Altering micro-climatic condition with green elements in industrial interiors

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Abstract : Indoor Plants as an element of landscape when systematically planned and arranged can beneficially and favorably affect micro-climate inside the industry. The effort is with the purpose to beneficially and favorably control the micro-climate to enhance the productivity as well as sound health condition of the workers. To validate this hypothesis experiments were conducted simultaneously within three industries by adopting the varying density of indoor plants for specific gaseous pollutants. In this process the focus was to achieve the reduction of indoor temperature with the change in density of indoor plants. The results obtained have shown encouraging outcome and simultaneously put forward in comparative analysis of results in three industries. This methodology when properly designed planned and executed besides mitigating micro-climate can further be adopted in creating conducive work environment as well as increase productivity.
IndexTerms - Micro-climate, health condition, productivity, gaseous pollutants, work environment**.**

I. INTRODUCTION

The effort through this experimentation was to find out what density of plants (vegetation) can alter micro-climatic condition positively with emphasis on indoor temperature, humidity and reduction of volatile organic compound. For this purpose the experimentation apparatus which include measurement of micro-climatic factors were set up simultaneously in three industries. The industries shortlisted for this purpose were steel circlips manufacturing unit, an aluminum powder industry of grade (PAG-4CL) and an indoor office space of Enviro LTD., all located in and around Nagpur, Maharashtra. The experiments at all the two industries and one office space were conducted for first 10 days in the month of May, July and December respectively. Altering micro-climatic condition positively with indoor plants (an element of landscape) without use of any mechanical systems was tried in these experiments. In experimentation the effort was to observe the changes in micro-climatic conditions with respect to increasing numbers of indoor plants strategically arranged on the mild steel fabricated stands. The observations were recorded with the emphasis on reduction in indoor temperature, increase of humidity and reduction in Volatile Organic Compound concentration in all the industries and office space. For Experimentation in all two industries and office space the following micro-climate measuring equipments were arranged at 1.40 mtr from the floor level, in critical area indoors.

II. OBJECTIVE

Altering micro-climatic conditions as well as with indoor plants(an element of landscape) without the use of any mechanical systems.

III. PARAMETER

The micro-climatic measurements were performed at every three hours interval with a view to coincide with meteorological data. The parameters considered for the experimentation were as under:

- Wet Bulb Temperature (WBT)
- Relative Humidity (RH)
- Air Velocity (m/s0)
- Illumination (LUX)
- Volatile Organic Compound (VOC)

IV. SITE DETAILS

A. CICLIPS INDUSTRY, M.I.D.C. BUTIBORI, NAGPUR, MAHARASHTRA, INDIA

The industrial unit is situated at M.I.D.C. Butibori, Nagpur. The unit manufactures the CIRCLIPS, a metal ring sprung into a slot or groove in a bar to hold something in place, and used in wide range of industrial products. The major component of raw material is steel. The unit operates in three shifts with around 450 workers. The site was identified for the experimentation to examine the effect of vegetation (indoor plants) on indoor industrial environment with emphasis as temperature, humidity and Volatile Organic Compound (VOC).

B. Enviro Ltd. Khamla, Nagpur, Maharashtra, India

The unit Enviro Ltd, is situated near somalwar school khamla, Nagpur, Maharashtra, India. The unit under experimentation is an office building for Enviro Ltd. which deals with the environmental treatment of waste disposal in various industries. The unit operates in two shifts with around 15-16 employees. The site was identified for the experimentation to examine the effect of vegetation on micro-climate control with emphasis on temperature, humidity and VOC control in indoor environment.

C. ALUMINUM POWDER INDUSTRY, Bhandara, Near Nagpur, Maharashtra, India

The aluminum powder manufacturing industry located at Bhandara, near Nagpur deals manufacturing of aluminum powder. The unit operates in three shifts with around 1060 employees. The site was 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.

