itself is a non-renewable material and hence it was not considered as a sustainable material. Also, there have been large scale researche on its adsorptive properties; it is a well-developed product used for removing volatile organics in industrial applications (Dinh, et al., 2016; Lee, et al., 2013; Mangun, et al., 2001). Lime slices soaked in water, straw soaked in water, baking soda, apple cider vinegar, and coffee powder were the materials selected for stage 1 of the experimental program.

3.2 Experimental Program

A detailed experimental program was conducted to investigate the absorption rate of pollutants by the substances recommended in the questionnaire survey. The experimental program consisted of three stages including selection of the most effective substance for absorption of pollutants, the second stage to quantify the absorption, and the third stage to project the chamber study results to an actual scenario.

- Stage 1: To identify the substance that has the most effective TVOC and CO removal capability from the materials recommended in the questionnaire survey.
- Stage 2: To quantify the TVOC absorption of the selected material using a chamber study.
- Stage 3: To project the results obtained in the chamber study to actual indoor spaces.

FIGURE 1. Results of the questionnaire survey.



It was reported in literature that the monitoring of air quality is affected by several environmental parameters, which in turn demands controlled indoor conditions in the experimental program. Therefore, most of the indoor air quality testing had been carried out in chambers under controlled conditions (Wolverton, et al., 1989; Raza, et al., 1995). However, it was also found that the results of chamber studies could not be directly correlated to actual indoor spaces.

3.2.1 Experimental Chamber

In order to conduct the experiments, an air tight chamber of size 1.15m × 0.6m × 0.6m (volume 0.41 m^3) was fabricated using Perspex (Figure 2). The edges of the chamber were sealed with a sealant to maintain air tightness. To ensure the grip between the top covering and vertical edges of the sides, a rubber gasket seal was fixed to the vertical edges. To guard against further leakages, a thin layer of grease was applied on the rubber gasket. The top covering was held in place tightly using nuts and bolts. The chamber was kept open for a few days so that the emission from the sealants and Perspex was completely dispersed.

3.2.2 Air Quality Measurements

A factory calibrated Aeroqual air quality meter was used to take measurements. It has four sensors to measure CO_2, CO, NO_2 and TVOC. It consists of a Photo Ionization Detector (PID) type sensor to measure TVOC. This type of a sensor is non-selective, which means it can be used for measuring a wide variety of VOCs. To achieve this function, it has been calibrated against isobutylene which allows it to respond to a wide range of VOCs at varying degrees of sensitivity.

3.2.3 Pollutant Source

In order to create a polluted environment inside the chamber, anti-corrosive paint was used as the source, since it emits noticeable amounts of TVOC. The same type of anti-corrosive

FIGURE 2. A chamber study with a purifying material inside.

paint was used throughout the experiment. Also, the rate of application of the paint was kept constant throughout. A plywood sheet was used as the substrate for the paint application. The size of the sheet and the painted area was kept at 0.32 m^2 (400 mm × 800 mm) for stage 1 and 2 of the experiment.

Before the application of anticorrosive paint on the substrate, the wooden sheet was kept inside the chamber and a set of air quality measurements was taken for TVOC, CO and CO_2 concentrations. No emissions were recorded for the plywood sheet, and the effect of the substrate material was found to be negligible for the air quality measurements.

4. RESULTS OF THE EXPERIMENTAL PROGRAM

Results for three stages of the experimental program are presented separately.

4.1 Stage 1 of the Experimental Program—Selection of the Most Effective Substance

In stage 1 of the experiment, five different substances identified in the questionnaire survey were assessed for their absorption of TVOC and CO concentration inside the chamber.

The following parameters were kept constant in the experiments:

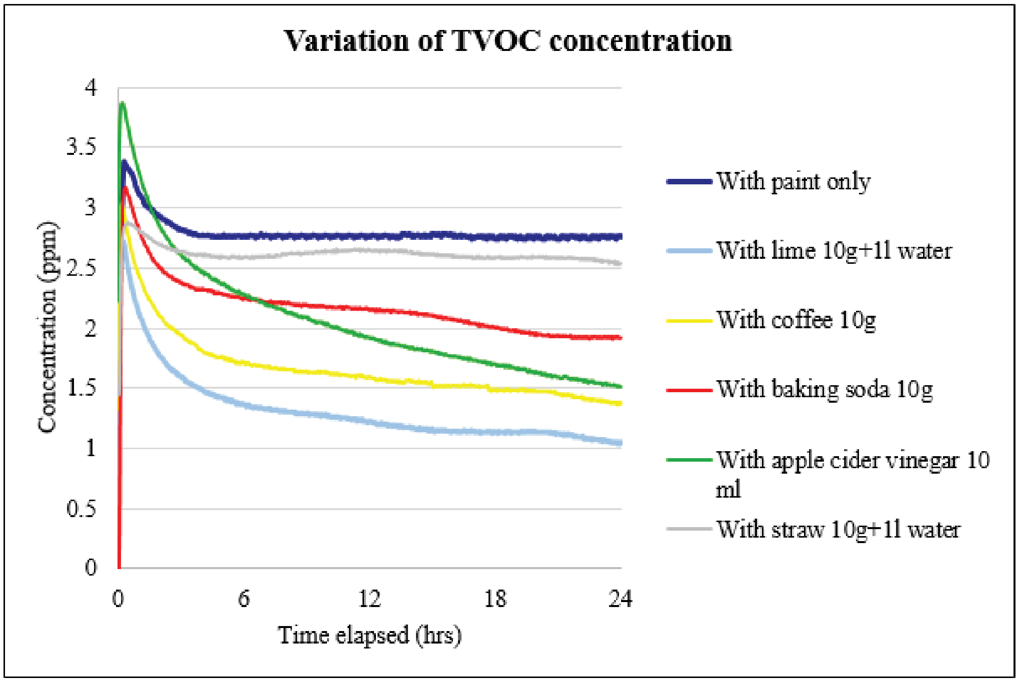
- The same quantity of each substance was used in stage 1 of the experiment (10 g of each material was used to compare the absorption of pollutants in the chamber. For the materials dipped in water, 1 litre of water was used together with 10g of the material).
- The exposed area of the material was kept constant by using containers of similar sizes.
- The source and the intensity of the selected pollutant was maintained the same and kept constant throughout the experiment.
- The substrate used for the source (paint application) was the same and for each material a fresh board of plywood was used.
- The source (the wooden piece painted with anti-corrosive paint) and the container consisting of absorption material was kept at a location which was constant throughout the experimental program.
- A minimum of 24-hour testing was carried out for all the experiments.

