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Micro-Climate and Suspended Particulate Matter in Industrial Interiors, its Effect and Methods to Control Using Landscaping Green Elements.

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ABSTRACT
This paper deals with effect of plants an element of landscape on micro-climate inside aluminum powder producing industry. With the objective to bring micro-climate conditions within or near comfort zone and also create better health condition to benefit health of workers in industry. The experiments were conducted with increase in density of plants in shortlisted experimental area. Identification and adoption of plants with glossy foliage for aluminium powder industry of grade (PAG-4C) is crucial for optimum results. The outcome has shown encouraging results to facilitate architectural intervention towards creating conducive work environment within the industry.

Introduction

Controlling micro-climate positively with plants (an element of landscape) to bring positive change, without use of any mechanical systems can be an innovative idea and especially a method to reduce suspended particulate matter in an aluminum powder producing industry. Indoor plants and foliage within the work area is not only soothing to human eye but also can play a positive role specially in controlling the temperature rise but also improve humidity levels. It will be a worthwhile effort to experiment with the indoor plants in increasing their numbers, placing them effectively and subsequently measure the micro-climatic factors as well as the Volatile Organic Compound within the indoor industrial environments. The validity of above hypothesis was verified with experimentation at a factory producing aluminum powder, Bhandara Nagpur. Experiments were conducted and observations obtained at aluminum powder industry, Bhandara, Maharashtra, near Nagpur. The objective of this experimentation was to ascertain the possibility of the control of micro-climate closer to comfort zone with placement of plants in indoor industrial environment. The experiments were conducted in all seasons, namely the first to tenth day of May, July and December 2016.

Parameters

The micro-climatic measurements were planned to be done at every three hours interval so as to coincide with meteorological data. The parameters considered for the experimentation are as under:

- Dry Bulb Temperature (DBT)
- Wet Bulb Temperature (WBT)
- Air Velocity
- Relative Humidity (RH)
- LUX (Illumination)
- Volatile Organic Compound (VOC counts)

Site details

The aluminum powder manufacturing industry at Bhandara, Nagpur.

The experiments were planned to effectively deal with the micro-climate control with emphasis on VOC control. The unit operates in three shifts with around 1060 employees. The site is identified for the experimentation to examine the effect of vegetation on micro-climate control with emphasis on temperature, humidity, suspended particulate matter control and VOC control in indoor environment.

Figure 1. Epipremnum aureum placed in experimentation area within the industry.

Adopted methodology and strategies

The areas within the industry were properly identified cautiously such as areas of high temperature zone; noisy spaces and area with higher level of pollution of suspended particulate matter of aluminum were mapped.

In order to achieve reduction in the temperature, increasing the level of humidity and bring the air pollution within the comfort zone the planters were arranged in a specific manner illustrated in figure 4. The planters were filled half way with activated charcoal and remaining half with micro-nutrients and compost with an idea to facilitate the absorption of VOCs not only by plants but also by the activated charcoal and compost.

1) Placement of planter was considered to be placed at the breathing level of workers either in sitting position (1.10m) or at standing position (1.40m).

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2)Planting arrangement design and placement of vertical stands was also carefully be worked out so as to assure sufficient illumination levels can be maintained in the indoor environment.

3)Maintaining a continuous irrigation of hanging baskets for their proper and healthy substance was worked out as illustrated in the figure 4.

Ficus benjamina.

Dracaena marginata.

Epipremnum Aureum Golden Pathos.

Epipremnum aureum (marble queen) variegated.

Epipremnum aureum.

Dracaena fragrans

Figure 2. Plants with glossy foliage were identified and shortlisted in aluminum powder industry, Bhandara Nagpur.

This indoor plant species due to their glossy foliage coupled with the activated charcoal planting mixture performed at the maximum level in reduction of fine aluminum grade (PAG-4C) suspended particulate matter.

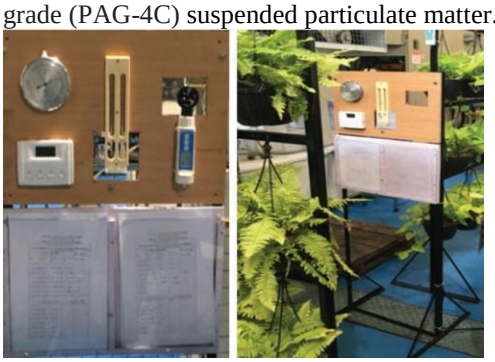

Figure 3.Mounting of Measurement Equipment.

