GREEN PLANT WALLS AS INDOOR AIR QUALITY ENHANCER IN THE RECENTLY BUILT OFFICE BUILDING

Aneka KLAVINA*[1], Buka BERZINA[2], Marta FJODOROVA[1] and Zanna MARTINSONE[1]

[1] Riga Stradiņs university, Riga, Latvia
[2] Ko tu elpo, Riga, Latvia
** Corresponding author: aneka.klavina@rsu.lv*

ABSTRACT

Nowadays one of the main focus of public and occupation health is maintaining good indoor air quality in office building and public spaces. The aim of this study was to identify indoor air quality, its influencing factors, sources of pollution and air quality enhancers. The results indicate that indoor air quality does not exceed the permissible levels for office buildings based on found chemical pollutants and CO_2 readings. Identified sources of chemical pollutants were printers with tonner, personal cosmetic products of workers, hand disinfectant and office cleaning products. Measurements indicated well-ventilated rooms. However, the control floor showed lower air humidity levels. Results shows up to 21% air humidity boost from plant green walls on weekends and up to 9% boost on workdays. The green walls with living plants help maintain good humidity levels.

INTRODUCTION

Air quality and microclimate is closely connected to human well-being, health and productivity (Al horr et al., 2016). It is estimated that in developed countries people spend up to 89% of their time indoors (Spalt et al., 2016; Thach et al., 2020), so it is important to keep this place clean. There are many ways to keep air clean like ventilation, mechanical air filtration, using non-toxic chemicals for cleaning and maintaining buildings. In addition to all of traditional ways there is bio-filtration as well (Nazaroff, 2021; Weschler, 2009; WHO Regional Office for Europe, 2010). Biofilters are also known as plant – based biowalls which are standalone system in which several houseplants are grown on growth medium and are indoor air bioremediation(Luengas et al., 2015; Mikkonen et al., 2018).

Bioremediation is the ability of living organism to cleanse the environment from pollution. For indoor air purification plants and microorganisms are practically used for this purpose (Mikkonen et al., 2018). Plants purify the air (Yang, Pennisi, Son, & Kays, 2009) and through root secretions, maintain microorganisms that also symbiotically support plant growth (Masciandaro, Macci, Peruzzi, Ceccanti, & Doni, 2013) and perform most of the degradation of harmful substances (Irga, Pettit, & Torpy, 2018).

It should be noted that in addition to the air purification function, biofilters also provide indoor air humidification and the benefits of biophilic design (Darlington, 2000). Biophilic design has a positive effect on human well-being and stress reduction (Gillis & Gatersleben, 2015) and productivity and work capacity (Browning, Ryan, & Clancy, 2014).

Optimal humidity ensures human health, especially the condition of the mucous membranes, eyes, mouth, nose and skin (Wolkoff, 2018). Temperature and humidity has been investigated in several studies and it shows that higher indoor air humidity decreases odour intensity and it has effect on perception of indoor air pollutants (Fang, 1998; Jin et al., 2020; Wolkoff, 2018)

Studies suggest that thermal comfort is very important in stress reduction (Zuo, Luo, & Liu, 2020); biowalls can ensure better temperature and humidity levels.

METHODS

The Building

The testing area was chosen in new co-working space office building. Completed in 2018, the 16-story office building is composed of 16 300 m^2 of A class office rooms, meeting rooms, conference places also services and public spaces. It is located in the VEFRESH area, which is centre for information and communication technology (ICT) professionals and companies in the region, accounting for more than 43% of Latvia's ICT industry exports also it is home for finance workers and other business in region. Building is located in industrial area between railroads and main street.

Building has united ventilation system for all floors. It is air exchange heating – cooling system without recuperation. Fresh air is coming in 45 m above the ground level. Extract is on the roof, supply is taken from fountain side (opposite side from front door) on sixteenth floor through the grill. Air ducts are cleaned every five years (after commissioning they have not been cleaned yet) air-handling units are cleaned every 3 months. Ventilation system uses pocket filters, F7 class for supply and M5 for exhaust. Air exchange rate is 2.5 times per hour. Ventilation works from 7:00 till 18:00 on working days and does not work on weekdays.