4.1.1 Impact on TVOC Concentration

Once the pollutant source was created inside the chamber, measurements were taken for pollutant concentration and the obtained dispersion curves for the TVOC concentration are presented in Figure 3. Separate sets of measurements were taken by keeping each substance inside the chamber. Both the pollutant source and the absorption material were kept inside at the starting point of each step of the experiment. Dispersion curves for all five material substances presented in Figure 3 were compared with that of the curve obtained for the pollutant source without any air purifying substance. The peak value of the curves (TVOC) was used to compare the effectiveness of the material substances. The peak TVOC concentration reported with each material substance is indicated in Table 1.

Except for the experiment with apple cider vinegar, the other four materials/material combinations showed a reduction in TVOC peak value. Although the difference in peak value is not very significant, there is nearly a 20% reduction in peak value observed with lime slices soaked in water. Three other substances: coffee, baking soda and straw have indicated a slight

FIGURE 3. Dispersion of TVOC concentration with different substances.



reduction in TVOC peak value, while Apple cider vinegar contributed to TVOC concentration with an increase of peak value by 14%.

4.1.2 Impact on Carbon Monoxide Concentration

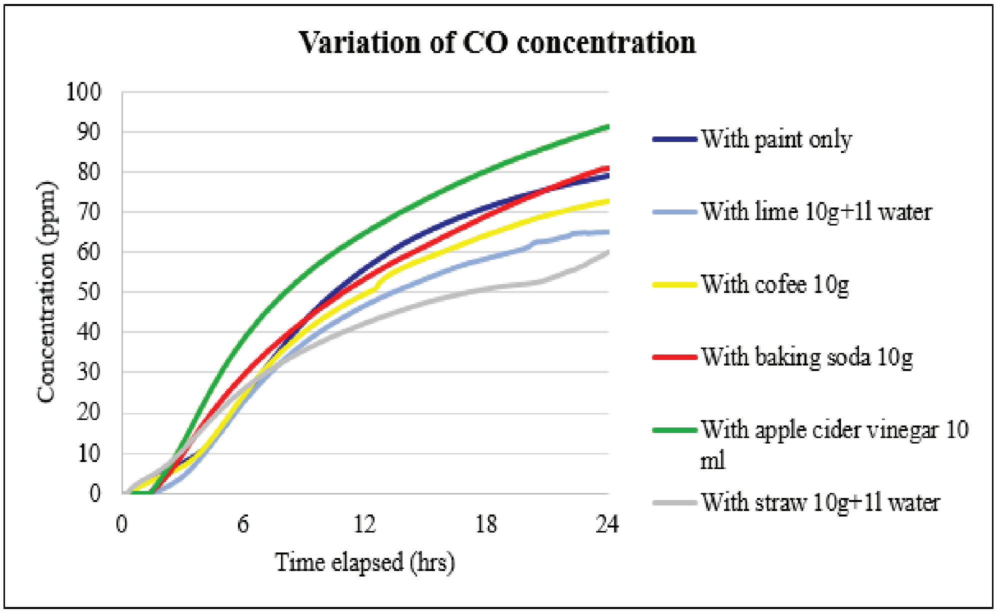
The variation of CO concentration with the pollutant source and with different substances of absorption material is presented in Figure 4.

Increasing CO concentration for a period of 24 hours was observed in all cases with the pollutant source. In order to monitor the dispersion of CO concentration, a subsequent

TABLE 1. Stage 1: Peak values of TVOC concentration with different substances.

Substance inside the chamber	Peak value of TVOC/ppm	Comparative reduction in peak value	
		ppm	%
With paint only	3.39	—	—
With lime 10g + 1l water	2.72	0.67	19.76%
With coffee 10g	3.04	0.35	10.32%
With baking soda 10g	3.17	0.22	6.49%
With apple cider vinegar 10 ml	3.87	–0.48	–14.16%
With straw 10g + 1l water	2.88	0.51	15.04%

FIGURE 4. Stage 1: Variation of CO concentration.



experiment was carried out and the dispersion curve for a period of 8 days is presented in Section 4.2.2. The monitoring was continued until the CO concentration had fallen below the threshold value, as shown in Figure 8. The increase in CO concentration in the initial segment of the curve could be due to following reasons:

- CO could be generated when VOC in the paint reacts with the substrate. The substrate alone does not emit any pollutant (verified from the experiment done inside the chamber by placing a fresh plank of wood without applying the paint) when it comes in contact with the paint;
- CO might be generated due to the reactions of constituents of the substrate and the paint. The substrate used in the experiment is a sheet of plywood which is manufactured with thin layers of wood, glued together with a resin which may contain phenol or urea formaldehyde. Since such organic substances can react with the solvent based paint applied, a high CO concentration may result at the initial phase with a dispersion over a period.