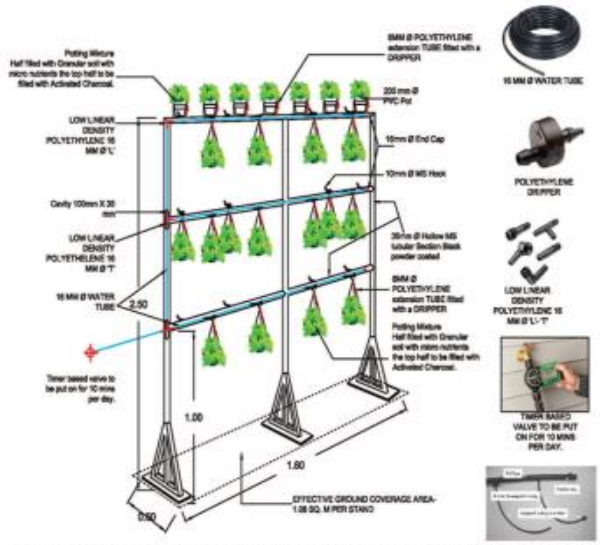

Figure 4. View of a typical tubular M.S. fabricated stand with built in position of drip irrigation system along with placement of hanging baskets of shortlisted plants.

Dry Bulb as well as Wet bulb thermometer was used to record the temperatures which were then documented by scaling them on histogram. Histogram was used to find at the resulting comfort zone indices. Hygrometer was used for the measurement of relative humidity within the experimental zone.

The experiment in shortlisted areas was carried out under the artificial illumination of 12 lumens /1.15 Foot candles. Histogram was used for finding out effective temperature

(ET) and to calculate if the value of E.T. whether it lies closer to comfort zone. From the Histogram it was observed that effective temperature drops closer to the comfort zone with placement of 240 hanging baskets / pots for the indoor at the indoor velocity of 1 m/s. The Dry Bulb Temperature (DBT) of 31.2°C and correspondingly Wet Bulb Temperature (WBT) recorded at 11.30AM. on 10th May 2016 was plotted on the Histogram as illustrated in figure 5. The straight line joining the plotted temperature of 31.2°C DBT and 27.4°C WBT intersects the air velocity curve of the value of 1 m/s and the temperature readingat this intersection which is regarded as effective temperature (ET) reads as 28.10°C.

The comfort zone indicates temperature in range of 22°C–26°C and the readings available are 27.3°C. This suggests that the indoor temperature of the industrial unit at 11.30 AM was higher by 3.5°C. The entire micro-climatic data at the time of experimentation was tabulated at every three hours per day and analysed as per the meteorological data.

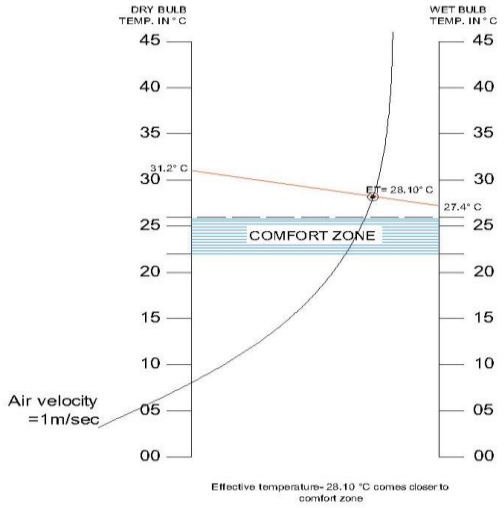

Figure 5. Histogram depicting the effective temperature.

Figure 6. Aluminum Suspended particulate matter deposition on the Dracaena leaves.

Figure 7. Aluminum Suspended particulate matter deposition on the Bougainville shrubs immediately outside the Pilot Plant section.

Figure 8. Suspended particulate matter settled on the equipments in the production area .

Figure 9. A series of Epipremnum aureum plants arranged on low rise stands in the administrative section.

Figure 10. Epipremnum aureum (Money plant) kept in the finished product area.

Table 1. Experimentation Inside Aluminium powder industry, Bhandara, Nagpur 1St and 10th Day of May 2016.