Facilities

The experiment was performed in two of the buildings floors, where finance sector workers are located. The 7th floor was chosen as control floor and the 8th floor was the test floor (the floor housing the Biofilter). The total floor area was 700 square meters. Both floors have the same floor layout, workplace stations, flooring material, ventilation modes also both floors have option to open windows during working hours. In the testing floor there were six Biofilter systems (fig.1). The study took place for 6 months during heating season.

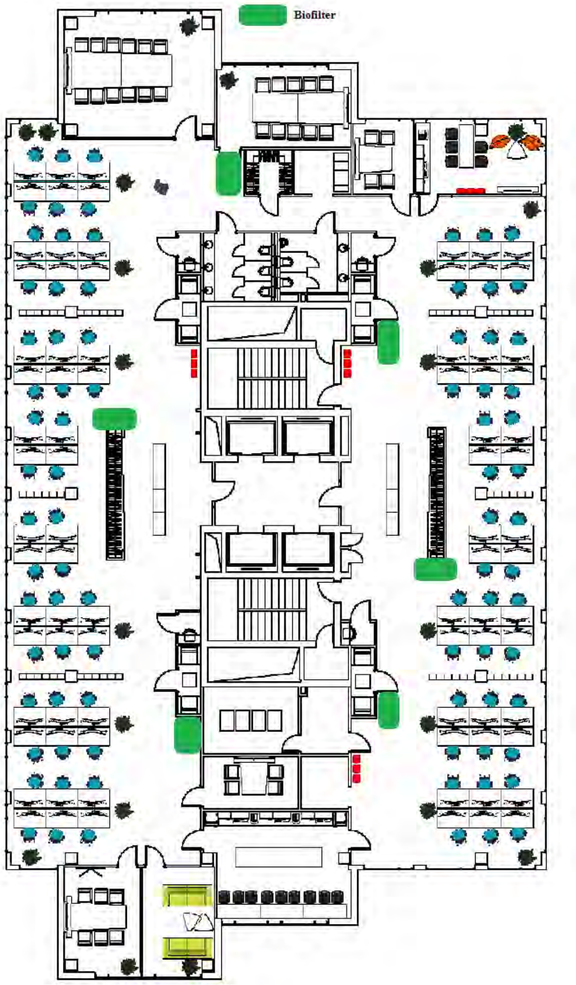

Figure 1. Test floor schematic plan and Biofiter placement.

The Bio-filtration System

There are six functional components of the system: hydroponic plants, air fan, self-watering system, self-regulated light system, clay pebbles as growth medium and microbes that degrade indoor air pollutants. Biofilter is standalone system, dimensions 110 x 240 x 40 cm, made from concrete, aluminium and PU material. Biofilter working principle – fan pushes indoor air through the porous clay substrate with regulated air flow (fig.2 and fig.3).

Air is forced by a ventilator through a wet ceramic substrate populated by plant roots and microorganisms. Pollution is adsorbed on their surface resulting in air that is cleaner and more humid returning to the room. The substrate is lightweight expanded clay aggregates which are very porous, adsorbent and have great air permeability.