However, further investigations are necessary to verify the secondary reactions occurred inside the chamber which resulted in an increase in CO concentration at the initial part of the experiment.

Since CO levels increased in all cases, the concentration at the end of 24 hours was considered for comparison purposes. With the presence of straw soaked in water, lime slices soaked in water and coffee powder, there was a reduction in the maximum amount of CO accumulation. This implies that these materials have contributed to absorbing the volatile organics emitted by the pollutant so that there is a lesser amount of organic contents to get oxidized using the limited amount of O_2 in the chamber.

When Apple cider vinegar is used as the purifying agent, a higher amount of CO is accumulated inside the chamber. This could be justified with the higher level of TVOC peaks obtained when apple cider vinegar is placed inside the chamber as the purifying agent. Since there is no fresh air supplied into the chamber, the concentration of CO has passed the threshold value, which is 8 ppm (WHO, 2010) excessively. Though straw and lime slices in water indicated lower values of CO, the concentration did not disperse to the threshold value within 24 hours. The maximum levels of CO concentration observed are presented in Table 2. Further discussion on CO concentration is presented in Section 4.2.2.

4.1.3 Impact on CO_2 concentration

Although Carbon dioxide is not identified as a toxic gas, it is a good measure of ventilation inside buildings and also it was recorded in the experiment to assess the impact of different substances on the quality of air inside the chamber. Figure 5 presents the variation of CO_2 concentration and shows values less than 1000 ppm within 24 hours. The threshold value for CO_2 recommended in ASHRAE for good ventilation is 1000 ppm (ASHRAE, 2016).

Since the CO_2 level at the start of the experiment affects the final level of accumulated CO_2 inside the chamber, the difference between the final and initial levels of CO_2 was considered for comparison purposes. Table 1 and Table 3 presents the change in CO_2 concentration from the base case, where only the pollutant source, i.e., painted wooden board is inside the chamber.

Results of stage 1 of the experiment has been compiled in Table 4 for the three parameters considered in the study (TVOC, CO and CO_2 concentrations), together with variations from the base case.

Lime slices soaked in water has shown the best performance with respect to absorption of TVOC concentration and the CO concentration, and it has reported a nominal amount of increase in CO_2 concentration. Straw soaked in water has also shown better results with the absorption of TVOC and CO. However, an increase in CO_2 concentration due to straw has a detrimental impact on indoor air quality. This can be due to the fermentation of straw in water, with CO_2 as a by-product released. Coffee has also shown some positive effect on purifying indoor air, although the magnitude of pollutant absorption is relatively less.

TABLE 2. Stage 1: Peak values of CO concentration with different substances.

Substance inside the chamber	Highest value at 24 hrs (CO in ppm)	Comparative reduction in accumulated CO in 24 hrs	
		ppm	%
With paint only	79.17	—	—
With lime 10g + 1l water	65.12	14.05	17.75%
With coffee 10g	72.91	6.26	7.91%
With baking soda 10g	80.99	–1.82	–2.30%
With apple cider vinegar 10 ml	91.10	–11.93	–15.07%
With straw 10g + 1l water	60.08	19.09	24.11%

FIGURE 5. Stage 1: Variation of CO_2 concentration.

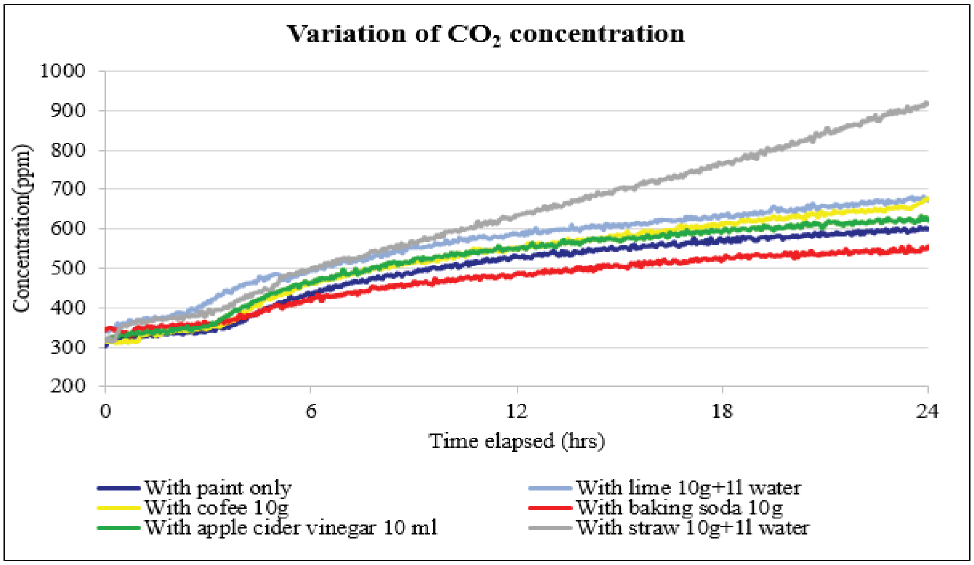


TABLE 3. Stage 1: Comparison of ΔCO_2 values.