V. PROCESSES

A. Ciclips Industry, M.I.D.C. Butibori, Nagpur, Maharashtra, India

Experimentation stations were strategically identified and mapped on the architectural plan with emphasis on areas in proximity to high temperature zones, noisy spaces, dust pollution/sources of volatile organic compound (VOC) generation. Identification of the critical areas for detail experimentation includes varieties of spaces, as well as that of heavy work station

Fig. 1 Plant suitability for absorption of VOC (Volatile Organic Compound) produced in the Circlips industry, Nagpur

B. Enviro Ltd. Khamla, Nagpur, Maharashtra, India

The complete office was properly and carefully surveyed, studied and placing emphasis on areas with comparatively high temperatures, high noise levels were shortlisted. Identified critical areas for purpose of experimentation mostly included spaces of computer operation of printer and connected related electronic gadgets since they generated due to their continued operations. All such identified (Shortlisted) pockets within the office building were carefully mapped.

Fig. 2 Plant suitability for experimentation in Enviro Ltd., Nagpur

C. Aluminium powder industry , Bhandara, Nagpur

Adopting almost identical strategy as was followed in two precisely described buildings, here also the complete industry was carefully studied and placing emphasis on areas with comparatively high temperature, high noisy levels and especially where higher levels of air pollution was identified due to suspended particulate matter of aluminum were shortlisted and all such pockets within the industry were carefully mapped.

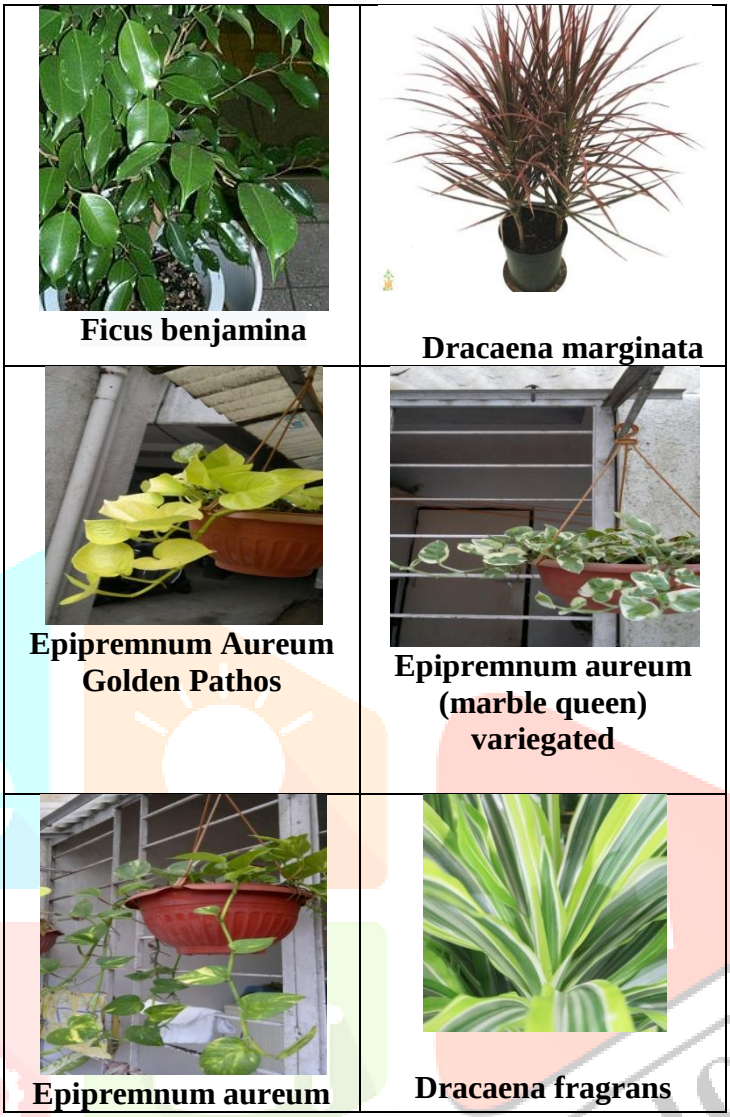

Fig. 3 Plants with glossy foliage were experimented in aluminum powder industry Aluminium powder industry, Bhandara, Nagpur