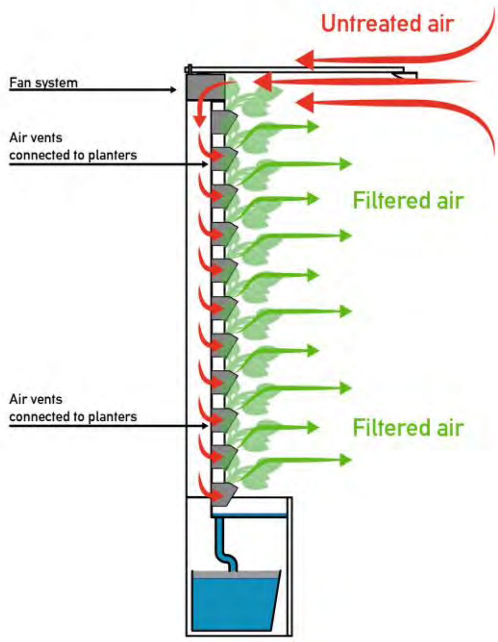

Figure 2. Air circulation process in Biofilter system

Average humidity output from one biofilter is 1.5 L/h, consensually output from six biofilters is 9 L/h, and nevertheless, levels were calculated in controlled environment and may differ during the experiment.

Plant species used in biofilters:

1. Aglaonema sp.
2. Chamaedorea elegans
3. Monstera adansonii
4. Schefflera sp.
5. Philodendron erubescens 'Imperial red'
6. Philodendron hederaceum
7. Philodendron hederaceum 'Brasil'
8. Epipremnum aureum 'Golden pothos'
9. Epipremnum aureum 'Marble Queen'
10. Scindapsus pictus 'Argyraeus'
11. Epipremnum aureum 'Neon'

A metagenome analysis for this biofilter was done by one of related studies. As far as studies suggest, no species of human pathogens can be found in the biofilters. The biofilter microbiome is space specific, because of its interaction with the room's air. Also, every plant species interaction can lead to wildly different microbiomes. In this case, the biofilter microbiome can only be characterized generally. The biofilter affected barely indoor air microbiome and humans were the greatest source of microorganisms in air (Berg, Mahnert, & Moissl-Eichinger, 2014; Kalniņš, Žorža, Sieriņa, Epners, & Muter, 2020). Furthermore, the microorganisms released by the biofilter are in insignificant concentrations in comparison to human sourced microorganisms.

The biofilter operation parameters followed a set schedule that encompassed the working day. The substrate and plants were watered with the nutrient solution every two hours for 10 minutes from 9:10 until 21:10. Ventilators operated between 9:00 and 21:00 and the light worked between 8:00 and 21:00, both continuously. Ventilators were set to an air delivery speed of 80 m3/h and 150 m3/h.

Lights illuminate the biofilter inducing photosynthesis which is needed for exudate production, and, of course, for the plants to live and look appealing.

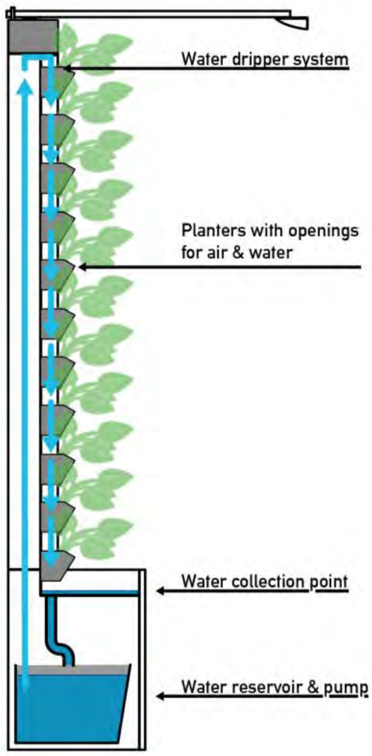

Figure 3. Biofiltration system - water circulation in boifilter.

Physical measurements

Air quality quantitative measurements were performed with Aranet T/RH and CO_2 monitoring device. Air was sampled at 0.8 m above the floor at regular intervals of 10 minutes throughout day for all of the study period. All data were logged in data cloud and analysed in multiple intervals - weekly, monthly and for all study period to determine possible bias.

