Feasibility Study of Biomimicry Approach to Improve Indoor Air Quality in Green Building

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Abstract— **This paper presents the study of potential of integration of indoor plants in building's indoor environment. Essentially this incorporation is considered as elaborate understanding of the concept called "Biomimicry". Biomimicry is an approach which adopts the design principals of natural elements; flora and fauna as the baseline of the design. The adaptation of this approach in this project is to utilize indoor plants in building in terms of imitating the plant biological activity for abatement of indoor air pollution and improvement of indoor air quality to satisfy one of the objectives of green building. To accommodate the study, a building is identified and the plants are provided. The study focused on evaluating potential amount of VOCs removed from indoor air. The study also identifies the number of points gained as per IGBC's Green Interior rating system. Further the study investigates the potential benefits of adaptation of indoor plants in indoor environment in Indian context.**

Keywords— Biomimicry, Green Building, Indoor air quality, Biophilia

I. INTRODUCTION

Considering the global scenario, buildings consumes huge amount of resources viz., water, material, energy and electricity. Buildings are responsible 18% of the total global emission.[1] However, building sector has great potential to significantly reduce the emission and environmental impact. Here the need of Green building arises. According to U.S Environmental Protection Agency, Green building is the practice to building structures which is resource efficient and environmental friendly throughout its life cycle. i.e., from designing to construction and from renovation to demolition. The practice expands to durability as well as comfort and well-being of occupant.[2] However among the objectives of green building, Indoor Environment Quality is of great concern.[3] The IGBC (Indian Green Building Council) Green Interior Rating System address the design and construction guidelines of Indoor air Quality [4]

Green Building brings together various approaches of technologies to satisfy its objectives. Biomimicry is one of the advanced approaches. Biomimicry is study and adaptation the design principals of natural elements; flora and fauna in order to solve the design problems. Hence this approach use natural elements and processes as "model, mentor and measure" and adapt the natural design techniques at all level of design. [5] Biomimicry approach is divided in two categories; one is to solve the design problem by identifying the ways other ecosystem or an organism solve it and second is to solve the human design problem by identifying a particular characteristics, behavior, function or principal in ecosystem or in an organism. The first aspect is conceptualized as "Design looking to Biology" while the second approach is conceptualized as "Biology influencing design". [6]

This study explores second type of Biomimicry i.e., adopting specific aspect of flora and fauna. This study focuses on use of indoor plants for abatement of indoor air pollution. The indoor plants removes the three common VOCs; Trichloroethylene, Benzene, Formaldehyde from the indoor environment.[7,8] This study investigate the benefit of incorporating indoor plants in the building by measuring the quantity of potential removal VOCs from the indoor environment. Biophilia which means love of nature is the inherent attraction to the nature as well as to the natural processes. It states that we human have genetic connection to the natural world.[9] From research it have proven that incorporation of direct or indirect elements of nature into built environment results in reduce in blood pressure, stress level and heart rates while it increase productivity and creativity.[10,11]

To accommodate the study, the indoor plants are provided as per the IGBC Green Interior rating system Indoor Environment Credit no. 6 compliance standard. For this, a guest house building in Vadodara, India is identified. Further the indoor plants selected and provided in the different spaces of the building. And the removal of the VOCs analyzed on the basis of the report of NASA [8] which quantifies the amount of the VOCs removed from the selected plants. Then it is identified that how many points gained from the provision of indoor plants as per IGBC Green Interior Rating System, Version 1.0,2015. The paper also discusses benefit of provision of indoor plants through the Biomimetic and additional Biophilic approach and potential of use of indoor plants in the built environment in India.

II. BENEFITS OF PROVISION OF INDOOR PLANTS: INDIAN SCENARIO

The Construction industry in India expects a growth rate of 7-8% per annum over the next 10 years.[12] While the green building industry in India will grow by 20 per due to environmental regulations and demand for healthier neighborhoods .[13] Hence it is observed that there is huge potential of green building sector growth in India. Similarly the Indian working population facing the stress related issues. According to a study on IT and BPO employees, it is observed that around 56% had musculoskeletal symptoms. 22% had newly diagnosed hypertension, while 10% had diabetes, 36%

had dyslipidemia, 54% had depression, anxiety and insomnia, 40% had obesity.[14] Hence there is need to adopt the Biomimetic and Biophilic approach in indoor environment by incorporating the indoor plants in building spaces. This approach not only improve the indoor air quality but also reduce workplace stress, [10,15,16], reduce stress and negativity [17,18], Indoor plant presence increases productivity, performance, job satisfaction, by >10%.[19] Hence indoor plant provision have potential to solve the health issues facing by the indoor occupants. Hence as the Indian Green construction sector rises sharply and the need of the healthy and efficient indoor environment arises, incorporation of Indoor plant in the Building will prove an effective solution to improve the health and the well-being of the occupant.