Substance inside the chamber	ΔCO_2 (ppm)	Increase in CO_2 concentration from the base case	
		ppm	%
With paint only (base case)	297	—	—
With lime 10g + 1l water	328	31	10.44%
With coffee 10g	362	65	21.89%
With baking soda 10g	211	–86	–28.96%
With vinegar 10 ml	304	7	2.36%
With straw 10g + 1l water	602	305	102.69%

TABLE 4. Summary of results in Stage 1.

Substance inside the chamber	Reduction TVOC peak value	Reduction in highest CO value in 24 hrs	Increase in CO_2 concentration (ΔCO_2)
Lime 10g + 1l water	19.76%	17.75%	10.44%
Coffee 10g	10.32%	7.91%	21.89%
Baking soda 10g	6.49%	–2.30%	–28.96%
Apple cider vinegar 10 ml	–14.16%	–15.07%	2.36%
Straw 10g + 1l water	15.04%	24.11%	102.69%

Baking soda as a substance to absorb pollutants has not performed at an acceptable level and hence can be eliminated as an air purifying agent. Apple cider vinegar has also not performed as expected and can be eliminated in further analysis.

Considering the overall performance of all the substances, lime slices soaked in water has performed fairly well compared to coffee and straw soaked in water. Therefore, lime has been selected for further analysis to quantify its effectiveness as a purifying substance of indoor air.

4.2 Results and Analysis of Stage 2 of the Experiment (Optimum Quantity of the Purifying Agent)

The chamber study was continued to determine the optimum quantity of purifying agent to be used with a certain concentration of a pollutant. Based on stage 1 of the experimental program, lime slices soaked in water had been used to proceed with stage 2 of the experiment. The quantity of lime used was varied as 20g, 30g, 40g and 50g with a constant amount of water (1 litre), and the air quality was monitored with the same pollutant source i.e., with the same painted area on a wooden piece. The impact on three parameters TVOC, CO and CO_2 are presented in sections 4.2.1 to 4.2.3.

4.2.1 Impact on Total Volatile Organic Content (TVOC)

The results of the TVOC concentration at stage 2 of the experiment are presented in Figure 6 with different quantities of lime slices soaked in water.

It can be observed that 40g and 50g of lime soaked in water demonstrates the peak value closer to the threshold (0.75 ppm) and also a dispersion to lower concentrations after about 12 hours. Table 5 presents the peak values of TVOC concentration with different quantities of lime inside the chamber.

The percentage reduction of TVOC concentration is substantial in the range of 40 to 50g of lime slices soaked in water. Therefore, the optimum quantity of lime slices can be proposed

FIGURE 6. Stage 2: Dispersion of TVOC concentration with different lime contents.

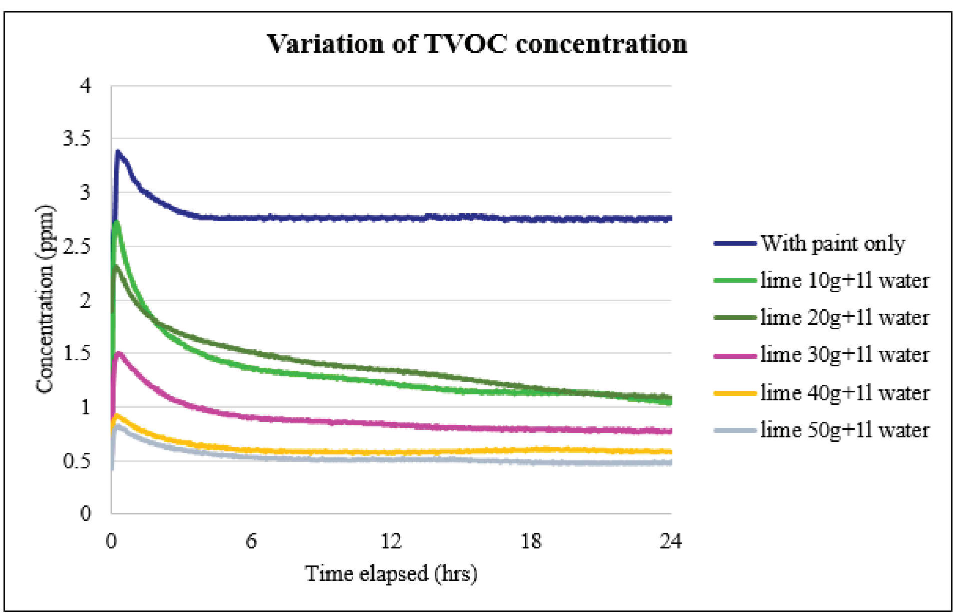


TABLE 5. Stage 2: Comparison of TVOC peak values.

Material combination	Peak value TVOC/ppm	Comparative reduction in peak value	
		ppm	%
With paint only	3.39	—	—
With lime 10g + 1l water	2.72	0.67	19.76%
With lime 20g + 1l water	2.31	1.08	31.86%
With lime 30g + 1l water	1.5	1.89	55.75%
With lime 40g + 1l water	0.92	2.47	72.86%
With lime 50g + 1l water	0.83	2.56	75.52%

as 40 to 50g soaked in 1 litre of water. However, this needs further experimentation before recommending it as guidance for a real indoor environment.