Fig. 4 Mounting of measuring equipments

VI. STRATEGIES AND PROCESS ADOPTED

Since the principle adjective in all three types of buildings was to mitigate micro-climatic conditions without the use of an mechanical systems, common strategies and process were experimented, which are spelled out as follows :-

• In order to lower temperatures, increase relative humidity and lowering air pollutants which are primary parameter, which proper control is requested to achieve comfort, as a strategy it was decided to control all these primary parameters by identified and employing indoor plants which have natural characteristics to regulate and mitigate the above stated parameters (Ref Figure 1,2 and 3)

• The identified indoor plants as next strategy were decided to be placed in planters, wherein it was also decided to fill these planters half way with activated charcoal and remaining half with micro-nutrients and compost, with a view to facillate absorption of Volatile Organic Compound (VOC) not by plants alone but by the activated charcoal and compost as well.

•For Placing and positioning of the selected indoor plants along with planters it was found appreciate to position them at the breathing level of human being, either at sitting position (1.10m) or at standing position (1.40m). To achieve these strategic levels it was decided to place these planters over stands, either designed vertically or side by side in linear format (Refer figure 5, 6, 7 and 8)

•As next strategic step it was decided to work out and design the vertical stands to ensure adequate lighting levels to maintain proper environment in and around where such planters will be positioned (Refer Figure5,6,7 and 8)
•The next obvious strategy was to ensure adequate and continuous irrigation of planters placed in stands designed either vertically or linearly and this was assured by carefully designed and worked out dripp-irrigation system (Refer figure 5)
•Due to higher percentage of polluting suspended particles in ALUMINUM POWDER INDUSTRY industry, Bhandara a strategic decision was to use plant with glossy foliage for experimentation (Refer Figure 3).
•To measure the temperature ($°C$) Dry Bulb Thermometer (DBT), and Wet Bulb Thermometer (WBT) were employed (Refer Figure 4)
•The Collected and recorded / documented temperature readings from DBT and WBT thermometers were then skilled / plotted on histogram. Histogram were used since this charts for useful as methodology to measure to comfort zone indices, with respect to corresponding DBT and WBT temperatures.
•The Histograms were used for calculating Effective Temperatures ET to ascertain whether the resultant ET lies close to comfort zone (Refer Figure 6.)
•Hygrometer was employed to obtained percentage of relative humidity. The resultant readings / findings between from Histogram and Hygrometer are not connected when working out the calculations for VOC control / count (Refer Figure 4)
•To measure levels of illumination (both from natural and artificial sources) LUX meter was used.
•All this measuring equipments namely DBT, WBT, ET, Hygrometer, LUX meter were mounted at a height of 1.40mtr. stand fabricated out of M.S. section (Refer Figure 4) and positioned strategically in the areas of the experimentations (Refer Figure 4 and 7).
•As a part of methodology and strategy the experiments were carried out simultaneously in all three identified industrial interiors spaces and were conducted in all seasons starting from 1st day to 10th day of months of May(Summer), July(Monsoon) and December(Winter) in the year 2016.
•The entire recorded micro-climatic data observed during the course of examinations in all the three buildings. As a part of methodology and strategy was tabulated at every three hours every day to synchronies this method with that followed by meteorological department of Nagpur (Refer Table No.1,2, and 3)

