

# **BUILDING DESIGN AND INDOOR AIR QUALITY IN RESIDENTIAL HOUSEHOLDS**

**UMMARA AMREEN**

**B.Sc. (Home Science)**

**MASTER OF SCIENCE IN HOME SCIENCE  
(RESOURCE MANAGEMENT AND CONSUMER SCIENCES)**



# **BUILDING DESIGN AND INDOOR AIR QUALITY IN RESIDENTIAL HOUSEHOLDS**

**BY**

**UMMARA AMREEN**

**B.Sc. (Home Science)**

**THESIS SUBMITTED TO THE PROFESSOR JAYASHANKAR  
TELANGANA STATE AGRICULTURAL UNIVERSITY IN PARTIAL  
FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF  
THE DEGREE OF**

**MASTER OF SCIENCE IN HOME SCIENCE**

**(RESOURCE MANAGEMENT AND CONSUMER SCIENCES)**

**CHAIRPERSON: Dr. NEERAJA TELAPROLU**



**DEPARTMENT OF RESOURCE MANAGEMENT AND CONSUMER  
SCIENCES**

**COLLEGE OF HOME SCIENCE**

**PROFESSOR JAYASHANKAR TELANGANA STATE  
AGRICULTURAL UNIVERSITY  
SAIFABAD, HYDERABAD-500 004**

**2015**

## **DECLARATION**

I, **Ms. UMMARA AMREEN**, hereby declare that the thesis entitled **“BUILDING DESIGN AND INDOOR AIR QUALITY IN RESIDENTIAL HOUSEHOLDS”** submitted to the **Professor Jayashankar Telangana State Agricultural University** for the degree of **Master of Science in Home Science** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

Place:

**(UMMARA AMREEN)**

Date:

**I.D. NO. HHM/2013-013**

## **CERTIFICATE**

**Ms. UMMARA AMREEN** has satisfactorily prosecuted the course of research and that thesis entitled “**BUILDING DESIGN AND INDOOR AIR QUALITY IN RESIDENTIAL HOUSEHOLDS**” submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by her for a degree of any university.

**Date:**

**Dr.(Mrs.)Neeraja Telaprolu**  
**Chairperson**

## CERTIFICATE

This is to certify that the thesis entitled “**BUILDING DESIGN AND INDOOR AIR QUALITY IN RESIDENTIAL HOUSEHOLDS**” submitted in partial fulfillment of the requirements for the degree of ‘Master Of Science In Home Science’ of the Professor Jayashankar Telangana State Agricultural University, Hyderabad is a record of the bonafide original research work carried out by **Ms. UMMARA AMREEN** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

### **Thesis approved by the Student’s Advisory Committee**

Chairperson    **Dr.(Mrs.)NEERAJA TELAPROLU**  
Professor  
RMCS Department  
College of Home Science, PJTSAU  
Saifabad, Hyderabad

---

Member        **Dr. (Mrs.)V. VIJAYALAKSHMI**  
Associate Professor,  
RMCS Department  
College of Home Science, PJTSAU  
Saifabad, Hyderabad.

---

Member        **Dr. (Mrs.)V. VIJAYALAKSHMI**  
Professor,  
Department of Foods and Nutrition  
College of Home Science, PJTSAU  
Saifabad, Hyderabad-04.

---

**Date of final viva-voce:**

## **ACKNOWLEDGEMENTS**

*Alhumduliah, firstly I humbly extol the “Almighty” for having bestowed upon me his grace and blessings, which have helped me to complete this piece of work with more dedication and hardwork.*

*I place my profound etiquette and deep sense of gratitude and regard to major advisor **Dr. (Mrs). T. Neeraja**, Professor, Department of Resource Management and Consumer Sciences, College of Home Science, Hyderabad. Her constant support, meticulous help, encouragement, valuable guidance, suggestions and constructive criticism helped me immensely in the successful completion of my research work. It was a great pleasure for me to conduct this thesis under her supervision.*

*My profound thanks are extended to my minor advisor **Dr.(Mrs). V.Vijayalakshmi**, Associate Professor, Department of RMCS and **Dr. (Mrs). V.Vijayalakshmi**, Professor, Department of Foods and Nutrition, College of Home Science, Hyderabad, for her useful suggestions and timely help throughout this study.*

*I am extremely grateful to **Dr. (Mrs.) Mahalakshmi.V.Reddy**, Professor and Head, Department of RMCS, **Dr. (Mrs.) A. Mrunalini**, Professor and University Head, Department of RMCS, **Dr. (Mrs.) D. Ratna Kumari**, professor and **Dr. (Mrs.) Radha Rani** of Department of RMCS for their co-operation in helping me in carrying out the research work.*

*I extend my special thanks to **Anil kumar vemula**, statistician, scientific officer, ICRISAT, for his constructive guidance and suggestions for helping me in statistical analysis of the data.*

*Also express my sincere thanks to the **staff members** of library for providing me all the facilities throughout the course of study.*

*I take a great pleasure to express my heartfelt sense of love, obseccion and honours to my beloved parents **Mr. Md. Ahmed Nizami and Mrs. Lubna Ahmed** and my brother **Adil**, and sister **Husna** who were a great support throughout the study. I affectionately acknowledge my loving family Grand mother,Aunts, Uncles, cousins for been supportive.I dedicate this to my late grandfather **Md.Manzoor Siddiqui** whose morals were pillar of strength for me to work harder with dedication.*

*I extent my heartfelt thanks to my friends **Srilakhshmi, Deepika and Anusha** for their co-operation and help rendered during the study and making it a memorable one. Also my seniors **Ayesha and Sana** for always been supportive. My special thanks to **Fariya and Juveria** for their encouragement which always helped perform better.*

*My sincere thanks to all those have helped me In successful completion of work*

*(UMMARA AMREEN)*

## LIST OF CONTENTS

<b>Chapter No.</b>	<b>Title</b>	<b>Page No.</b>
I	INTRODUCTION	1-7
II	REVIEW OF LITERATURE	8-41
III	MATERIALS AND METHODS	42-55
IV	RESULTS AND DISCUSSION	56-153
V	SUMMARY AND CONCLUSIONS	154-166
	LITERATURE CITED	167-180
	APPENDICES	181-195

## LIST OF TABLES

S. No.	Table No.	Title	Page No.
1.	4.1	Distribution of households by Number of family members	57
2.	4.2	Distribution of households by sex and age of family members	58
3.	4.3	Distribution of households by geographical location of building site	59
4.	4.4	Distribution of households by site orientation	59
5.	4.5	Distribution of households by building design parameters	62
6.	4.6	Distribution of households by material used for construction wall construction	65
7.	4.7	Distribution of households by finishing material used for walls	65
8.	4.8	Distribution of households by frequency of household cleaning	68
9.	4.9	Distribution of households by feeling of Congestedness	68
10.	4.10	Distribution of households by extent of use of cleaning reagent	69
11.	4.11	Distribution of households by extent of use of personal care product	70
12.	4.12	Distribution of household by CO <sub>2</sub> level in the indoors	71
13.	4.13	Distribution of household by VOCs level in the indoors	72
14.	4.14	Distribution of household by PM <sub>10</sub> level in the indoors	73
15.	4.15	Distribution of household by PM <sub>4</sub> level in the indoors	73
16.	4.16	Distribution of household by PM <sub>2.5</sub> level in the indoors	74
17.	4.17	Distribution of household by RH level in the indoors	75