III. MECHANISM OF INDOOR PLANTS TO CLEAN AIR

Indoor air pollution causing household products and chemicals include furniture waxes, paints plastics, rubber , grocery bags, waxed papers, cleaning products, disinfectants, printing inks, paints, lacquers, and cosmetics, varnishes, and adhesives , facial tissues, and paper towels, gasoline, oils. Some of these products release chemicals into the air during use, whereas others emit chemicals as they age, dry, or cure; this is known as out-gassing. Benzene, Trichloroethylene, and formaldehyde are major VOCs emitted from the above products. [7, 8]

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IV. METHODOLOGY

The study quantifies the potential amount of VOCs from the Indoor environment of the building. To facilitate the quantification; indoor plants are selected and provided in the building environment of identified building. Then the removal of VOCs is calculated.

The building of Guest house of Maharaja Sayajirao University of Baroda, Vadodara, Gujarat is identified for the applications. The research steps can be explained as follows:

1. To determine the total carpet area: The total carpet area is determined in order to identify numbers of plants to be provided in each building spaces according to compliance standard in IGBC Green Interior rating system Indoor Environment Credit no. 6. It states that at least one plant should be provided per 100 sq.ft. of carpet area.

2. To select the indoor plants: Indoor plants are selected on the basis of step number one, Chemical vapors removal rating, requirement of light, and removal of all three major VOCs and difficulty to grow. [7, 8]

3. Provision of indoor plants: The plants are provided in different section of the building. However by satisfying criteria aesthetic liberty is considered for provision of plants.

5. Analysis of Removal of Volatile Organic Compounds: The total removal of the three major VOCs; Trichloroethylene, Benzene and Formaldehyde by the total surface area of the provided plants for 24hr of exposure is evaluated on the basis of report of NASA[8].

6. IGBC credit: The gain in points of IGBC Green Interior Rating System, Indoor Environment credit 6 is evaluate to prove the acceptability of the Biomimetic approach in Indoor Environment.

IV. RESULTS AND DISCUSSION

Then biomimicry approach in the building environment is incorporated and the removal of major VOCs is quantified for 24 hr of exposure. For the analysis the area of each building section is identified in order to provide minimum one plant per 100sq ft. For different section of buildings, it is found that Minimum 74 plants have to be provided to satisfy the criteria for provision of number of plants. However 170 plants are provided after selection of plants, considering the aesthetic liberty and availability of spaces which is adequate. Table I shows the min required plants provided and the total number of plants provided in each section of the building after selection of plants.

Five plants are selected as per the criteria discussed in step 3 of the methodology. Also these plants are recommended in the Annexure No.3 of IGBC Green Interior Rating System, Version 1.0, 2015. The selected plants are Bamboo Palm, Janet Craig, English Ivy, Peace Lily, Dragon tree. (See Table II and Fig 1)

A) Bamboo Palm (Dypsis Lutescens)   B) Janet Craig (Dracaena deremensis)   C) English Ivy (Hedera helix)

C) Peace Lily (Spathiphyllum wallisii)   D) Dragon tree (Dracaena Marginate)

Fig. 1 Provided Indoor plants

After selection of plants the selected plants are provided in each section of the building. The type and number of plants provided in each section of the building are represented in table III.

After provision of plants it is observed that 59 Bamboo Palm, 22 Janet Craig, 26 English Ivy, 10 Peace Lily and 17 Dragon tree plants are provided in building. Each plant has its own capacity of removal of VOCs.