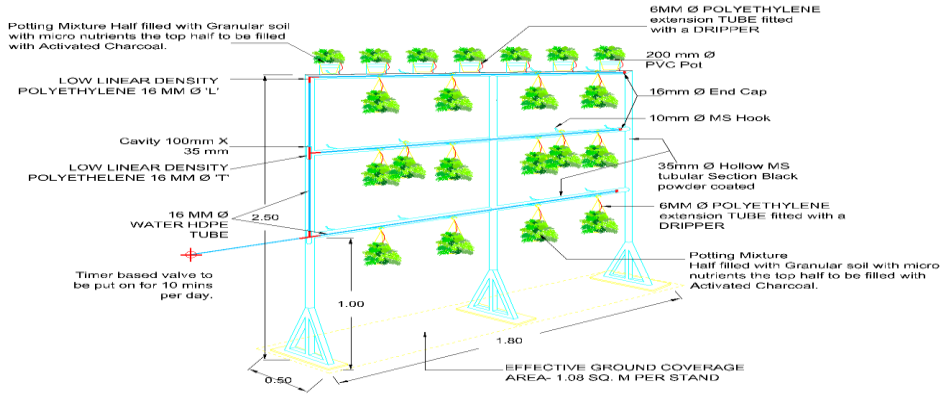

Fig. 5 Isometric view of M.S. fabricated stand with inlay of drip irrigation system along with placement of hanging baskets of shortlisted plants.

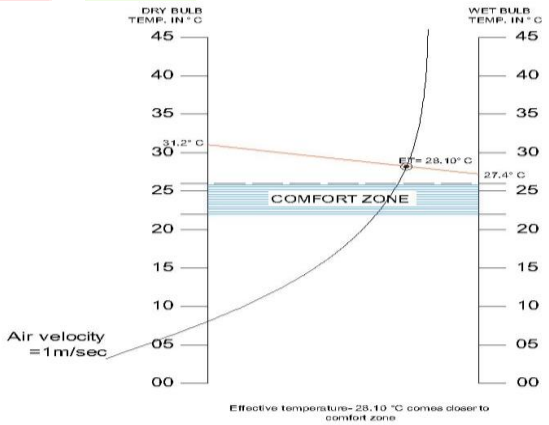

Fig. 6 Histogram during effective temperature

From the Histogram it was observed that effective temperature drops closer to the comfort zone for the indoor air velocity to be 1m/s.
The experiments were conducted under the artificial source of light12 lumen.
Histogram was used for calculating effective temperature (ET) to find out whether the value of ET lies closer to the comfort zone. The chart given above provides values of dry bulb measurements of 31.2° C and Wet bulb temperature is 27.4° C on 10th day of May, 2016. These observations intersect air velocity curve for the value of 1 m/sec and the resultant intersection is referred to as effective temperature (ET) at the level of 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.

Fig. 6 Hanging baskets / potted plants arranged on M.S. stand

Fig.7 Position of experimental measurement units /panels

Fig. 8 Golden pathos plant baskets in three rows hung vertically On M.S. stand

Fig.9 Suspended Particulate matter of Aluminum on settled on the foliage of Dracaena

Table 1.1: Experimentation Inside Circlips Industry, Butibori 1St and 10th Day of July 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)	
	Day1	Day10	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10
02:30 am	28	25.4	87%	92%	31.5	29.9	27.4	32.4	92%	97%	6.8	3.2
05:30 am	30.3	27.7	99%	95%	33.4	31.4	33.9	28.8	92%	98%	6.7	3.3
08:30 pm	30.7	25.4	90%	96%	34.8	29.8	34.3	27.3	95%	99%	7.2	3.0
11:30 am	32.8	27.8	67%	85%	36.3	32.3	37.1	29.6	91%	92%	9.8	3.9
02:30 pm	32.6	27.2	63%	95%	35.8	31.1	36.3	28.2	86%	96%	9.5	4.8
5:30 pm	31.1	25.7	90%	88%	35.4	30.1	35.5	27.5	94%	95%	9.3	4.4
08:30 pm	28.4	25.4	95%	93%	33.1	29.9	33.2	27.2	99%	98%	8.4	3.9

	Data from MET. Dept. Nagpur		Data from MET. Dept. Nagpur		Indoor- Dry Bulb Thermometer		V O C METER (READINGS WITHIN THE EXPERIMENTATION ZONE)					
11.30 pm	25	25.4	93%	93%	29.8	30.3	29.7	27.7	37%	99%	8.7	3.7

From the table, it could be inferred that inside the building in Experimental area of Circlips Industry on 10th day of July, 2016:

1) TEMPERATURE at 11:30 am

The outdoor temperature 27.8°C is less than the indoor temperature that is 29.6°C.