18.	4.18	Distribution of household by temperature level in the indoors	75
19.	4.19	Distribution of household by dew point level in the indoors	76
20.	4.20	Analysis of variation in indoor air quality parameters with regard to Geographical location of building site	80
21.	4.21	Mean comparison and significant probabilities between Geographical location of building site with respect to CO <sub>2</sub>	81
22.	4.22	Mean comparison and significant probabilities between Geographical location of building site with respect to PM <sub>4</sub>	81
23.	4.23	Mean comparison and significant probabilities between Geographical location of building site with respect to Relative Humidity	82
24.	4.24	Mean comparison and significant probabilities between Geographical location of building site with respect to Temperature	83
25.	4.25	Analysis of variance in indoor air quality parameters with regard to Site orientation	84
26.	4.26	Mean comparison and significant probabilities between Site orientation with respect to CO <sub>2</sub>	85
27.	4.27	Mean comparison and significant probabilities between Site orientation with respect to PM <sub>2.5</sub>	85
28.	4.28	Mean comparison and significant probabilities between Site orientation with respect to Relative Humidity	85
29.	4.29	Mean comparison and significant probabilities between Site orientation with respect to Dew point	86
30.	4.30	Analysis of variance in indoor air quality parameters with regard to Height of the building site with reference to main traffic road	87

31.	4.31	Mean comparison and significant probabilities between Height of the building site with reference to main traffic road with respect to PM <sub>2.5</sub>	88
32.	4.32	Analysis of variance in indoor air quality parameters with regard to Height of the building with reference to road in front of the house	89
33.	4.33	Analysis of variance in indoor air quality parameters with regard to Side of the building facing the main road quality	90
34.	4.34	Mean comparison and significant probabilities between Side of the building facing the main road with respect to VOC	91
35.	4.35	Mean comparison and significant probabilities between Side of the building facing the main road with respect to PM <sub>4</sub>	91
36.	4.36	Mean comparison and significant probabilities between Side of the building facing the main road with respect to PM <sub>2.5</sub>	92
37.	4.37	Mean comparison and significant probabilities between Side of the building facing the main road with respect to Relative Humidity	92
38.	4.38	Mean comparison and significant probabilities between Side of the building facing the main road with respect to Temperature	93
39.	4.39	Mean comparison and significant probabilities between Side of the building facing the main road with respect to Dew point	93
40.	4.40	Analysis of variance in indoor air quality parameters with regard to Plot area	95
41.	4.41	Mean comparison and significant probabilities between Plot area with respect to CO <sub>2</sub>	96
42.	4.42	Mean comparison and significant probabilities between Plot area with respect to PM <sub>4</sub>	96

43.	4.43	Mean comparison and significant probabilities between Plot area with respect to PM <sub>2.5</sub>	96
44.	4.44	Mean comparison and significant probabilities between Plot area with respect to Relative Humidity	97
45.	4.45	Analysis of variance in indoor air quality parameters with regard to Plinth area	98
46.	4.46	Mean comparison and significant probabilities between Plinth area with respect to CO <sub>2</sub>	98
47.	4.47	Mean comparison and significant probabilities between Plinth area with respect to PM <sub>2.5</sub>	99
48.	4.48	Mean comparison and significant probabilities between Plinth area with respect to RH	99
49.	4.49	Mean comparison and significant probabilities between Plinth area with respect to Dew point	100
50.	4.50	Analysis of variance in indoor air quality parameters with regard to Landscape area	101
51.	4.51	Analysis of variance in indoor air quality parameters with regard to Floor area ratio	102
52.	4.52	Mean comparison and significant probabilities between Floor area ratio with respect to PM <sub>4</sub>	102
53.	4.53	Analysis of variance in indoor air quality parameters with regard to Open area on the wall of the building facing the main traffic road	104
54.	4.54	Mean comparison and significant probabilities between Open area on the wall of the building facing the main traffic road with respect to Temperature	105
55.	4.55	Analysis of variance in indoor air quality parameters with regard to Open area on the outer wall of the building	106

56.	4.56	Mean comparison and significant probabilities between Open area on the outer wall of the building with respect to CO <sub>2</sub>	106
57.	4.57	Analysis of variance in indoor air quality parameters with regard to Height of the building	108
58.	4.58	Analyses of variance in indoor air quality parameters with regard to Ceiling height	109
59.	4.59	Mean comparison and significant probabilities between Ceiling height with respect to PM <sub>4</sub>	109
60.	4.60	Mean comparison and significant probabilities between Ceiling height with respect to PM <sub>2.5</sub>	109
61.	4.61	Mean comparison and significant probabilities between Ceiling height with respect to Temperature	109
62.	4.62	Mean comparison and significant probabilities between Ceiling height with respect to Dew point	110
63.	4.63	Analysis of variance in indoor air quality parameters with regard to Number of rooms	111
64.	4.64	Mean comparison and significant probabilities between Number of rooms with respect to CO <sub>2</sub>	111
65.	4.65	Mean comparison and significant probabilities between Number of rooms with respect to Relative Humidity	112
66.	4.66	Mean comparison and significant probabilities between Number of rooms with respect to Dew point	112
67.	4.67	Analysis of variance in indoor air quality parameters with regard to Extent of dust accumulation features	113

68.	4.68	Mean comparison and significant probabilities between Extent of dust accumulation features with respect to CO <sub>2</sub>	114
69.	4.69	Mean comparison and significant probabilities between Extent of dust accumulation features with respect to RH	114
70.	4.70	Mean comparison and significant probabilities between Extent of dust accumulation features with respect to Temperature	115
71.	4.71	Analysis of variance in indoor air quality parameters with regard to Wall material	116
72.	4.72	Mean comparison and significant probabilities between Wall material with respect to CO <sub>2</sub>	117
73.	4.73	Mean comparison and significant probabilities between Wall material with respect to VOC	118
74.	4.74	Mean comparison and significant probabilities between Wall material with respect to PM <sub>4</sub>	119
75.	4.75	Mean comparison and significant probabilities between Wall material with respect to PM <sub>2.5</sub>	119
76.	4.76	Mean comparison and significant probabilities between Wall material with respect to Relative Humidity	120
77.	4.77	Mean comparison and significant probabilities between wall material with respect to Temperature	121
78.	4.78	Mean comparison and significant probabilities between Wall material with respect to Dew point	121
79.	4.79	Analysis of variance in indoor air quality parameters with regard to Finishing material for walls	123

80.	4.80	Mean comparison and significant probabilities between Finishing material with respect to CO <sub>2</sub>	124
81.	4.81	Mean comparison and significant probabilities between Finishing material with respect to VOC	124
82.	4.82	Mean comparison and significant probabilities between Finishing material with respect to PM <sub>4</sub>	125
83.	4.83	Mean comparison and significant probabilities between Finishing material with respect to PM <sub>2.5</sub>	126
84.	4.84	Mean comparison and significant probabilities between Finishing material with respect to Relative Humidity	126
85.	4.85	Mean comparison and significant probabilities between Finishing material with respect to Temperature	127
86.	4.86	Mean comparison and significant probabilities between Finishing material with respect to Dew point	128
87.	4.87	Analysis of variance in indoor air quality parameters with regard to Flooring material	129
88.	4.88	Mean comparison and significant probabilities between Flooring material with respect to PM <sub>2.5</sub>	130
89.	4.89	Mean comparison and significant probabilities between Flooring material with respect to temperature	130
90.	4.90	Mean comparison and significant probabilities between Flooring material with respect to Dew point	131
91.	4.91	Analysis of variance in indoor air quality parameters with regard to Ceiling type	132