4.2.2 Impact on Carbon Monoxide Concentration (CO)

Figure 7 presents the variation of CO concentration for different contents of lime slices present inside the chamber.

A reduction in CO was observed with lime slices soaked in water and having a maximum impact with 40 to 50g of lime inside the chamber. Table 6 presents the reduction in CO concentration with different lime contents kept inside the chamber.

FIGURE 7. Stage 2: Variation of CO concentration.

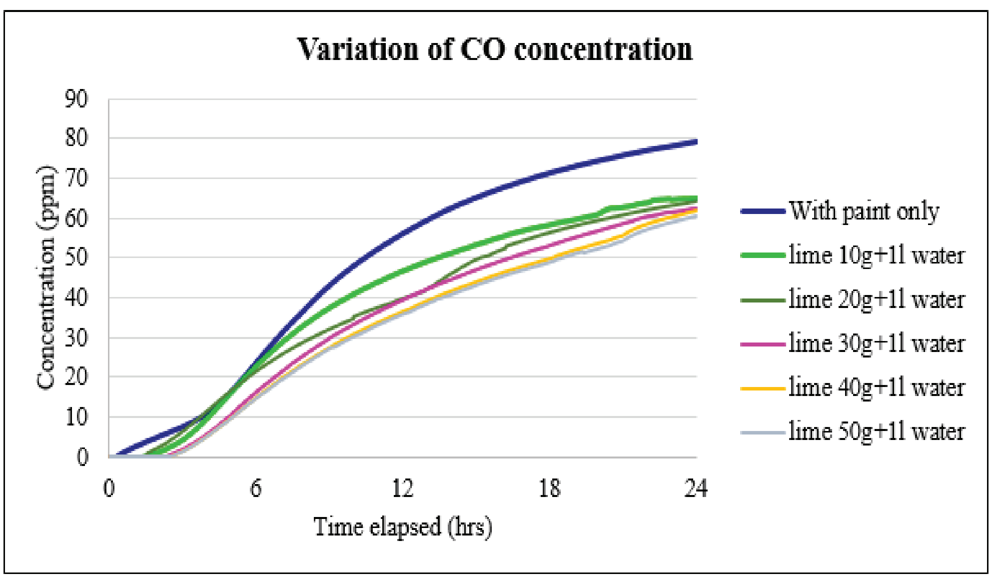


TABLE 6. Stage 2: Comparison of accumulated CO.

Material combination	Highest value in 24 hrs (ppm)	Comparative reduction in accumulated CO	
		ppm	%
With paint only	79.17	—	—
With lime 10g + 1l water	65.12	14.05	17.75%
With lime 20g + 1l water	64.17	15.00	18.95%
With lime 30g + 1l water	62.58	16.59	20.95%
With lime 40g + 1l water	61.85	17.32	21.88%
With lime 50g + 1l water	60.65	18.52	23.39%

It is seen that when the lime concentration was increased, the comparative reduction in accumulated CO level also increases.

Further testing was carried out to verify the higher values observed for CO concentration. A follow up experiment was conducted to monitor the same variations with 40g of lime slices soaked in 1 litre of water together with a different brand of the same type of paint applied on the same type of a substrate and with the same amount of area as in the experiments for stage 1 and 2. The measurements were continued for about 8 days to determine the dispersion of CO concentration towards the end of the testing period. After eight days, the CO concentration had fallen below the threshold value of 8 ppm (8-hour exposure threshold) (WHO, 2010). The dispersion curve is presented in Figure 8.

FIGURE 8. Variation of CO Concentration.