	Data from MET. Dept. Nagpur		Data from MET. Dept. Nagpur		Indoor- Dry Bulb Thermometer		V O C METER (READINGS WITHIN THE EXPERIMENTATION ZONE					
Time	**Outdoor Temperature ^{0}C**		**Humidity %**		**Indoor Temperature ^{0}C**		**Temperature ^{0}C**		**Humidity %**		**VOC count (PPM**	
	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10
02:30 am	27	30	49%	39%	30.6	34.5	Dd 30.1	32.0	44%	54%	9.7	6.5
05:30 am	27	27.4	50%	41%	29.2	31.1	28.6	28.5	48%	53%	9.3	6.2
08:30 am	35	37.2	42%	36%	39.3	41.3	38.8	39.8	32%	37%	10.2	5.9
11:30 am	38.6	43.4	39%	36%	42.4	47.9	41.9	45.2	29%	32%	7.9	5.2
02:30 pm	41	44.2	29%	13%	44.8	48.1	44.3	45.24	21%	32%	9.8	5.8
5:30 pm	39	42.8	33%	13%	42.9	47.2	42.4	44.6	20%	37%	9.1	6.1
08:30 pm	33.2	36.4	54%	31%	37.7	40.9	37.2	38.2	23%	42%	8.7	6.0
11.30 pm	31.4	31	48%	30%	35.5	35.9	35.0	33.3	37%	54%	9.1	5.9

From the above table, it can be observed that inside the conditions in the experimental area inside the building of aluminum powder industry 10th day of May, 2016 are as given below:

1) TEMPERATURE at 11:30 am

The outdoor temperature 43.4°C is less than the indoor temperature that is 47.9°C.

The indoor temperature in experimental zone as per VOC meter is 45.2°C and the indoor Dry Bulb Temperature is 47.9°C.

The temperature in experimental zone thus is reduced by 2.7°C.

From the graph, we could be inferred that in the month of May, the temperature is reduced by 2.7°C and brings it closer to comfort zone.

2) Humidity at 11:30 am

The outdoor humidity on first day is 39% and on the 10th day, it is 36%.

In experimentation zone on first day is 29% and on the 10th day it is 32%.

It can be inferred that the humidity level increases by 3%.

The increased 3% humidity level brings it closer to the comfort zone

3) VOC (Volatile Organic Compound) at 08:30 pm

The VOC is reduced from 9.1 ppm to 5.9 ppm in 10 days. By putting 250 numbers of potted plants/hanging basket.

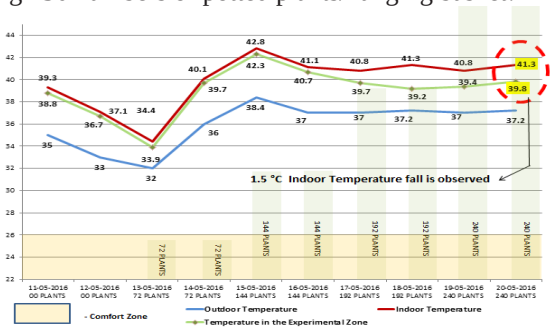

Figure 11. Graph illustrating VOC at Bhandara, Nagpur on May-2016 at 8.30AM.

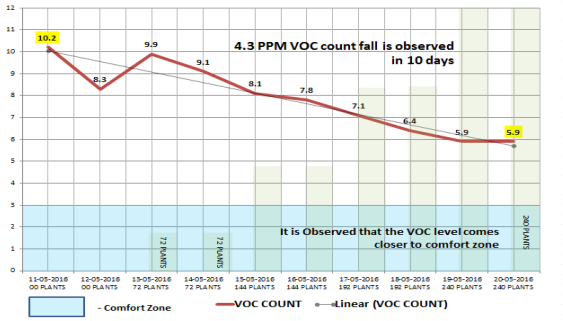

Figure 12. Graph illustrating Temperature at Bhandara, Nagpur on May-2016 at 8.30AM.

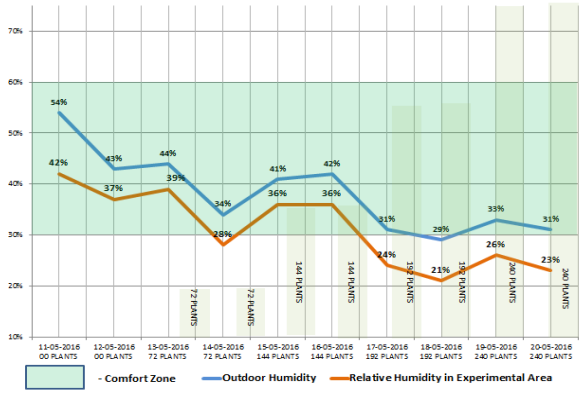

Figure 13. Graph illustrating Humidity at Bhandara, Nagpur on May-2016 at 8.30AM.