92.	4.92	Analysis of variance in indoor air quality parameters with regard to Extent of presence of dust in the house	133
93.	4.93	Mean comparison and significant probabilities between Extent of presence of dust in the house with respect to PM <sub>4</sub>	134
94.	4.94	Mean comparison and significant probabilities between Extent of presence of dust in the house with respect to PM <sub>2.5</sub>	134
95.	4.95	Mean comparison and significant probabilities between Extent of presence of dust in the house with respect to Relative Humidity	134
96.	4.96	Mean comparison and significant probabilities between Extent of presence of dust in the house with respect to Dew point	135
97.	4.97	Analysis of variance in indoor air quality parameters with regard to Frequency of household cleaning	136
98.	4.98	Mean comparison and significant probabilities between Frequency of household cleaning with respect to CO <sub>2</sub>	136
99.	4.99	Mean comparison and significant probabilities between Frequency of household cleaning with respect to PM <sub>10</sub>	137
100.	4.100	Mean comparison and significant probabilities between Frequency of household cleaning with respect PM <sub>2.5</sub>	137
101	4.101	Mean comparison and significant probabilities between Frequency of household cleaning with respect to Temperature	137
102.	4.102	Analyses of variance in indoor air quality parameters with regard to Feeling of congestedness	138

103.	4.103	Mean comparison and significant probabilities between Feeling of congestedness with respect to CO <sub>2</sub>	139
104.	4.104	Mean comparison and significant probabilities between Feeling of congestedness with respect to VOC	139
105.	4.105	Mean comparison and significant probabilities between Feeling of congestedness with respect to PM <sub>4</sub>	139
106.	4.106	Mean comparison and significant probabilities between Feeling of congestedness with respect to RH	140
107.	4.107	Mean comparison and significant probabilities between Feeling of congestedness with respect to Temperature	140
108.	4.108	Mean comparison and significant probabilities between Feeling of congestedness with respect to Dew point	140
109.	4.109	Analysis of variance in indoor air quality parameters with regard to Extent of use of cleaning reagent	141
110.	4.110	Mean comparison and significant probabilities between Extent of use of of cleaning reagent with respect to PM <sub>10</sub>	142
111.	4.111	Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to PM <sub>4</sub>	142
112.	4.112	Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to PM <sub>2.5</sub>	142
113.	4.113	Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to Relative Humidity	143
114.	4.114	Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to Dew point	143

115.	4.115	Analysis of variance in indoor air quality parameters with regard to Extent of use of electrical gadgets	144
116.	4.116	Analyses of variance in indoor air quality parameters with regard to Extent of use of personal care products	145
117.	4.117	Mean comparison and significant probabilities between Extent of use of personal care products with respect to PM <sub>4</sub>	146
118	4.118	Mean comparison and significant probabilities between Extent of use of personal care products with respect to PM <sub>2.5</sub>	146

## LIST OF ILLUSTRATION

S. No.	Figure No.	Title	Page No.
1.	4.1	Distribution of households by height of the base of the building site with reference to the main road	60
2.	4.2	Distribution of households by height of the base of the building site with reference to the road in front of the house	60
3.	4.3	Distribution of households by the side of the building facing the main road	61
4.	4.4	Distribution of households by extend of dust accumulation features	64
5.	4.5	Distribution of households by flooring material	66
6.	4.6	Distribution of households by ceiling type	66
7.	4.7	Distribution of households by extent of presence of dust in the house	67
8.	4.8	Distribution of households by the extent of use of electrical gadgets	70
9.	4.9	Contribution of variables under study towards the level of CO <sub>2</sub> in residential households	147
10.	4.10	Contribution of variables under study towards the level of VOCs in residential households	148
11.	4.11	Contribution of variables under study towards the level of PM <sub>4</sub> in residential households	149

12.	4.12	Contribution of variables under study towards the level of PM <sub>2.5</sub> in residential households	150
13.	4.13	Contribution of variables under study towards the level of Relative Humidity in residential households	151
14.	4.14	Contribution of variables under study towards the level of Temperature in residential households	152
15.	4.15	Contribution of variables under study towards the level of Dew point in residential households	153

## LIST OF PLATES

<b>S.NO.</b>	<b>PLATE NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
1	Plate no.1	Environmental monitor (EVM-7)	44
2	Plate no.2	Tiger VOC detector	44
3	Plate no.3	Laser distance measurer.	49

## LIST OF APPENDICES

<b>S.NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
1	Appendix:A Interview schedule to elicit information on building design, personal and household maintenance practices	181-189
2	Appendix:B Correlation between building independent variables of the study and indoor air quality parameters	190-191
3	Appendix:C Stepwise regression	192-195

Name : **UMMARA AMREEN**  
I D NO : **HHM/ 2013/013**  
Title of the Thesis : **BUILDING DESIGN AND INDOOR AIR  
QUALITY IN RESIDENTIAL  
HOUSEHOLDS**  
Degree to which it is submitted : **MASTER OF SCIENCE IN HOME  
SCIENCE**  
Major Field : **RESOURCE MANAGEMENT AND  
CONSUMER SCIENCES**  
Faculty : **HOME SCIENCE**  
Major advisor : **DR. (Mrs.)NEERAJA TELAPROLU  
PROFESSOR  
DEPT.OF RESOURCE MANAGEMENT  
AND CONSUMER SCIENCES**  
University : **PROFESSOR JAYASHANKAR  
TELANGANA STATE AGRICULTURAL  
UNIVERSITY**  
Year of submission : **2015**

---

## **ABSTRACT**

The study was planned with an aim to explore building location characteristics, design aspects, material and maintenance practices that affect the Indoor air quality of the residential buildings. Sample for research was drawn from five highly polluted zones of Hyderabad and Secunderabad.

The houses near to heavy traffic roads were found with inadequate ventilation due to closing of windows to prevent the entry of outdoor polluted air. This resulted in high concentration of CO<sub>2</sub> in indoors. The release of VOCs in indoor was mainly when the residents were using cleaning reagents and personal care products. Relatively more amount of VOCs were released in indoors where residents were using cosmetics, like body lotion, nail polish, perfumes, deodorants, lipsticks and so on. Majority of the houses were found to have level of Relative Humidity, Dew point and Temperature more than the acceptable levels in indoor air

The building location characteristics selected for the study were found to be affecting the IAQ of residential buildings. CO<sub>2</sub> was found to be influenced by geographical location of building site and site orientation. VOC was found to be influenced by only side of the building facing the main road. None of the building location characteristics were found influencing the level of PM<sub>10</sub> in indoor air of residential buildings. PM<sub>4</sub> was found to be influenced by geographical location of building site and side of the building facing the main road. PM<sub>2.5</sub> was found to be influenced by site orientation, height of the building with reference to main traffic road, side of the building facing the main road. Relative Humidity was found to be influenced by geographical location of building site, site orientation, and side of the building facing the main road. Temperature was found to be influenced by geographical location of building site, and side of the building facing the main road. Dew point was found to be influenced by site orientation and side of the building facing the main road. Side of the building facing the main road was found to be a major factor that influence the IAQ.

As the area of the plot increased, the concentration of CO<sub>2</sub> in indoor air decreased. Significant variation according to the plinth area with regard to indoor air quality was found in the level of CO<sub>2</sub>, PM<sub>2.5</sub>, Relative Humidity and dew point. Level of Relative Humidity and Dew point decreased with increased plinth area.