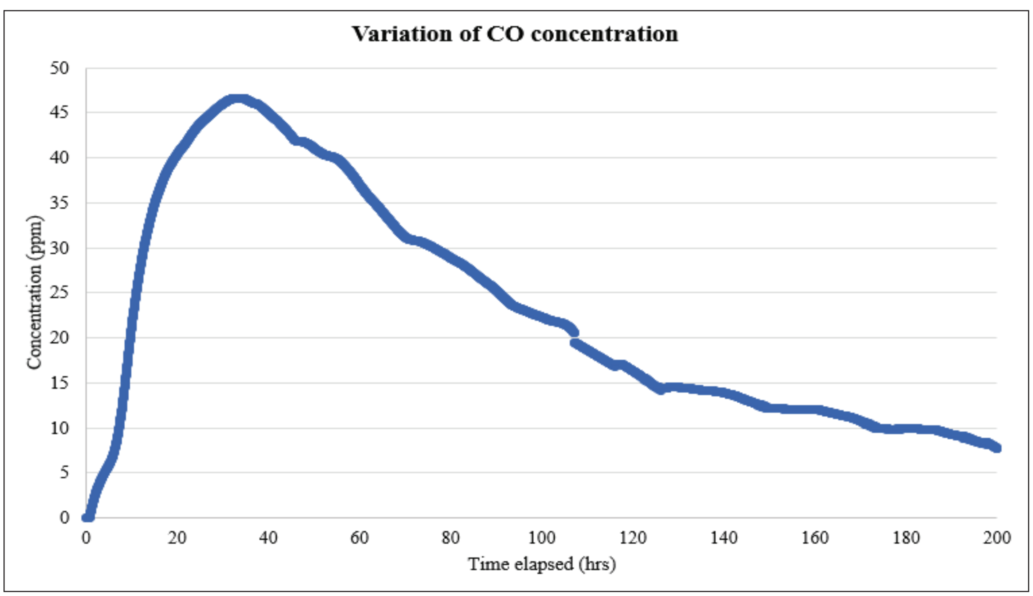
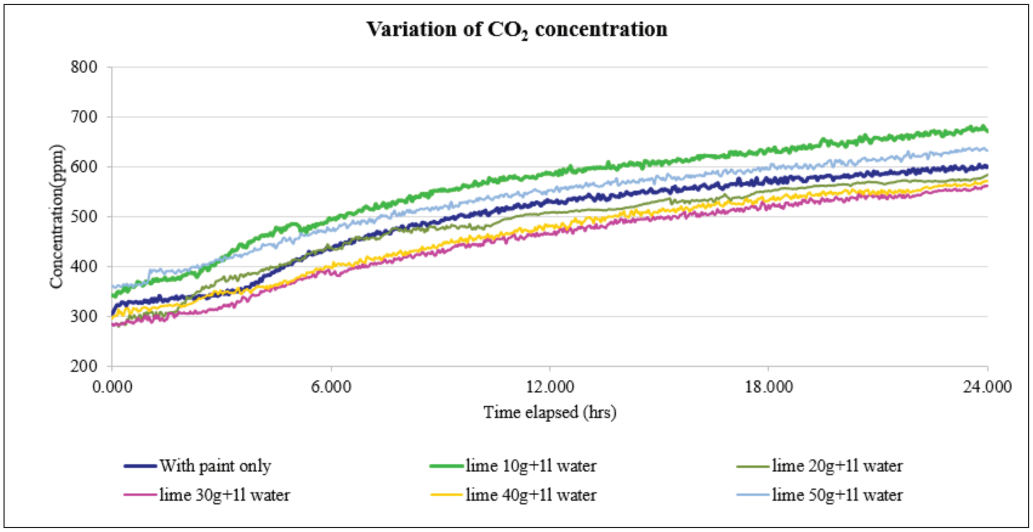


FIGURE 9. Stage 2: Variation of CO_2 Concentration.



4.2.3 Impact on Carbon Dioxide Concentration (CO_2)

It can be seen from the curves in Figure 9 that, in all the cases, CO_2 concentration has increased. Table 7 presents CO_2 differences between the final and initial levels of CO_2.

With an increase in material concentration, the comparative change in ΔCO_2 does not seem to have a direct correlation. The reason could be that CO_2 is produced as a by-product of the secondary reactions occurring inside the chamber between the organic substances of the substrate and the paint.

Table 8 presents the summary of the results of stage 2. The impacts on pollutant concentrations are presented as percentages of the base value, which is the paint only case.

It can be clearly seen that there is a positive correlation between the increase of material quantity and the reduction of TVOC peaks and accumulated CO concentration. However, an

TABLE 7. Stage 2: Comparison of ΔCO_2 values.

		Increase in CO_2 concentration from the base case	
Material combination	**ΔCO_2 (ppm)**	**ppm**	**%**
With paint only	297	—	—
With lime 10g + 1l water	328	31	10.44%
With lime 20g + 1l water	301	4	1.35%
With lime 30g + 1l water	278	–19	–6.40%
With lime 40g + 1l water	276	–21	–7.07%
With lime 50g + 1l water	269	–28	–9.43% %5%

TABLE 8. Stage 2: Summary.

Material combination	Reduction in peak TVOC concentration	Reduction in peak concentration of CO in 24 hrs	Impact on change in ΔCO_2
Lime 10g + 1l water	19.76%	17.75%	10.44%
Lime 20g + 1l water	31.86%	18.95%	1.35%
Lime 30g + 1l water	55.75%	20.95%	–6.40%
Lime 40g + 1l water	72.86%	21.88%	–7.07%
Lime 50g + 1l water	75.52%	23.39%	–9.43%

optimum amount of lime as an air purifying agent should be calculated for a specific activity space and in terms of a practical scenario. To make these determinations, more experimentation with several trials of varying lime contents is required, which is beyond the scope of research in this paper.

This research has identified material substances that can perform better in absorbing pollutants, as well as the trend of higher pollutant absorption corresponding with optimum amounts of the selected material substance.

4.3 Projection of Results of Chamber Study to the Actual Indoor Environment

With the aim of projecting the results of the chamber study to an actual indoor environment, stage 3 of the experiment was carried out. In this stage, a chamber study was carried out using a reduced painted area and reduced material quantity so that the material quantities could be proportionately increased in a practically reasonable manner to a real activity space.

The activity space was selected in an educational institute. The selected space is used as a utility room in a laboratory, which is maintained at the same controlled environmental conditions as that of the chamber, with 25°C temperature and 60% relative humidity. Figure 10 shows the layout of the selected activity space. The room was kept closed during the experiment. The size of the room is 18.95 m^3 (2.286m × 2.591m × 3.200m).

In order to project the chamber study to the real room, the volume ratio of the chamber and the room (0.41:18.95 => 1:46.20) was considered. As a reasonable material quantity for the chamber study, 10g of lime slices soaked in 100 ml of water was used. As the pollutant source, a piece of wood having a 0.052 m^2 area was painted using the same anticorrosive paint used in stages 1 and 2.