Chemical pollution sampling and analysis

Aldehydes

Measurements for indoor air pollutants such as formaldehyde, acetaldehyde and other aldehydes was done using passive air sampling with Aldehydes & Ketones Diffusive Sampling Device DSD-DNPH from Supelco. Method principle: Carbonyl compounds like formaldehyde pass through the diffusive membrane and reacts with 250 mg, 2,4-dinitrophenylhydrazine (DNPH) coated silica gel absorbent to produce a hydrazine derivative. This derivative was eluted by acetonitrile, then analysed by HPLC using Hypersil C18 (4.5x150 mm) column 60/40 Acetonitrile/water as mobile phase. Air sampling was done at 1.2 meters above floor level, in the beginning of experiment and one month after Biofiter installation each time collecting and analysing 12 samples for total of 24 samples.

Volatile organic compounds

VOCs measuring were done with two methods: passive 3MTM Organic Vapor Monitors and active air sampling pumps (Gilian air LFS 113) that drew air (ca 100mL/min) through sorbent tubes. In the same way, samples were collected before Biofilter installation and one month after installation. SHIMADZU GC - 2010 Plus Gas Chromotagraph with FID detector and Rxi – 5 (0.25 µm x 60 m x 0.32 mm) column was used for VOC analysis. Likewise, 24 samples were collected and analysed.

To determine a relationship between the results nonparametric analysis methods in *The R Project for statistical Computing* program were used.

RESULTS

Chemical pollution

The results indicated that indoor air quality did not exceed the permissible levels for office buildings based on found chemical pollutants. The results of the chemical pollutants found in the both floors are summarized in the Table 1.

However, formaldehyde and acetaldehyde were found in detectable level, but other carbonyl compounds were below detection levels. The Formaldehyde levels for both floors (see in Table 1) were lower or close to WHO reported median formaldehyde levels of 25 ug/m^3 in non-industrial facilities and lower than reported mean levels of 40 µg/m^3 (WHO Regional Office for Europe, 2010). There were significantly lower results after a month in the floor with biofitration. But it is valuable to note that also control floor had lower aldehyde results after a month, yet there were no significant differences in reduction in pollution between the test floor and control floor.

Table 1. Chemical pollutants in the control floor and in the test floor before biofilter and one month after biofilter installation

Monitored site	Pollutant name	Concentration µg/m^3
The test floor before biofilter installation	Formaldehyde	37.2
	Acetaldehyde	13.5
	VOCs	429

The control floor in beginning of experiment	Formaldehyde	16.4
	Acetaldehyde	7.7
	VOCs	416
The test floor after biofilter installation	Formaldehyde	13.7
	Acetaldehyde	7.4
	VOCs	469
The control floor after one month	Formaldehyde	10.6
	Acetaldehyde	4.6
	Summary VOCs	470

Accordingly VOCs levels were higher than 300 μg/m^3 WHO threshold limit for good indoor quality (WHO Regional Office for Europe, 2010). Aldehydes were taken out of VOC calculation. There were higher results of VOCs after one month in experiment; results were connected with disinfectant usage during pandemic. For example, ethanol, isopropanol, chloric compounds and benzene were found in air samples, but in small concentration to raise concern. Literature suggests that biofilters may be lowering VOC levels, but there was no substantial evidence; more research needs to be done using more sensitive methods for VOC detection and longitudinal monitoring approach for evaluation of chemical exposure.

Indoor air microclimate

Carbon dioxide measurements were monitored through all experiment period, results showed that CO_2 concentration is connected with working hours and cleaning schedule (fig,4); worker count in both floors were similar and fluctuation difference were 3 to 6 persons per day. The concentration levels during week day ranged from 434 to 750 ppm; average CO_2 concentration in test floor was 554 ppm and in control floor - 556 ppm. There was statistically significant improvement ($t=3.9332$; $p<0.001$) on test floor with biofiltration systems. Overall, CO_2 levels were lower in test floor thus biofitration can help reduce CO_2 concentration (Darlington, 2000). According to the analysis of carbon dioxide concentration in the aspect of meeting international standards and recommendations, it was determined that measurement results of CO_2 concentration did not exceeded the recommended limit of 1000 ppm for public spaces (Azuma, Kagi, Yanagi, & Osawa, 2018). On the contrary of reducing indoor CO_2 levels to minimum possible level by ventilation with ambient air, which as a result increases energy consumption in an air-conditioned building. The building's owners could lower ventilation air exchange rate or introduce air recuperation system.