Open area in the form of windows, doors and ventilators had impact only on the level of indoor air temperature. The concentration of CO<sub>2</sub> in indoors increased with an increase in the open area on the outer wall of the building. Height of the building had no impact on indoor air quality. Residential buildings with medium ceiling height were found to have high indoor temperature. Relative Humidity and Dew point in the indoor air decreased with an increase in the number of rooms. Concentration of VOC, PM<sub>2.5</sub>, Relative Humidity, and Dew point were high in the houses used cement brick, cement mortar and cement plaster for wall construction.

Indoor temperature was relatively high in the houses that used traditional brick, lime mortar and cement plaster for wall construction. Walls finished with luppum finish and paint were found to be contributing for relatively high level of CO<sub>2</sub>, and VOC in indoor air. Walls finished with white wash and distemper contributed for relatively high level of PM<sub>4</sub> and walls finished with luppum and paint contributed for high indoor temperature.

The houses used granite as flooring material were found to be with relatively high level of PM<sub>2.5</sub> in indoor air. The type of ceiling had not shown any impact on indoor air pollution.

Household maintenance practices like extent of presence of dust in the house, frequency of household cleaning, feeling of congestedness, extent of use of cleaning reagents for household maintenance were found to be significantly contributing to accumulation of pollutants like CO<sub>2</sub>, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity, Temperature and Dew point

No significant variation was found in the level of CO<sub>2</sub>, VOC, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative humidity, temperature and dew point in indoor air of the residential households with reference to the extent of use of electrical gadgets.

Highly Significant difference was found between houses with high and low extent of use personal care products on level of PM<sub>2.5</sub>, whereas significant difference was found between houses with high and medium extent of use personal care products on level of PM<sub>2.5</sub> in indoor air. Use of personal care products by the residents was found to have an impact on the level of PM<sub>4</sub>, and PM<sub>2.5</sub> in indoor air.

The contribution of cleaning practices for the presence of CO<sub>2</sub> in residential buildings was relatively more. The contribution of height of the building towards the presence of VOCs in residential buildings was relatively high. With reference to the presence of PM<sub>10</sub> in indoor air, there was no difference in the extent of influence exerted by selected variables. The contribution of side of the building towards the presence of PM<sub>4</sub> in indoor of residential buildings was more followed by wall material.

Floor area ratio, followed by dust accumulation features contributed towards the presence of variations in the level of PM<sub>4</sub> in residential buildings. Highest contribution towards the presence of Relative Humidity in indoor air was from personal care products. Highest contribution towards the presence of Temperature in indoor air was from geographical location. Major contribution towards the presence of Dew point in indoor air was from floor material.

The results of the study can act as guidelines for developing residential buildings with good Indoor Air Quality and promote health and comfort in living..

# CHAPTER 1

## INTRODUCTION

Indoor air quality refers to the quality of the air inside buildings as represented by concentrations of pollutants and thermal conditions that affect the health, comfort, and performance of occupants. Indoor air can be characterized as of acceptable quality when it contains no known contaminants at harmful concentrations and a substantial majority of people exposed to it do not express dissatisfaction or develop ailments over time. The Environmental Protection Agency (EPA, 2004) defined Indoor Air Quality as the temperature, humidity, ventilation and chemical or biological contaminants of the air inside a building. The quality of indoor air is a result of a complex relationship between the various contaminants, indoor sources, ventilation rate, dilution of indoor contaminants with outdoor air and air quality of the outdoor environment.

The sources of indoor air pollution can be both external and internal. External sources include air pollution from combustion processes, road traffic, factories, and leakages from the tank with fuel pollution around intake ducts through which the air flows to the building. A major contribution comes from indoor sources. These sources include poor ventilation, controlling temperature, high or low humidity, recent remodeling, and other activities in or near a building that can affect the fresh air coming into the building. Sometimes, specific contaminants like dust from construction or renovation, mold, cleaning supplies, pesticides, or other airborne chemicals including small amounts of chemicals released as a gas over time may cause poor indoor air quality. Apart from these the growing proliferation of chemical pollutants in consumer and commercial products, the tendency toward tighter building envelopes and reduced ventilation to save energy, and pressures to defer maintenance and other building services to reduce costs may foster indoor air quality problems.

A typical modern urban home contains a chemical soup of Volatile Organic Compounds (VOCs) like Formaldehyde, Xylene, Isobutyl Aldehyde, Vinyl Chlorides, Monomer, and other organic chlorides, Aldehydes and Phenols from all kinds of manufactured wood products, paints, carpets and synthetic textiles including furniture and

carpets , plastics, foam tile, and carpet glue and so on. A part from these, Radon from soil, Ozone from some electric appliances, and micro sized particles from many sources adds to the health risk in indoors. Volatile Organic Compounds and many other indoor air pollutants are emitted over periods of weeks or years from construction, furnishing products, consumer products, electrical goods such as computers and printers as well as cleaning reagents and air fresheners (Nazaroff,2004).These chemicals has the potential to cause poor indoor air quality.

In developing countries like India people still do not have safe and healthy buildings. Due to the combustion of bio fuels, majority of women in the country are exposed daily to concentration of respirable particles that are from 10 to 100 or even more than 1000 times higher than levels established as ‘Safe’ by the U.S. Environmental Protection Agency (Smith, 2002, U.S.EPA,2001).According to estimates by the World Health Organisation (WHO, 2002) indoor air pollution accounts for more than 5,000 premature deaths a day on a global scale , most of them in developing countries from low quality solid fuels burnt in open fires for heating or cooking. Globally, exposure to these combustions by products is estimated to cause 36% of all lower respiratory infections and 22% of all chronic obstructive pulmonary disease (WHO, 2002).

Even in the ‘developed’ countries where the recourses are available to create safe buildings, there are many more subtle hazards that contribute to unsafe, unhealthy, or uncomfortable buildings (Mendell, 2007). Pollution emissions are associated with modern buildings. These modern buildings have a problem of providing a healthy or even appropriate indoor environment. Developed countries in the past reported that about 30% of new or renovated buildings have serious indoor air quality problems and ranked indoor air quality as the most prominent environmental problem (Roodma and Lense, 1995).

Health effects that are experienced by the occupants of certain buildings range from severe effects like asthma, Allergic response, Cancer risks. Numerous studies have found association between indoor air pollution and acute lower respiratory infections (Smith *et al.* 2000), Chronic obstructive pulmonary diseases (Bruce *et al.* 2000), and lung cancer (Humford, 1987).There is emerging evidence that indoor air pollution is a risk factor for child and adult health problems, including low birth weight, prenatal mortality, asthma,

tuberculosis, nasopharyngeal cancer, cataracts, blindness, cardio vascular diseases (World Health Organisation,2002).

In children under the age of five, acute respiratory infections caused by exposure to indoor air pollution is the largest category of deaths (Smith *et al.*2003). In general, acute respiratory infections which do have causes other than indoor air pollution are responsible for more childhood mortality than the other main killer of children, diarrhea (Smith, 2002). It also has been estimated that 22% of the global burden of disease due to chronic obstructive pulmonary disease, which is the world's sixth leading cause of death is due to indoor smoke. More striking is that 40-45% of the burden of this same category of disease experienced by women in the developing world is caused by indoor air pollution from solid fuel use (Smith and Sivertsen, 2004).

The concentration of pollution in indoor air depends to a great extent on the physical layout of the building, flow rates of ventilation, space planning and interior treatments. A number of factors like physical layout of the building and building ventilation can affect the indoor air quality of a building. Changing the layout of the building by erecting walls or dividers inside can change the air circulation patterns and can lead to poor air circulation or concentration of contaminants in certain areas. The Building Heating Ventilation and Air conditioning systems are designed to distribute outdoor air throughout the building, remove contaminants and odors, and control the indoor air temperature and humidity. A poorly designed or maintained house along with the occupants of a building also affects the indoor air quality by smoking, cooking, using cosmetics or scents or producing body odors.