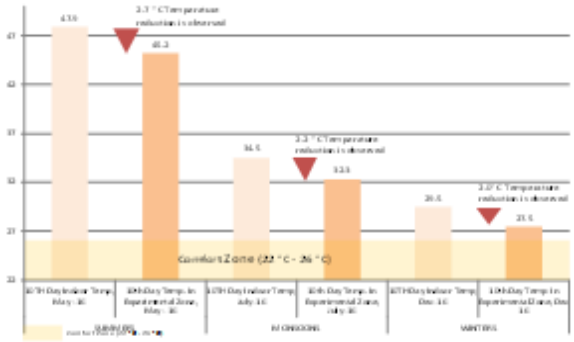

Figure 14. Comparative Analysis of Temprature at Bhandara,Nagpur on May-2016 at 8.30AM.

From the above table, it can be observed that the conditions in the experimental area inside the building of aluminum powder industry on 10th day of Dec, 2016**:**

1) TEMPERATURE at 11:30 am

The outdoor temperature 28.2°C is less than the indoor Dry Bulb Temperature that is 28.7°C.

The indoor temperature in experimental zone as per VOC meter is 29.9°C and the indoor temperature is 28.7°C.The temperature in experimental zone is reducing by 1.2 °C.

From the graph, it could be inferred that in the month of May, the temperature is reduced by 2.7°C which brings it closer to comfort zone.

2) Humidity at 11:30 am

The outdoor humidity on first day is 39% and on the 10th day, it is 47%.

In experimentation zone on first day is 35% and on the 10th day it is 36%.

It can be inferred that the humidity level decreases by 11%.

The decreased humidity levels maintain it within comfort zone.

Table 2. Experimentation Inside Aluminium powder industry, Bhandara, Nagpur 1St and 10th Day of December 2016.

	Data from MET. Dept. Nagpur		Data from MET. Dept. Nagpur		Indoor- Dry Bulb Thermometer		V O C METER (READINGS WITHIN THE EXPERIMENTATION ZONE					
Time	Outdoor Temperature ^{0}C		Humidity %		Indoor Temperature ^{0}C		Temperature ^{0}C		Humidity %		VOC count (PPM	
	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10	Day 1	Day10	Day 1	Day 10	Day 1	Day 10
02:30 am	14.4	10.6	89%	92%	17.9	15.1	Dd 17.4	12.6	84%	87%	5.1	3.1
05:30 am	12	9	93%	84%	15.1	12.7	14.5	10.1	80%	77%	5.1	2.9
08:30 am	17.6	14.6	55%	63%	21.7	18.7	21.2	17.1	50%	55%	5.5	2.9
11:30 am	27.6	25	35%	29%	31.1	29.5	34.5	29.4	24%	21%	5.3	3.2
02:30 pm	30.8	28.4	27%	29%	35	32.3	24.8	19.8	53%	52%	5.5	2.9
5:30 pm	21	18	57%	59%	25.3	22.4	21.8	16.8	64%	69%	5.4	3.0
08:30 pm	17.6	14.6	69%	70%	22.3	19.1	20.1	15.1	71%	79%	5.4	2.8
11.30 pm	15.8	12.8	77%	86%	20.6	17.7	20.1	15.1	71%	79%	5.4	3.3

3) VOC (Volatile Organic Compound) at 08:30 pm

The VOC is reduced from 8.3 ppm to 5.0 ppm in 10 days. By putting 250 numbers of potted plants/hanging basket in experimental area of 1820Sqm. The VOC absorbed count was down by 3.3 thereby bringing the VOC count to comfort zone.

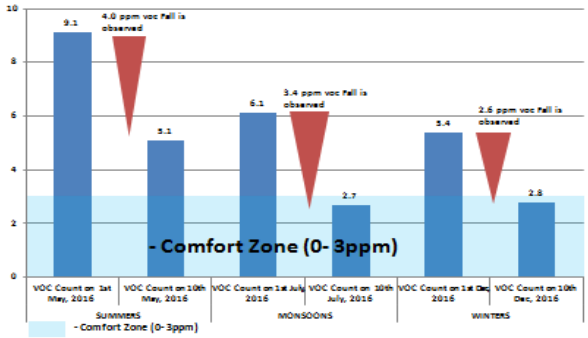

Figure 15. Comparative Analysis VOC at Bhandara, Nagpur on May-2016 at 8.30AM.