Moreover, temperature measurements did not show any statistical differences between test floor and control floor. Mean temperature during experiment period was 23.2°C in test floor and 23.4°C in control floor. Biofilter had no impact on temperature, however many studies suggest plant based thermoregulation in indoors (Darlington, 2000; Gillis & Gatersleben, 2015; Llewellyn & Dixon, 2011).

Finally, humidity levels were improved by biofiltration system. Biofitration worked in two modes, both shows improvement. The first mode was in beginning of experiment from 45th to 48th week; mean relative humidity level in the test floor was 35.4%; in the control floor 33.0%. There was notable statistical improvement on relative humidity levels 7% ($t=-13.119$; $p < 2.2e-16$) from 45th to 48th week.

Mean relative humidity levels in test floor was 24.1%; in control floor 20.9% from 49th to 50th week. Relative humidity improvement was 16% in this period ($t=-15.29$; $p < 2.2e-16$). Relative humidity results and percentage improvement are summarized in the Table 2.

In all the test period humidity improvement was 9% in week day and 21% in weekends. The difference is so excessive on weekends because ventilation was switched off and extra humidity from biobiolters was not ventilated out (fig.5).

Table 2. Relative humidity results with different watering methods

		Method 1 (week 45 - 48)	Method 2 (week 49-50)	Overall results (week 45 – 50)
C*	Mean relative humidity levels, %	33.0	20.9	24.2
T**		35.4	24.1	27.3
Relative humidity levels percentage improvement in week days		7%	16%	9%
Relative humidity level percentage improvement in weekends		15%	50%	21%
* Control floor ** Test floor with biofiltration system				

In addition, theoretical calculation shows that there should be extra 6 litres water vapour per hour in test area, but real situation shows different results. As biofilter is a living organism and its behaver is room specific, extra measurements need to be done before and after placing biofilter in the office environment to gain maximum outcome. Nevertheless, humidity levels enhanced in the test floor.

Moreover, a considerable effort was made to avoid indoor air pollution thanks to ventilation requirements.

Of course, the testing of biofiltration systems is continuing and adjustment and selection of monitoring methods are provided during each evaluation period, nevertheless 12-month study would be recommended for throughout impact on air quality depending on time of year.

CONCLUSIONS

There is small improvement investigated between test floor and control floor regarding chemical pollution such as aldehydes and VOC's.

The more sensitive and longitudinal testing is necessary for chemical pollutants (e.g., aldehydes, VOC's) detection and evaluation.

The bio-filtration systems impact to air humidity is significant to improve indoor air conditions and human well-being in general.

With biofiltration system it is advisable to reduce air exchange rate and maintain CO_2 concentration within recommended values to reduce energy consumption which in turn is a desirable effect.

The longitudinal assessment approach and more sensitive methods selection are necessary to improve complex evaluation of bio-filtration systems effectiveness during next research periods.