Increased desire of occupants for comfortable living environment and the availability of commercial fittings and fixtures contributed towards indoor air pollution. The urban homes in our country are highly mechanized to meet the needs of sophisticated life style. Many of the materials and systems used in older constructions were more forgiving of variations in temperature and humidity and they often acted as filters or sponges for absorbing contaminants. Today light weight systems with their gaskets, seals and tight tolerances are intended to function as a barrier to both indoor and outdoor conditions rather than as a floating filter permeable to moisture and gaseous compound. As a result, not only have these systems tended to exacerbate the precursor conditions for poor

air quality, but they have also resulted in a reduction in the sink area for contaminant absorption.

The European Commission Scientific Committee on Health and Environment Risks reviewed current approaches to risk assessment of indoor air pollutants (SCHER, 2007). It concluded that indoor air may contain over 900 chemicals, particles and biological materials with potential health effects. Many researchers have addressed the phenomena of particle penetration through the building structure into the indoor environments (Maston, 2005; Meng *et al.* 2005; Hoek *et al.* 2008).

## **Justification**

The concept of health is no longer thought of as simply the absence of disease. The World Health Organisation (WHO) has done much to advance a definition of health that encompasses mental and physical well being, access to clean and safe environment and health care. World Health Organisation (WHO, 2007) ranked air pollution as 8<sup>th</sup> on a scale of worldwide risk factors very close to clean water and appropriate sanitation in terms of its effects upon human health throughout the world.

The urbanization process has both positive and negative effects on indoor air quality in many cities. More than 72% of the Indian households according to 2010 census still use unprocessed biomass as their primary cooking fuel, in rural areas (ORG, 2011). As a result, India bears one of the largest burdens of diseases due to the use of unclean household fuels. According to WHO comparative risk study, 28% of all deaths are caused by indoor air pollution in developing countries (WHO, 2007).

In developing countries like India, poor indoor air quality can cause health problems to building occupants as the building are not designed to protect indoor air quality. Contamination of indoor air by building materials, human activities, outdoor pollutants, ineffective ventilation, and malfunctioning of central heating and cooling systems was found to be common. To eliminate or reduced contaminants to acceptable levels, it is necessary to either remove the specific contaminant by physical or chemical means, or to dilute the air until the concentration is too low to be considered a potential hazard.

Indoor air quality is a public interest, as it has direct and indirect impact on the health. Addressing and dealing with Indoor air quality problems is a continuous effort. To design the basic structure and interiors of building that can maintain the appropriate Indoor air quality is the prime responsibility of architects and interior designers. To come up with appropriate technologies and strategies that protect indoor air quality, it is essential to understand what site and location parameters affect the Indoor air quality of the building? What are the design aspects that effect Indoor air quality? What material and maintenance practices affect Indoor air quality?

As indoor air quality is regarded as a major global public threat requiring greatly increased efforts in the area of research there is a need to answer these research questions and fill the existing research gap. Hence, the present study “Building design and Indoor Air Quality in Residential Households” is designed with the following objectives.

### **Objectives of the study**

1. To assess the indoor air quality of selected households.
2. To explore the design features of residential buildings with reference to building location characteristics, design features, and construction material.
3. To find out the household maintenance practices, extent of use of electrical gadgets, and personal care products.
4. To establish the relation between indoor air quality and selected independent variables viz., (i) Building location characteristics (ii) Building design features (iii) Construction material (iv) Household maintenance practices (v) Extent of use of electrical gadgets and (vi) Extent of use of personal care products.

### **Hypothesis**

H1: There exists a relation between selected building location characteristics and Indoor Air Quality.

H2: There exists a relation between building design features and Indoor Air Quality.

H3: There exists a relation between building construction and finishing material and Indoor Air Quality.

H4: There exists a relation between the household maintenance practices and Indoor Air Quality.

H5: There exists a relation between extent of use of electrical gadgets and Indoor Air Quality.

H6: There exists a relation between extent of use of personal care products and Indoor Air Quality.

H7: There is a difference in the extent of influence exerted by selected independent variables on Indoor Air Quality.

### **Assumption**

The study is based on the assumption that

- In urban communities the probability of decrease in indoor air quality may exist because of both indoor and outdoor factors.
- The selected building design features exert influence on the indoor air quality
- The sophisticated life style of building inmates may contribute towards decrease in Indoor Air Quality.
- Use of chemical reagents for cleaning may have the impact on Indoor air quality.

### **De-limitation of the study**

The study was de-limited to

- Independent households that were situated near five heavy traffic zones identified by Pollution Control Board of Telangana Viz., Abids, Kukatpally,,Mahatma Gandhi road and Punjagutta,

- Measuring the Indoor Air Quality by assessing the selected parameters such as Carbon dioxide (CO<sub>2</sub>), Volatile organic compounds (VOCs), PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity, Temperature, and Dew point.
- Studying the building location characteristics in terms of geographical location of the building site, site orientation, height of the base of the building site with reference to main traffic road, height of the base of the building site with reference to road in front of the house and side of the building facing the main road.
- Studying the building design features in terms of plot area, plinth area, landscape area, floor area ratio, open area on the wall of the building facing the main traffic road, open area on the outer wall of the building, height of the building, ceiling height, no. of rooms and extent of dust accumulation features.
- Studying the construction material in terms of wall material, finishing material for walls, floor material and ceiling type .
- Studying the household maintenance practices in terms of extent of presence of dust in the house, frequency of household cleaning, feeling of congestedness, and extent of use of cleaning reagents.
- Measuring the extent of dust accumulation features in terms of number of nooks and corners, lighting fixtures, top of storage almarahs, TV stand computer stand , carpets/mats, curtains/draperies, window sills, furniture, cabinets and electrical gadgets in the house.
- Measuring the extent of presence of dust in the house as perceived by the investigator on items such as dust on the floors, on the walls, on the carpets/mats/ Rugs, curtains / draperies, lighting fixtures, furniture, home accessories, storage almarahs, window sills and gadgets .

## Chapter II

# REVIEW OF LITERATURE

The available literature related to the research problem “Building design and Indoor air quality in residential households” was surveyed and examined to get acquainted with the selected topic of research. From this literature survey knowledge as to what data and material are available for operational purpose was gained. According to Ackoff(1962). Knowing what data are available often serves to narrow the problem itself as well as the technique that might be used. This literature review enabled the researcher to identify research gaps and specify the research problem in a meaningful context.

The background information on the sources of indoor pollutants and their health effects that is related to the topic of research is present under the head ‘Theory’, followed by the empirical literature consisting of studies done earlier in the related field under the head ‘Research’.

### 2.1 Theory

Indoor air quality is a term referring to the air quality within and around the buildings and their structures, its significance especially being its relation to the health and comfort of building occupants (Darus *et al.* 2011). The air in the building is polluted due to combustion by products such as Carbon monoxide, Nitrogen dioxide, Ozone, allergens including mould spores, building material and furnishings, cleaning products, personal care products, air fresheners and pesticides used indoors, tobacco smoking, hobbies, cooking and other occupant activities as well as dry cleaned clothes, bio effluents, and soil gas intrusion including radon (Levin, 2006).

Historically, architects were not just concerned with the aesthetic aspects of the building. They addressed all aspects of building performance, albeit with far simpler requirements and none or little of the currently prevalent forms of environmental control ‘technology’(Banham and Reyner, 1984).