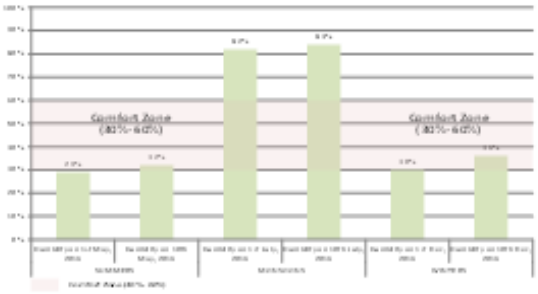

Figure 16. Comparative Analysis VOC at Bhandara, Nagpur on May-2016 at 8.30AM.

Observations and Inferences

• The experiments carried out within the industrial interiors of aluminium powder industry, Bhandara, in the month of May - 2016, it is noticed that indoor temperature reduced with the vegetation density of 240 hanging baskets, the effective temperature falls closer to comfort zone (22° C - 27° C) by 2.7°C.

-May -2016 temperature variation shows reduction from 47.9 ° C to 45.2 ° C that is 2.7°C at noon.

-July -2016 temperature variation shows reduction from 32.3° C to 29.6° C that is 2.2°C at noon.

-Dec -2016 temperature variation shows reduction from 29.9°C to 28.7°C that is 1.2°C at noon.

From the above it can be inferred that the effective temperature falls closer to comfort zone, that is 2.7°C in May, 2.2°C in July and 1.2°C in December**.**

• Relative Humidity with placement of 240 number of hanging baskets with vegetation at noon.

-May -2016 humidity variation recorded is 3% that is from 32% to 29%.

-July -2016 humidity variation recorded is 8% that is from 92% to 84%.

-Dec -2016 humidity variation recorded is 1.2% that is 29.9% to 28.7%.

From the above it can be inferred that the relative humidity level falls closer to comfort zone (30-60) that is 3% in May, 8% in July, reduced by 1.2% in December.

• The Volatile Organic Compound (*VOC)* an inherent component of the indoor air within the industrial envelope. The experiment reveals that Volatile Organic Compound (*VOC) and* suspended particulate matter of aluminium powder showed a definite trend in reduction with increase in plant density from 190 to 240.

-May -2016 VOC level falls from 9.1 ppm to 5.9 ppm that is 3.2 ppm at noon.

-July -2016 VOC level falls from 9.1ppm to 3.7 ppm that is 5.4ppm at noon.

-Dec -2016 VOC level falls from 8.3 ppm to 5.0 ppm that is 3.3 ppm at noon.

From the above it can be inferred that the VOC levels and suspended aluminum powder of grade(PAG-4C) falls closer to comfort zone that is 3.2 ppm in May, 5.4 ppm in July, 3.3 ppm in December.

From the experimentations carried out within the industrial interiors of aluminium powder industry, Bhandara during the year 2016 it can be established that the microclimatic factors such as Indoor Temperature, Relative Humidity and the VOC count can be regulated and brought closer to the comfort zone, by systematic placement of plants as element of indoor landscape.

Recommended Strategies to control and improve micro-climatic conditions, inside Industrial units, with the help of Green elements are as follows:

• A systematic identification and adoption of appropriate plants for aluminium powder industry of grade (PAG-4C) is primary consideration for results. As well as towards effectively designing architectural interventions to help creating conducive work environment within the industrial interiors.

• To regulate and mitigate the comfort level within the industrial units by adopting landscape interventions, use of various species of plotted plants and customises their arrangement and proper location with respect to work areas and or in critical areas.

• The encouraging results obtained through various field experiments and research process conducted in various kinds of built spaces the concept of adopting green landscape elements in the form of plotted plants or similar vegetation to regulate and mitigate comfort levels is worth recommendation and adoption for universal application.

• Research process adopted for conducting various experiments through the above explained research work can be effectively applied in industrial units as well as in other built spaces where the hazardous discharge of VOC is prevailing.

Conclusion

• Innovative landscape interventions similar to one as conducted through the experiments explained therefore can be effectively adopted in all work requirements to enhance micro-climate comfort levels resulting into the working effectively and improved healthy climate as well.

• Through experiments are conducted in tropical compost climate of several industry the final recommendation can also be implemented in other industries of similar nature in other type of climate region with alternate in selecting plant species keeping in mind special feature of climate.

From the survey conducted through the questionnaire to a great extent establishes that the workers working in this type of indoor environment suffer from Sick Building Syndrome (SBS) which affect their health resulting from causes such as drowsiness, irritations, fatigue, nausea, loss of concentration and appetite etc. Beside this survey also established that persons working within indoor spaces prefer an interaction (may be visual only) with natural elements such as vegetation.