Proportionately, for the real activity space, a quantity of 462g (i.e., 10g × 46.2) of lime slices soaked in 4.62l (100 ml × 46.2) of water was used. The painted area of the plank kept in the room was increased to 2.4 m^2 (0.052 m^2 × 46.2).

In both cases (chamber study and in the real room), the pollutant source was kept inside and a set of readings were taken. This was followed with a set of readings taken by keeping the lime slices soaked in water inside the chamber and in the real room.

The results of stage 3 of the experiment are presented in Figures 11 to 13, which compared the pollutant dispersion curves with and without lime slices soaked in water for the chamber and for the actual room.

FIGURE 10. The layout of the activity space where the actual study carried out in Stage 3.

4.3.1 Total Volatile Organic Compounds (TVOC)

The TVOC variation curves for the chamber study and the actual study are given in Figure 11.

A noticeable difference was observed for the TVOC dispersion rate and the peak values of the chamber study and that of stage 3 of the experiment carried out in an actual room. Table 9 presents the difference in peak values of the TVOC dispersion curves.

The chamber study shows a greater reduction in the peak value when lime slices soaked in water is kept inside the chamber. However, in the actual room, the reduction in peak value of TVOC concentration was half the value observed in the chamber study. It can be stated that by using the material substance inside an actual room, the maximum levels of TVOC cannot be reduced to the same extent that was observed inside a chamber.

FIGURE 11. Stage 3: Variation of TVOC Concentration.

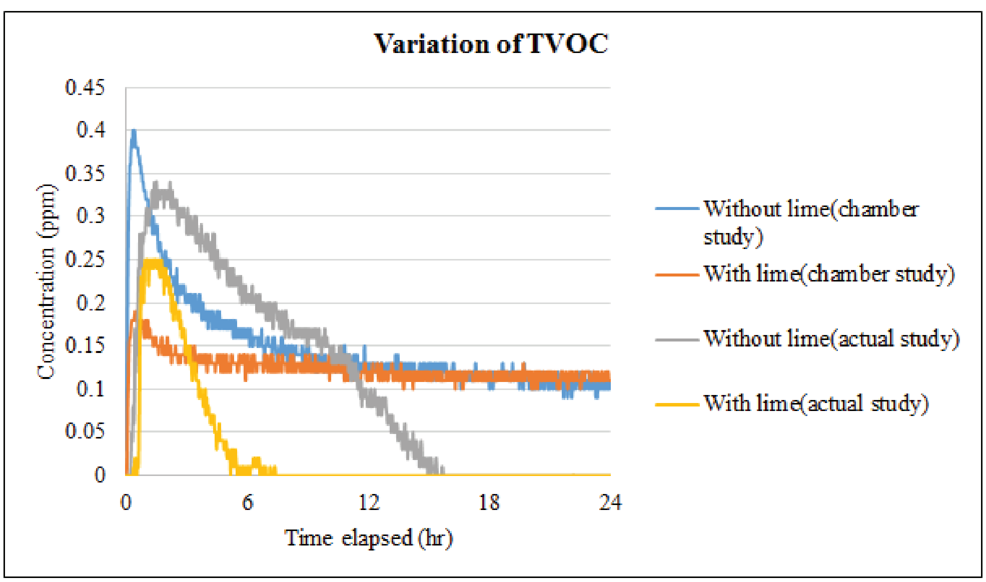


TABLE 9. Stage 3: Comparison of TVOC Peak Values.

Type of study	Material	Peak value TVOC/ppm	Comparative reduction in TVOC peak value	
			ppm	%
Chamber	With paint only	0.40	—	—
	With lime	0.19	0.21	52.5%
Actual	With paint only	0.34	—	—
	With lime	0.25	0.09	26.5%

It can also be observed that a faster dispersion of pollutants in the real room occurred compared to that of the sealed chamber. The difference in time taken to disperse the TVOC concentration with and without the pollutant absorbing agent is nearly 8 hours. This shows that there is a fair potential to use lime slices soaked in water as an air purifying agent in real building spaces.

4.3.2 Carbon Monoxide

Figure 12 presents the variation of CO concentration in the chamber study and in the actual room as a comparison.

It can be seen from the above graphs the highest CO concentration in the actual room was attained after 12 hours, followed by a gradual decrease to 0 ppm. However, in the chamber studies, there had been a continuous increase in CO concentration even at 24 hours, which could be due to the same phenomena explained in Section 4.2.2.

Table 10 presents the highest CO concentration reached during the experiments in both the chamber and in the actual room.

FIGURE 12 Stage 3: Variation of CO Concentration.