TABLE I. TOTAL PLANTS PROVIDED IN EACH BUILDING SECTION

Building	Activities	Area (Sq.ft)	Minimum no. of plant to be provided (area /100)	Approx. minimum no. of plants to be provided	Total plants provided
GF	Seminar hall	422	4.22	5	6
GF	Common Toilet	49	1.00	1	-
G.F	Conference Hall	397.5	3.98	4	11
G,F	Dining Room	506	5.06	5	10
G.F	Waiting Area	296	2.96	3	10
G.F	Meeting Room	333.5	3.34	4	16
G.F	Entrance	253	2.53	3	4
G.F	Pantry	97.5	1.00	1	4
G.F	Office	66	1.00	1	4
G.F	Toilet	49	0.49	1	-
G.F	Passage	740.3	7.40	8	18
F.F	Bedroom 1	506	5.06	5	13
F.F	Reading Room	333.25	3.33	4	6
F.F	Common Toilet	49	0.49	1	-
F.F	Bedroom 2	506	5.06	5	13
F.F	Dress	48	0.48	1	1
F.F	Toilet	68	0.68	1	-
F.F	Bedroom 3	210.8	2.10	2	10
F.F	Toilet	58.4	0.58	1	-
F.F	Bedroom 4	253	2.53	3	11
F.F	Bedroom 5	333	3.33	4	13
F.F	Toilet	56.25	0.56	1	-
F.F	Dress	46.5	1.00	1	1
F.F	Common Toilet	75.4	0.75	1	-
F.F	Passage	740.3	7.40	8	18
	TOTAL	6618.8	66.313	74	170

TABLE II. TOTAL PLANTS PROVIDED IN EACH BUILDING SECTION

Plant Name (Scientific)	Plant Name (Common)	Chemical Vapor Removal Rating	Light Requirement	Difficulty	Removal of VOCs
Dypsis lutescens	Bamboo Palm	9	Semi- Sun	Easy to grow	Removes Benzene, Formaldehyde and Trichloroethylene
Dracaena deremensis	Janet Craig	8	Semi- Shade	Easy to grow	Removes Benzene, Formaldehyde and Trichloroethylene
Hedera helix	English Ivy	9	Semi sun to semi shade	Easy to grow	Removes Benzene, Formaldehyde and Trichloroethylene
Spathiphyllum wallisii	Peace Lily	8	Semi- shade to shade	Easy to grow	Removes Benzene, Formaldehyde and Trichloroethylene
Dracaena Marginate	Dragon Tree	6	Semi sun to semi shade	Easy to grow	Removes Benzene, Formaldehyde and Trichloroethylene

Rating 1 to 10, with 10 being excellent

Source: 1. Kent D. Kobayashi, Using Houseplants To Clean Indoor Air, co-operative extension service, 2007
2. IGBC Green Interior Rating System, Version 1.0,2015 – Annexure 3

TABLE III.   PROVISION OF INDOOR PLANTS IN EACH SECTION OF THE BUILDING

Building	Activities	Approximate min. No. of plants to be provided	Name of Plant	Total Plants Provided
G.F	Seminar hall	5	Janet Craig	6
G.F	Conference hall	4	English Ivey	11
G,F	Dining Room	5	Peace Lily	10
G.F	Waiting Rom	3	Bamboo Palm	10
G.F	Meeting room	4	English Ivy	12
			Bamboo Palm	4
G.F	Entrance	3	Bamboo Palm	4
G.F	Pantry	1	Bamboo Palm	4
G.F	Office	1	Janet Craig	4
F.F	Bedroom 1	5	English ivy	7
			Janet Craig	6
F.F	Reading room	4	English Ivy	1
			Dragon Tree	5
F.F	Bedroom 2	5	English Ivy	7
			Janet Craig	6
F.F	Dress	1	Bamboo Palm	1
F.F	Bedroom 3	2	English Ivy	8
			Dragon tree	2
F.F	Bedroom 5	4	English Ivy	8
			Dragon tree	6
F.F	Dress	1	Dragon Tree	1
F.F	Bedroom 4	3	English Ivy	8
			Dragon tree	3
F.F	Passage	8	Bamboo Palm	18

Hence Removal of Trichloroethylene, Benzene and Formaldehyde is analyzed on the basis of the total area of the plant leaf surface and number of VOCs removed as per surface area. It is based on NASA, i.e., Interior Landscape plants for Indoor Air Pollution Abatement. The removal of the VOC is for 24 hrs. Of exposure. The totals microbial of VOCs given are removed after achieving the given surface area. Observe table IV.

The total micro-organisms of Trichloroethylene to be removed are 25, 82,566 ppm from total 743,794 sq.cm area of total plants. It is also observed that for 12, 36,534 sq.cm of the leaf surface area; indoor plants removes 44, 38,459 ppm of microorganisms of Benzene in 24 hr. exposure time.(Table V). Similarly 14, 49,182 sq.cm of the area of indoor plants removes 31, 58,169 ppm of microorganisms of Formaldehyde for 24 hr. of exposure time. (Table VI)