Ancient buildings and many traditional or vernacular forms of architecture were often far more massive than their modern counterparts. In temperate and cold climate,

massive structures stored heat in the day time when it was available from the sun or from fires inside the structures, then released it at night when temperatures were lower. In hot climate, the mass of the structure, shading, and coupling the structure to the earth provided more even temperatures over the course of the diurnal cycle. The form of the structure and its major material were strongly linked to thermal comfort, illumination, acoustic and ventilation design (Banham, 1984).

Even until a few decades ago, the level of thermal comfort, illumination, and air quality generally expected and required of buildings were vastly different from today's requirements. Expectations played and still playing an essential role in determining the performance standards to which buildings are designed (Banham and Reyner, 1984).

Research has shown repeatedly that buildings not designed to conform to current standards and guidelines fail to provide occupant satisfaction with one or more of the general indoor environmental parameters such as air quality, thermal conditions, illumination and acoustics (Levin, 2006).

Poor indoor air quality problems related to buildings that effect building occupants are referred as 'sick building syndrome', or 'Tight building syndrome' or 'Building related illness'. As defined by a working group of the World Health Organization, the "sick building syndrome" involves various non specific symptoms such as eye, skin, and upper airway irritation, headache, and fatigue (Burge *et al.* 1987). A building material manifests sick building syndrome when complaints of certain symptoms associated with acute discomfort persist at frequencies significantly greater than 20% over time, the cause of the complaints are not recognizable and a substantial percentage of complaints report immediate relief upon exiting the building( Balaras *et al.* 2000). Some of the most characteristics health symptoms with sick building syndrome are reported by the occupants include several or most of the mucous membrane irritation, eye irritation, headache, odor, skin irritation, rash, sinus conjection, cough, sore throat, shortness of breath, abnormal taste, dizziness, fatigue, nausea, wheezing, and hypersensitivity. These symptoms of different combinations thereof are the primary symptoms of sick building syndrome defined by The World Health Organisation (WHO, 2003).

Most air pollutants enter the human body through the process of inhalation. Air pollutants that enter the body through the respiratory system are transferred into the blood stream by the alveoli and then carried throughout the body. Once inside the bloodstream, the contaminants can be responsible for a variety of ailments, not just respiratory problems, but physical, neurological mental and behavioral problems. According to Sundell (2004) “Indoor air quality is a dominant exposure for humans” even though sources of ambient air pollution emit higher absolute quantities of pollutants. It has been estimated that people spend more than 90% of their time indoors; consequently, indoor air quality is of great importance (ECA, 2000). Besides causing adverse health effects, poor air quality may reduce productivity and lead to large economic losses (Seppanen, 1999). More than two million premature deaths are attributed to the effects of urban outdoor and indoor air pollution (WHO, 2003).

The air quality of the indoor environment is capable of affecting human comfort in many ways. Over 50 % of a person’s air intake is said to occur inside the home over the course of that person’s life (Sundell, 2004). During this time the nature of the enclosed environment directly affects the health and quality of life of individuals (Smith *et al.* 2003). The most common indoor air pollutants that affect human health include Carbon monoxide, Sulphur dioxide, Nitrogen oxides, and Particulate matter emitted from incomplete combustion processes, Ozone, Volatile organic compounds emitted from various sources, biological contaminants such as moulds, and Radon gas released from the soil.

### **2.1.1 Indoor pollutants sources**

#### **2.1.1.1 Asbestos fibres**

Asbestos fibres are used widely in many building products. The major building products manufactured are asbestos cement (AC) sheet products for interior and exterior cladding, flooring products (high density underlay sheets, vinyl-asbestos floor tiles, ‘cushion’ vinyl flooring) and fire, thermal or acoustic insulation products like asbestos millboard, sheet and pipe pre-formed insulation panels, sprayed asbestos insulation (Brown, 1981). These products vary greatly in the types and amounts of asbestos and binders that are used and in consequence exhibit large differences in their physical integrity and particularly friability. Friability is the ability of the material to be broken down to dust.

Most insulation products are considered friable, many sprayed asbestos insulation products being highly friable such that minor disturbance can result in a large airborne release of asbestos fibres. Sprayed asbestos insulation products are widely used in commercial and industrial buildings and can act as a major source of asbestos fibre exposure if the products are damaged or deteriorated particularly during building maintenance activities (Brown, 1981; Levin, 2006). Activities of general occupants are unlikely to result in elevated asbestos fibre concentrations but routine activities of maintenance workers may lead to localised elevation of concentrations, damaged friable sprayed asbestos particularly with visible debris has often been associated with elevated asbestos fibre concentrations in indoor air. Most asbestos building products other than insulation products are non-friable and release asbestos fibres as a result of intermittent machining processes that break down the product (e.g sawing, grinding and sanding) (Health effects institute - Asbestos Research, 1991).

#### **2.1.1.2 Radon**

Radon (radon-222) is an inert gas which is the decay product of radium 226. Since radon is gaseous it leaves the soil or rock and enters surrounding air or water and hence is ubiquitous in indoor and outdoor air. Radon decay leads to emission of alpha particles which can damage live tissue, such as that of the lung if radon is inhaled. Radon entry into building air is generally via the soil under a building but less significant sources such as natural gas for cooking/heating or some building materials are also known (Wadden and Scheff, 1983). Radon concentrations in indoor air will exceed those outdoors due to the restricted dispersion of air in buildings. Radon is naturally occurring radioactive gas that can enter buildings from the ground and the amount of ingress depend upon a number of factors including local geology, the type of foundation and floor, the positioning of service pipe work and internal ventilation levels. Measures such as installation or gas-proof membranes in the foundations of new buildings can significantly reduce levels of radon gas (HPA, 2008)

### **2.1.1.3 Environmental tobacco smoke**

Environmental tobacco smoke (ETS) is the term used to describe a complex airborne mixture of gases and particles that results from tobacco smoking in buildings. ETS from cigarettes is produced primarily by the smoke released at the burning end (side stream smoke) and smoke exhaled by the smoker (mainstream smoke). The smoke is quickly diluted and dispersed in building air and changes rapidly in its physiochemical properties, especially in the decreased proportion of constituents found in the particle phase relative to the vapor phase. Chemical composition also changes due to the way that constituents respond to ventilation and contact with indoor surfaces (Guerin *et al.* 1992).

### **2.1.1.4 Respirable suspended particulates**

Respirable suspended particulates (RSP) Airtight wood heaters will limit indoor leakage but still contribute substantially to outdoor air pollution are the fine fraction of the ambient and indoor aerosol. These are defined as Particulate matter with the aerodynamic diameter less than 2.5mm (PM<sub>2.5</sub>) and are generated by various sources. Fuel combustion processes in transportation and energy production are the primary sources of the outdoor PM<sub>2.5</sub>, while cooking, smoking, and cleaning activities contribute primarily to the indoor PM<sub>2.5</sub> levels. Traffic-related fine particles are recognized as an important contributor to outdoor PM<sub>2.5</sub> concentrations (Ferrari *et al.* (1988); Samet and Spengler,1991).Wood burning heaters and kerosene heaters can elevate RSP concentrations to short-term levels (Gertler *et al.*2000). This airborne particulate matter has been associated with various adverse health effects (Schwartz *et al.*1996, Brunekreef *et al.* 1997, Duhme *et al.* 1998).