The indoor temperature in experimental zone as per VOC meter 32.3°C and the indoor temperature is 29.6°C.

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

From the graph, we could infer that in the month of July, 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 67% and on the 10th day, it is 85%.

In experimentation zone on first day is 91% and on the 10th day it is 92%.

It can be inferred that the humidity level increases by 1%.

The increased 1% humidity level brings it closer to the comfort zone

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

The VOC is reduced from 8.4 ppm to 3.9 ppm in 10 days. By putting 250 numbers of potted plants/hanging basket.

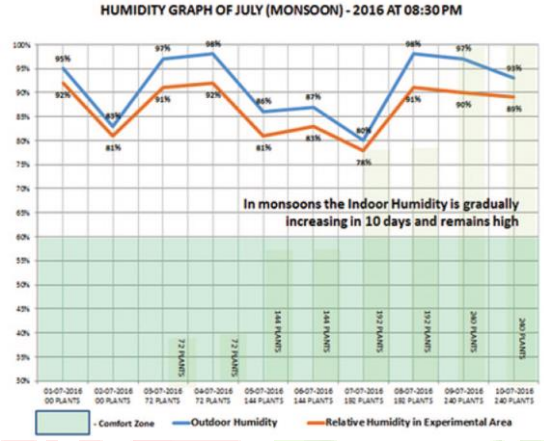

Fig. 10 Humidity graph during July (Monsoon) 2016 at 08:30 PM.

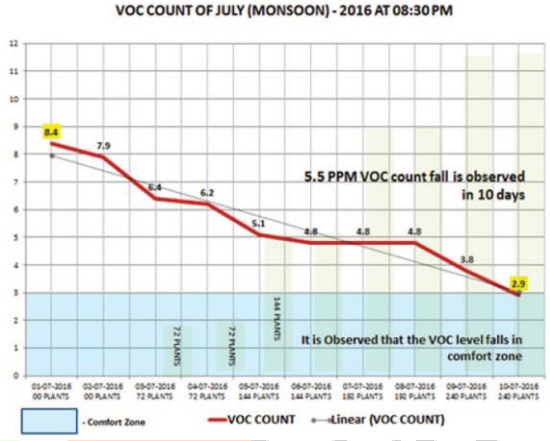

Fig. 11 Temperature graph during July (Monsoon) 2016 at 08:30 PM.

Table 1.2: Experimentation at Enviro Ltd., 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	Day1	Day10	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10
08:30 am	16.6	17	57%	56%	28.6	28	27.9	27.4	42%	45%	4.9	3.5
11:30 am	26.5	27	37%	36%	28.1	27.9	27.8	27.8	43%	46%	5.7	2.1
02:30 am	31.2	30.2	28%	32%	24.9	27.8	23.7	23.7	48%	46%	6.0	3.9
05:30 pm	19.6	21.2	58%	62%	24.4	27.3	23.3	24.7	43%	41%	5.8	3.2
08:30 pm	16.2	17.8	73%	67%	28.2	27.1	27.9	26.9	44%	49%	4.9	2.1

From the table, it could be inferred that inside the building in Experimental area of ENVIRO Ltd. on 10th day of May, 2016:

1) TEMPERATURE at 11:30 am

The outdoor temperature 27°C is more than the indoor temperature that is 27.9°C.

The indoor temperature in experimental zone as per VOC meter is 27.8°C and the indoor temperature is 27.9°C.

The temperature in experimental zone is increased by 0.1°C.

From the graph, we could assess that in the month of May, the temperature is increased by 0.1°C and brings it closer to comfort zone.

2) Humidity at 11:30 am

The outdoor humidity on first day is 37% and on the 10th day, it is 36%.

In experimentation zone on first day is 43% and on the 10th day it is 46%.

It can be inferred that the humidity level increases by 10%.