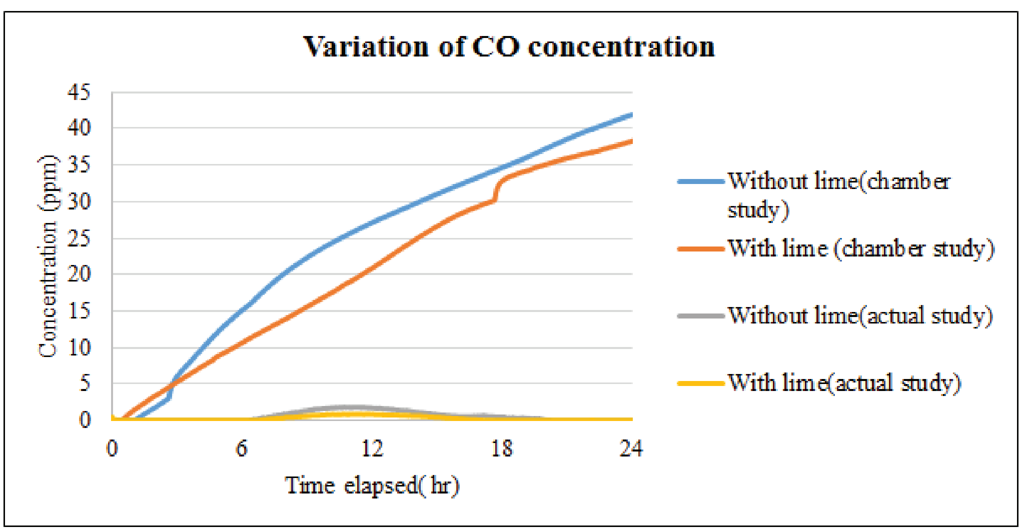


TABLE 10. Stage 3: Comparison of highest CO Concentration.

Type of study	Material	Highest value at 24 hrs (CO/ppm)	Comparative reduction in highest value attained in 24 hrs	
			ppm	%
Chamber	With paint only	41.94	—	—
	With lime	38.35	3.59	8.56%
Actual	With paint only	1.87	—	—
	With lime	0.88	0.99	52.94%

4.3.3 Carbon Dioxide

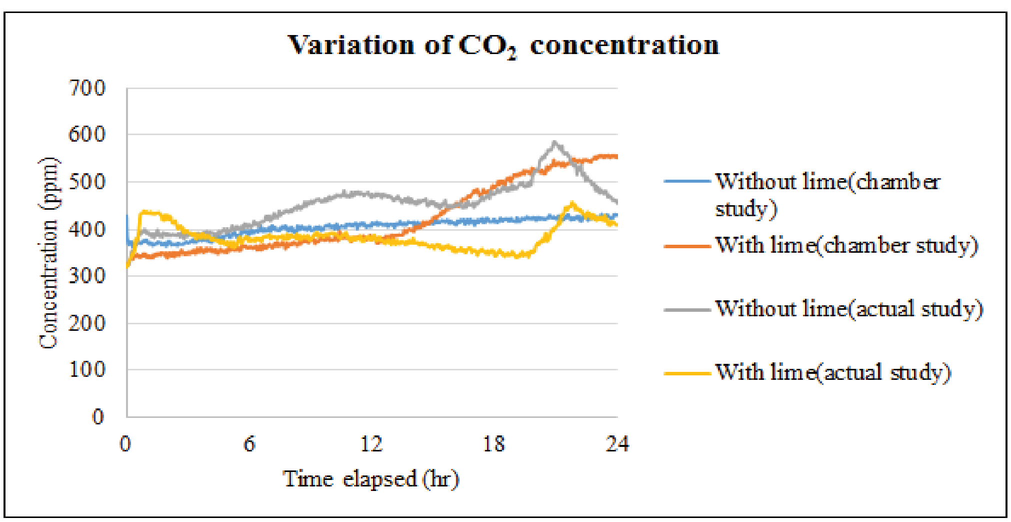
The CO_2 concentration variation curves of the chamber study and the actual study are presented in Figure 13.

In the chamber study, a relatively higher level of CO_2 concentration was observed whereas in the actual room it fluctuated around 400 ppm. A lower CO_2 concentration in the actual space was observed when the lime slices soaked in water was kept inside.

4.3.4 Stage 3: Discussion

The potential use of lime slices soaked in water as an indoor air purifying agent showed positive results in the chamber study as well as in the real indoor space. Although the magnitude of the purifying effect is not proportionate to derive a direct correlation between the chamber study and that in the actual indoor environment, a substantial reduction of TVOC and CO concentration was observed with lime slices soaked in water for both cases.

FIGURE 13. Stage 3: Variation of CO_2 Concentration.



5. CONCLUSION

Indoor air quality has been given much prominence in the sustainable design of the built environment. It is also a major component of indoor environmental quality, which is one of the main themes in most green building certification systems. The research covered in this paper was aimed at exploring some indigenous knowledge on indoor air purification and also to assess the feasibility of such knowledge for application in modern buildings. Based on the results of the questionnaire survey conducted among indigenous medical practitioners, a set of material substances was identified as indoor air purifying agents. These included lime slices soaked in water, straw soaked in water, baking soda, apple cider vinegar, coffee powder, and coal. In order to assess the effectiveness of such material substances, an experimental investigation was carried out in a chamber under controlled conditions. Lime slices soaked in water demonstrated the highest effectiveness, agreeing with the opinion of the majority of indigenous medical practitioners.

The chamber study has shown favorable results for the lime slices soaked in water showing a considerable reduction in TVOC and CO concentration. Further, regarding the positive trend of reducing the pollutant concentration observed with the increase in amount of lime slices, an optimum amount should be determined through further study.

To correlate the projection of the results of the chamber study to an actual indoor environment, the experiment was extended to a real indoor space. Although, it is hard to establish a clear correlation with the chamber study, a positive trend of air purification with lime slices soaked in water was observed in the real indoor space as well.

Therefore, lime slices soaked in water can be considered as an air purifying substance; further experimentation is needed to determine the optimum quantity required for a particular floor area of an indoor space. Future research should also focus on analyzing the impacts on air quality with material exposure for longer periods. Moreover, the type of volatile organic materials that can be removed by a particular substance should be chemically identified so that they can be targeted for air purification.

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