### **2.1.1.5 House dust mite**

House dust mites (HDMs) are a major source of allergen in common house dust from indoor furniture and furnishings. Allergens in the indoor environment are significant pollutants since they can sensitize various organs such that an inflammatory reaction occurs on repeat exposure. Allergic reaction in the lung leads to asthma; in the nose, to hay fever or allergic rhinitis; in the skin, to dermatitis or a form of eczema. (Woolcock, 1991).

### **2.1.1.6 Microbial contaminants**

These include viable and non-viable microbiological matter such as viruses, bacteria, fungi, protozoa, insect faeces and pollens. The major reservoir indoors is stagnant water or wet interior surfaces that accumulate microbes which enter the building with outdoor air. Such reservoirs may act as amplifiers for bacteria, while fungi can grow in relatively dry environments (Solomon and Burge, 1984). Airborne dispersion is relatively easy for microbes found in building ventilation systems (e.g. fungal and bacterial spores) or contaminated carpet.

### **2.1.1.7 Formaldehyde**

Formaldehyde is an irritating gas with a pungent odor and readily dissolves in water. Its major industrial application is in the production of different resins which are widely used in indoor materials and in consumer products, particularly pressed-wood and building products such as particleboard and medium density fibre board. Formaldehyde is also emitted by gas stoves and in tobacco smoke. The major source of formaldehyde in indoor air has been pressed-wood products such as particleboard, plywood and medium density fibre board which use formaldehyde-based resins. The amount of products used indoors and the level of building ventilation are significant factors in concentrations achieved (Brown, 1991).

### **2.1.1.8 Volatile Organic Compound**

Volatile organic compounds (VOCs) are organic compounds with boiling points between 40–60°C and 260°C (excluding pesticides) that arise from the large number of materials, equipment and consumer products used in buildings. The major sources of volatile organic compounds (VOCs) in indoor air are wet construction products like paints, adhesives, sealants in new buildings and a mixture of wet household products and other materials in established buildings (Brown, 1994). VOCs are emitted over periods of weeks or years from construction and finishing products and have the potential to cause indoor air quality. VOCs and formaldehyde have been regarded as the most important organic gaseous pollutants in indoor air.

### **2.1.1.9 Pesticides**

Generally, exposure to pesticides in dwellings occurs through the use of consumer products, intrusion of termiticides from foundations and contamination of house dusts. Exposure can occur by inhalation and by absorption through the skin after contact with treated surfaces and so airborne concentrations are not the only indicators for occupant exposure (Meaklin, 1992).

### **2.1.1.10 Nitrogen dioxide**

Nitrogen dioxide and nitric oxide occur in building air due to indoor combustion sources, but nitrogen dioxide is the oxide of principal health concern since it is known to cause lung damage at high concentrations (Samet and Spengler, 1991). Nitrogen dioxide is an oxidant gas deposited primarily in the large and small airways of the lungs. The major source of nitrogen dioxide in the indoor air of a large number of dwellings and schools is unflued gas heating appliances and cooking appliances (McPhail and Betts, 1992)

### **2.1.1.11 Carbon monoxide**

Carbon monoxide is a colorless, odorless gas, produced by the incomplete combustion of most fuels. Incomplete combustion can occur, when inadequate ventilation to an appliance results in depletion of the oxygen content of the air at the point of combustion. Major indoor sources of carbon monoxide are unflued gas heating appliances in dwellings and enclosed car parking sites in commercial buildings. Carbon monoxide is produced indoors primarily by fuel combustion (e.g. gas or wood-burning appliances, car exhausts) or infiltration of polluted outdoor air. Indoor carbon monoxide concentrations are expected to generally follow outdoor levels except where combustion sources occur in buildings without full venting (Coultas and Lambert, 1991).

### **2.1.1.12 Carbon dioxide**

Carbon dioxide is a natural constituent of air. It can be present in buildings as a result of respiration of people and animals, as a product of combustion and as a component

of soil gas. It is widely used as an indicator of ventilation rate and, effectively, as a proxy for body odor. In the absence of unvented combustion processes, building occupants are the major source of indoor carbon dioxide and the concentrations attained are largely a function of building ventilation rates and occupancy levels. The carbon dioxide concentrations generally encountered in buildings have no adverse health effects. However, the concentrations measured, in the absence of other sources (e.g. combustion processes), will be closely related to the ventilation rate relative to the number of occupants and building volume. Carbon dioxide concentration has been used as a surrogate measure of ventilation rate relative to its influence on indoor air quality (Reardon and Shaw, 1993).

### **2.1.1.13 Ozone**

Ozone is a strong oxidizer formed in outdoor air by photochemical reactions and is an irritant that affects the mucous membranes, other lung tissues and lung function. Indoor sources were considered of minor significance once upon a time but this is changed with the increased use of electrostatic photocopiers and laser printers in offices, which have been reported to emit substantial quantities of ozone (Cutter Information Corporation, 1992). Many of the suppliers of such equipment limit ozone emissions by use of charcoal filters on exhausts but these must be replaced regularly. The NOHSC, (1989) noted that a combination of heavy use, poor maintenance and inadequate ventilation could result in excessive ozone levels in indoors.

### **2.1.2 Health effects of indoor air pollution**

Health effects that are experienced by the occupants of certain buildings range from severe effects like asthma, allergic response, cancer risks to a series of mild symptoms, generally non-specific in nature, which exhibit an association with the indoor environment, particularly indoor air. Collectively, all such health effects are termed 'building-related illness' and many arise from identifiable causes, for example specific pollutants, poor ventilation, humidifier fever, poor thermal comfort, poor lighting, psychosocial factors. However, it has been found that a range of subjective symptoms, termed the 'sick building syndrome' by the World Health Organisation (WHO, 1982) occur in a high proportion

(30% or more) of occupants of specific buildings (generally, but not exclusively, air-conditioned offices) without clearly identified causes.

Raw (1992) summarized Sick Building Syndrome symptoms as irritated, dry or watering eyes described as itching, tiredness, smarting, redness, burning, difficulty wearing contact lenses. Irritated, runny or blocked nose described as congestion, nosebleeds, itchy or stuffy nose. Dry or sore throat described as irritation, oropharyngeal symptoms, upper airway irritation, difficulty swallowing, dryness, itching or irritation of the skin, occasionally with rash or specific clinical terms such as erythema, rosacea, urticaria, pruritis, xerodermia less specific symptoms such as headache, lethargy, irritability and poor concentration (Sundell, 1994)

### **2.1.2.1 Respiratory health effects**

Several effects on the respiratory system have been associated with exposure to indoor air pollution. These include acute and chronic changes in pulmonary function, increased incidence and prevalence of respiratory systems, acute pre-existing respiratory systems, and sensitization of the airways to allergens present in the indoor environment. Observed changes in pulmonary function due to exposure to tobacco smoke in the home, have mostly been due to acute or chronic airway narrowing leading to obstruction in air flow. Asthma, manifested by attacks of excessive airway narrowing leading to shortness of breath, and wheezing, can be caused or aggravated by exposure to allergens in the home, but it has also has been associated with exposure to substances such as nitrogen dioxide and environmental tobacco (ETS). Bronchitis, manifested in inflammatory changes in the airways and mucus hyper secretion has been linked to high levels of ambient air pollution and to exposure to the ETS in the home. Respiratory symptoms which have been associated with exposure to indoor air pollutants are symptoms mostly related to the lower airways such as cough, wheeze, shortness of breath and phlegm (Smith, 1999).