The increased 10% humidity level brings it closer to the comfort zone

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

The VOC is reduced from 4.9 ppm to 2.1 ppm in 10 days. By putting 250 numbers of potted plants/hanging basket

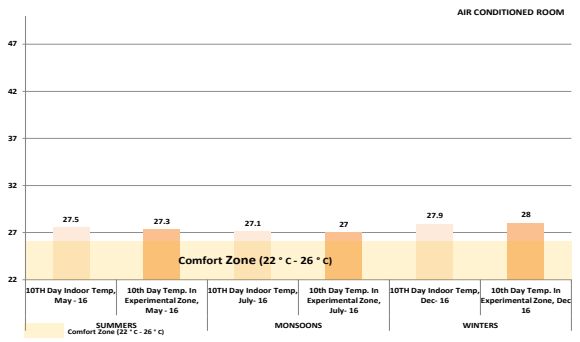

Fig. 12 Comparative Analysis of temperature at Enviro Limited, Nagpur on May-2016 at 8.30 AM

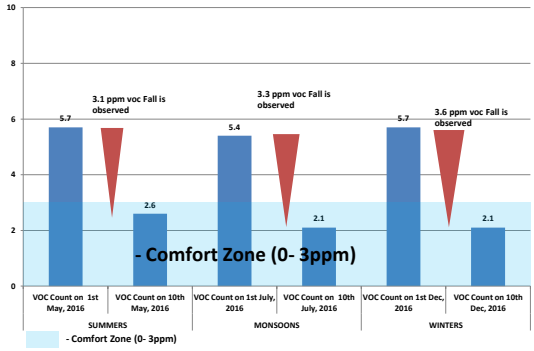

Fig. 13 Comparative Analysis of VOC at Enviro Limited, Nagpur on May-2016 at 8.30 AM

Table 1.3: Aluminum 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)	
	Day1	Day10	Day 1	Day 10	Day 1	Day 10	Day1	Day10	Day 1	Day10	Day1	Day10
02:30 am	14.4	10.6	89%	92%	17.9	15.1	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%	43%	31.1	29.5	30.6	27.5	30%	36%	5.6	3.2
02:30 pm	30.8	28.4	27%	29%	35	32.3	34.5	29.4	24%	21%	5.3	2.9
5:30 pm	21	18	57%	59%	25.3	22.4	24.8	19.8	53%	52%	5.5	3.0
08:30 pm	17.6	14.6	69%	70%	22.3	19.1	21.8	16.8	64%	69%	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

From the table, it could be inferred that inside the building in Experimental area of Aluminum powder industry on 10th day of July, 2016:

1) TEMPERATURE at 11:30 am

The outdoor temperature 25°C is less than the indoor temperature that is 27.5°C.

The indoor temperature in experimental zone is 30.6°C and the indoor temperature is 29.5°C.

The temperature in experimental zone is reduced by 1.1°C.

From the graph, we could inferred that in the month of Dec, the temperature is reduced by 1.1°C and brings it closer to comfort zone.

2) Humidity at 11:30 am

The outdoor humidity on first day is 35% and on the 10th day, it is 43%.

In experimentation zone on first day is 30% and on the 10th day it is 36%.

We could assess that the humidity level increases by 6%.

The increased 6% humidity level brings it closer to the comfort zone

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

The VOC is reduced from 5.4 ppm to 2.8 ppm in 10 days. By putting 250 numbers of potted plants/hanging basket.

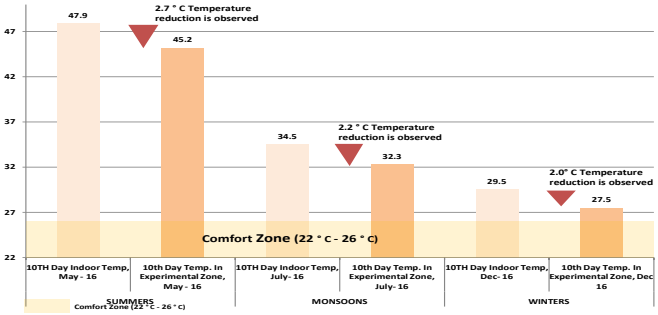

Fig. 14: Comparative Analysis of Temperature at ALUMINUM POWDER INDUSTRY, Bhandara, Nagpur