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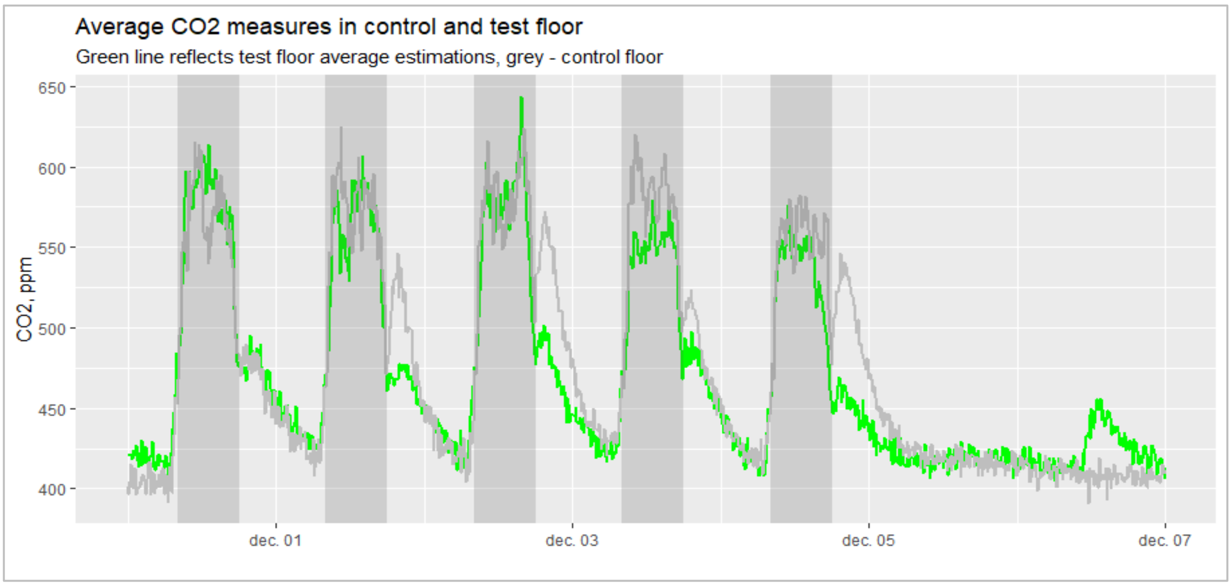

Figure 4. Average CO_2 levels in test floor and control floor during one week in experiment period. It shows that CO_2 levels are connected with working hours and are lower in test floor.

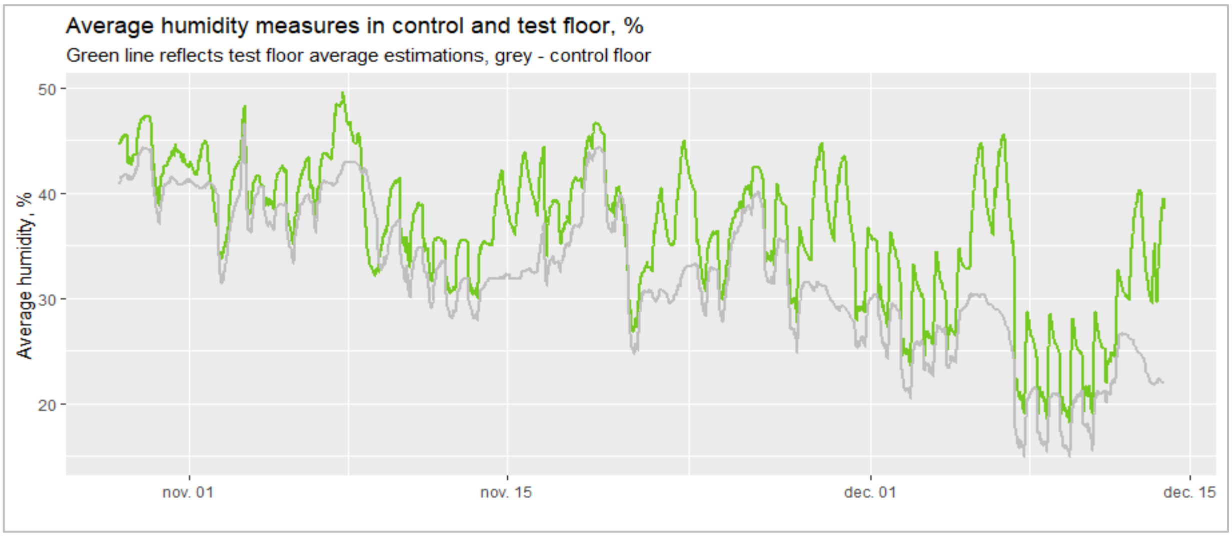

Figure 5. Average relative humidity levels in test floor and control floor from 45 to 50 week with both watering methods in biofilter.