TABLE IV.   REMOVAL OF TRICHLOROETHYLENE BY SELECTED INDOOR PLANTS FOR 24-HRS EXPOSURE

Plant Name (Scientific)	Plant Name (Common)	Surface area of one plant (sq.cm)	Removal of Trichloroethylene by one plant (ppm)	Total number of plants provided	Total surface area of plant (sq.cm)	Total removal of Trichloroethylene (ppm)
Dypsis lutescens	Bamboo Palm	10.325	16,520	59	609,175	974,680
Dracaena deremensis	Janet Craig	15,275	18,330	22	336,050	403,260
Hedera helix	English Ivy	981	7,581	62	608,22	470,022
Spathiphyllum wallisii	Peace Lily	7,960	27,064	10	79,600	270,640
Dracaena Marginate	Dragon tree	7,581	27,292	17	128,877	463,964
TOTAL				170	12,14,524	25,82,566

Source: Wolverton B.C, Interior landscape plants for indoor air pollution abatement, NASA, 1989

TABLE V.   REMOVAL OF BENZENE BY SELECTED INDOOR PLANTS FOR 24HRS EXPOSURE

Plant Name (Scientific)	Plant Name (Common)	Surface area of one plant (sq.cm)	Removal of Trichloroethylene by one plant (ppm)	Total number of plants provided	Total surface area of plant (sq.cm)	Total removal of Trichloroethylene (ppm)
Dypsis lutescens	Bamboo Palm	10,325	34,073	59	609,175	2,010,307
Dracaena deremensis	Janet Craig	15,275	28,968	22	336,050	637,296
Hedera helix	English Ivy	1,336	13,894	62	82,832	861,428
Spathiphyllum wallisii	Peace Lily	7,960	41,392	10	79,600	413,920
Dracaena Marginate	Dragon tree	7,581	30,324	17	128,877	515,508
TOTAL				170	12,14,524	44,38,459

Source: Wolverton B.C, Interior landscape plants for indoor air pollution abatement, NASA, 1989

TABLE VI.   REMOVAL OF FORMALDEHYDE BY SELECTED INDOOR PLANTS FOR 24HRS EXPOSURE

Plant Name (Scientific)	Plant Name (Common)	Surface area of one plant (sq.cm)	Removal of Trichloroethylene by one plant (ppm)	Total number of plants provided	Total surface area of plant (sq.cm)	Total removal of Trichloroethylene (ppm)
Dypsis lutescens	Bamboo Palm	14,205	16,520	59	838,095	974,680
Dracaena deremensis	Janet Craig	15,275	48,880	22	336050	1,075,360
Hedera helix	English Ivy	985	9,653	62	61070	598,486
Spathiphyllum wallisii	Peace Lily	8,509	16,167	10	85090	161,670
Dracaena Marginate	Dragon tree	7,581	20,469	17	128877	347,973
TOTAL				170	12,14,524	31,58,169

Source: Wolverton B.C, Interior landscape plants for indoor air pollution abatement, NASA, 1989

It is observed that the indoor plants potentially removes significant amount of VOCs form indoor environment for 24 hr. of exposure period. Hence considering number of plants provided, as shown in Fig.1 and Table II, the points are gained from Credit No 6 of IGBC Green Interior Rating System, Version 1.0, 2015. The credit number 6 is for Indoor Environment Encourage usage of indoor plants to enhance indoor air quality, thereby improving the health and wellbeing of occupants [4]. Hence to gain credit of the credit system, IGBC's Rating System for Green Interior, points to be awarded are as shown in table VII.

TABLE VII. POINTS GIVEN AS PER CREDIT NO.6 OF IGBC GREEN INTERIOR RATING SYSTEM

Indoor Plants in regularly office spaces	Points
50%	1
95%	2

Source: IGBC Green Interior Rating System, Version 1.0,2015

As 1 plant is to be provided for 100 sq.ft 170 plants are provided which are covering 261.94 % of the carpet area of the identified building. It is almost double of the carpet area. Taking the above criteria into consideration, in the identified building, the total plants provided are covering space which is

more than 95% of total carpet area which is the required criteria. Hence by providing the Indoor Plants to improve the indoor Air Quality, 2 points from credit No. 6 of IGBC Green Interior Rating system, Version 1.0, 2015.

V.   CONCLUSION

The Biomimicry approach in indoor air quality improvement is analyzed by incorporating the indoor plants in building environment of identified building. It is found that application Biomimicry approach by incorporating indoor plants in building environment improves the indoor air quality by the VOCs from the building environment. The application also gains points from IGBC Green Interior Rating system. In India, presence of indoor plants in Indoor Environment have feasibility to improves the health and well-being of the occupants in present and future buildings as it is one of the important objectives of Green building.

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