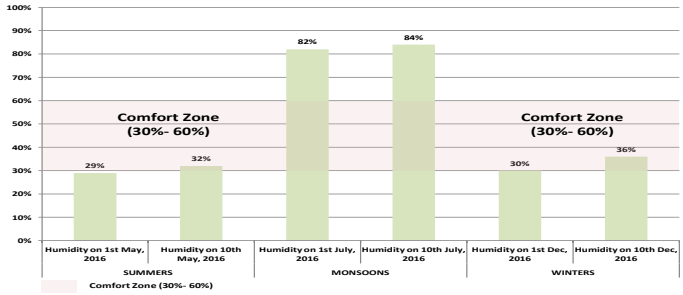

Fig. 15: Comparative Analysis of Humidity at ALUMINUM POWDER INDUSTRY Bhandara, Nagpur

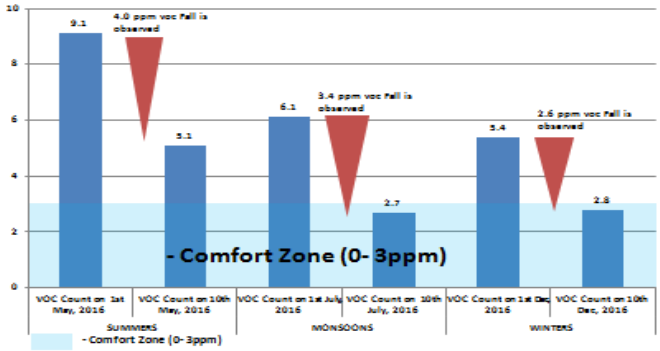

Fig. 16: Comparative Analysis of VOC at ALUMINUM POWDER INDUSTRY, Bhandara, Nagpur

VII. CONCLUSIONS

From the relative comparison of the data, information collected and recorded from experimentation conducted carried out in three different industrial interiors, following can be observed

1) Indoor temperature an important element related to micro-climate can be lowered by 2°-4°C and bring it close to comfort zone.
2) Another equally important element the relative humidity which also has direct bearing on comfort can also be regulated to a great extent and its level brought close to comfort zone of between 30-70%
3) The relatively analysed results also reveal that the Volatile Organic Compounds (VOC) gets reduced considerably to a level of comfort zone of below 3ppm.
4) This observation clearly establishes positively the hypothesis- that the micro-climate can be changed / mitigated and regulated by use of indoor plants(an element of landscape) which is possible to achieve by systematically arranging a concentration of 240 numbers of

hanging baskets / planters. of identified indoor plants, for a space covering area of about 80 sqm. Which is based on the experiments conducted in three buildings which were carried at 1st to 10th day of months May, July and December 2016.

5) From above detail out experiments it can be conclusively established that comfort level within the buildings can be reasonable altered by employing indoor plants without the interventions of mechanical systems, there by achieving the desirable and beneficial effects at very reasonable expenditure and at a same time helping enriching and quality of life and work environment for the employees and this beneficial and improved change also has resulted in well being of the employees giving rise to increased productivity from 4-5%. For all this beneficial counts it can be with full conviction summarised that use of indoor plants to regulate/ mitigate indoor climate is worth adopting and replicating in almost every type of indoor spaces; more so can be adopted / practised as a "way of life" For spaces within industrial establishment.

VIII. RECOMMENDED STRATEGIES

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

• Identification and adoption of the appropriate plants for different environments and pollutants is crucial for optimum result. To facilitate architectural intervention towards creating conducive work environment within the industrial interiors.

• The usage of plants of various species would help increase the comfort levels within the industrial unit and the landscape structure can be designed with customization.

• Looking into the encouraging results of the field experimentation, the concept is worth the recommendation for universal application.

• Research processes are seen to be applicable in industrial units where the hazardous VOCs are prevailing.

• Innovative landscape interventions similar to this can be adopted in all work environments to enhance micro-climatic comfort levels resulting into the operational efficiency.

IX. ACKNOWLEDGEMENT

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