Analysis of data obtained through the questionnaire survey also clearly establishes the fact that the work efficiency is directly proportional and relative to comfort zone in the work areas.

From the post experimentation questionnaire survey the well-being of the workers resulting in increased productivity by

3.42% and a positive outlook towards the company could be ascertained.

References

Air Quality Guidelines for Europe. World Health Organization European, Regional Office for Europe, Copenhagen, Series No.23, 1997.

Arvind Krishan. Climate Responsive Architecture. Fourth Reprint. Edited by Arvind Krishan. New Delhi, New Delhi: Tata McGraw Hill Education Private limited, New Delhi, 2009.

Environmental Interioscapes : A Designer Guide to Interior Plantscaping And Automated Irrigation System. New-York : Watson - Guptil Publications. p. 28. Vol. 2.Wolverton, B. C et al.. Interior landscape plants for indoor air pollution abatement. NASA/ALCA Final Report, Plants for Clean Air Council, Mitchellville MD, 1989.

Richard L. Austin, ASLA. Desining the natural landscape. New York, N. Y.: Van Nostrand Reinhold, Company Inc., 1983I*s Your Building Making You Sick?* Washington D.C. : Service Employees International Union, 2005. Vol. II.

Plann.ing, Design and Management of Engineering Services in Green Building Projects; SPA, New DelhiWolverton, B. C, PhD. Principal Investigator Interior Landscape plants for Indoor Air Pollution Abetement, Final Report SeptemberHammer, Nelson. *Green, Interior Landscape Design.* s.l. : ASLA, 1991. pp. 34-35.

Wolverton, B. C. Higher plants for recycling human waste into food, potable water and revitalized air in a closed life support system.

Interior Landscape Plant For Indoor Air Pollution Abatment. s.l. : NASA, John C. Stennis Space Center, 1989. pp. 1-5.

NASA/ERL Research Report No. 192, August 1980.

Health and Safety In the Office. New South Wales : WorkCover Publications.

Koenigsberger. et al. August 1973

Manual of Tropical Housing and Building, Orient Longman Limited, Chennai (Madras), India pp.49-60

U. S. Environmental Protection Agency. Report to Congress on indoor air quality, Vol. II: Assessment and control of indoor air pollution. EPA/400/1-89/001C, pp. 3-6.

Making a Healthy Living Space Through The Concept of Healthy Building of Building Medicine. Chang, Chich-Yuan. s.l. : FengChia University, Taiwan.

Message in Bottle. Charles, Fishman. s.l. : Fast Company Magzine, July 2007.

NASA John C Stennis Space Center, 1989. pp. 6-8.

Sick Building Syndrome : How indoor plants can help clear the air. Irga, Peter and Burchet, Prof. Margaret. Sydney : s.n., July 2013.

Snyder et al. Environmental Interioscapes: A Designer's Guide to Interior Plantscaping And Automated Irrigation System. New-York : Watson-Guptil Publications, 1995. pp. 26-29. Vol. 2.

Takayuki Kondo et al.Absorbtion of Formaldehyde by olender (Nerium Indicum). 1995, Vol. 29.

The Interior Plantscapers. Irga, Mr. Peter et al.Australia : Horticulture Australia Limited and Dutch Flower Foundation, 2013.

Wolverton, B. C., R. C. McDonald and E. A. Watkins, Jr. Foliage plants for removing indoor air pollution from energy-efficient homes. Economic Botany, 1984, 38(2):224-228.

U. S. Environmental Protection Agency. Report to Congress on indoor air quality, Vol. II: Assessment and control of indoor air pollution. EPA/400/1-89/001C, pp. 3-6.

Wood, R. A., M. D. Burchett, et al The potted-plant microcosm substantially reduces indoor air voc pollution; I. Office Field-Study. J. of Water, Air and Soil Pollution, 2006, 175(1-4):163-180.

http://www.rainbird.com/LANDSCAPE/resources/DesignGuides.htm

https://en.wikipedia.org/wiki/Volatile_organic_compound

https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds

https://en.wikipedia.org/wiki/NASA_Clean_Air_Study

http://www.health.state.mn.us/divs/eh/indoorair/voc/

https://www.health.ny.gov/environmental/indoors/voc.htm

https://www.cdc.gov/nceh/clusters/Fallon/Glossary-VOC.pdf