### **2.1.2.2 Allergic diseases**

Allergic asthma, extrinsic allergic alveolitis and hypersensitivity are the most serious allergic diseases caused by allergens in indoor air. Allergens asthma is

characterized by reversible narrowing of the lower airways. Pulmonary function during an attack shows an obstructive pattern in serious cases together with reduced ventilation capacity. Allergic asthma may be caused by exposure to indoor air pollutants, either acting as allergens or as irritants (Lewis *et al.* 2002). Allergic rhino conjunctivitis is also an allergic diseases, but while asthma occurs in all age groups, allergic rhino conjunctivitis is especially prevalent among children and young adults. The main symptoms are itching of the eye and the nose, sneezing watery nasal secretion and some stuffiness of the nose (Sundell, 1994).

### **2.1.2.3 Cancer**

Lung cancer is the major cancer which has been associated with exposure to indoor air pollution. Asbestos exposure has been linked to cancer in workers and also in workers family members, presumably due to asbestos fibres brought into the home on workers clothing. The principle agents present in indoors associated with lung cancer are ETS and radon decay products. Radon and radon decay products can be present in high concentration in homes built on soils which are rich in uranium. Asbestos, polycyclic aromatic hydro carbons, benzene, formaldehyde, some pesticides, and nitrosamines which may form on filters of re circulating kitchen exhaust fans, all of which have been found in indoor air, and all of which are known or suggested to be human carcinogens (Bahera *et al.* 2003).

### **2.1.2.4 Irritative effects on skin**

Exposure of the skin and mucous membrane to indoor air pollutants may cause effects on the sensory system and may result in tissue changes. Signs and symptoms of effects on skin and mucous membrane may appear at the sight of contact on the exposed skin, mucosa or manifest themselves in other tissues due to reflexes. Irritative effects causing tissue changes in the skin and mucous membranes have been reported in many forms. The symptoms and signs are often in specific and each may be caused by several different exposure factors (Brown, 1994).

### **2.1.2.5 Sensory effects on the nervous system**

Sensory effects are typically observed in buildings with indoor climate problems because many chemical compounds found in the indoor air have odorous or mucosal irritation properties. The senses responding to environmental exposure are not only hearing, vision, olfaction, and taste, but also the skin and mucous membrane. As pointed out by the WHO, (1989) many different sensory systems that respond to irritants are situated on or near the body surface. Some of these systems tend to respond to an accumulated dose and their reactions are delayed. On the other hand, in case of odor perception the reaction is immediate but also very much influenced by olfactory fatigue on prolonged exposure (Engen, 1982).

### **2.1.2.6 Cardiovascular effects**

Carbon monoxide exerts its influence primarily through binding to the hemoglobin in blood. The affinity of CO to hemoglobin is about 200 times higher than the affinity of oxygen to hemoglobin, so that at relatively low levels of CO in the air, oxygen is replaced by CO. The percentage of hemoglobin bound to CO (% carboxyhemoglobin) is a measure of recent exposure to CO. Organs with high oxygen demand, such as the heart and the brain, are particularly susceptible to a reduced oxygenation caused by CO exposure. ETS and CO are the main components; of indoor air that have been associated with cardiovascular effects (Guerin *et al.* 1992). Active smoking is a well known cause of cardiovascular disease. CO present in tobacco smoke is one of the likely causal agents, as smokers are known to have chronically elevated levels of carboxyhemoglobin in their blood.

## **2.2 Research**

Indoor air pollution as a topic of research attracted the attention of researchers long ago. Mostly the researcher focused on understanding the sources of indoor air pollutants and their impact on the health. Indoor air pollution specifically in relation to building components was not explored much. The research related to sources of indoor air pollution in built in environment and health effects of indoor air pollution that are conducted in India and other countries from the recent years to past are presented below.

Ashraf *et al.* (2013) explored the income wise household environmental pollution and its health impact on residents of Aligarh city of India. The study established the relation between fuels for cooking , place of cooking, indoor smoking, outside smoke coming inside the house, ventilation in the house, floor space per person in the sleeping room, poor environmental conditions and selected diseases namely conjunctivitis, rhinitis, sore throat, bronchitis, asthma, allergies, tuberculosis and pneumonia. The reasons for high occurrence conjunctivitis was per head living space availability, smoking in house, non ventilated house, use of kerosene and amount of smoke remain inside the house. Per head space availability was one of the reasons for diseases like sore throat, allergy, asthma, bronchitis and tuberculosis. Intensity of diseases increased with concentration of indoor air pollution and high content of suspended particulate matter. According to the study indoor air pollution was affected by housing conditions, living conditions and outdoor environment, in turn indoor air pollution was affecting the health of inmates.

A study to determine the impact of using a portable ion generator on indoor air quality in a room with varying ozone sinks and terpene concentrations was conducted by (Waring and Siegal, 2010). The study showed that under certain conditions in a residential room, the use of potable ion generator can increase concentration of ozone and aldehydes. Also increased concentrations of ozone were observed regardless of air freshener presence. Thus, according to the study use of ion generators had the potential to degrade indoor air quality.

Massey *et al.* (2009) conducted a study to find out the indoor outdoor relationship of fine particles. Particulate mass concentrations were measured using Grimm aerosol spectrometer for 24 hours inside and outside the homes located in roadside, rural and urban area, The indoor average concentrations recorded for  $PM_{2.5}$ ,  $PM_{1.0}$ ,  $PM_{0.5}$  and  $PM_{0.25}$  were maximum for the rural homes followed by roadside homes and then by urban homes. The average ratios for  $PM_{2.5}$ ,  $PM_{1.0}$ ,  $PM_{0.5}$  and  $PM_{0.25}$  in roadside and rural areas were close to or above 1.00 and less than 1.00 for urban areas. The ratios obtained were linked to the indoor activities using occupant's diary entries. The positive values of correlation coefficient indicated the indoor concentrations of particulate matter were correlated with the corresponding outdoor concentrations.

A study was conducted by Joshi *et al.* (2009) to determine the health impact of indoor air pollution in rural hill region of Nepal. The study was conducted in two phases, in first phase, adult kitchen dwellers were assessed for prevalence of respiratory disorder while in second phase the acute respiratory infection in children below two years were observed during the three months periods. The results showed that eight kinds of respiratory ailments and related symptoms were prevalent in adult respondents. It was found that cough phlegm, breathlessness, wheezing, chronic obstructive pulmonary disease, and bronchial asthma were significantly varied with higher exposure and smoking habit. Correlation analysis denoted higher prevalence of diseases and symptoms in smokers. There was a significant association between exposure level to smoke and prevalence of respiratory disorders in both adults and children.

Maier *et al.* (2009) discussed the difficulties of modeling the interaction of heat combustion, comfort parameters and indoor air quality at the design stage because of the influence of the behavior of occupants on building performance. They undertook a study of 22 identical houses with timber framed construction in Germany where four different ventilation systems such as, natural ventilation system with air heating, Mechanical Ventilation, Heat Recovery and Mechanical Ventilation with single ventilators had been installed. They measured CO<sub>2</sub>, temperature, relative humidity, energy consumption, window opening, mechanical ventilation use, and perceived thermal comfort, over a two year period. Mechanical Ventilation Heat Recovery demonstrated 10 to 30% lower energy consumption than the other strategies. CO<sub>2</sub> concentration were about 40 -50% lower than those found with natural ventilation. Installation cost was higher for the Mechanical Ventilation Heat Recovery system. Perceived air quality and comfort was good or very good with no difference between the four system types. In all cases occupants adapted their environment by opening windows rather than modifying ventilation air flows. The study showed an effect of occupant behavior on the interaction of energy use, comfort, indoor air quality, and ventilation.

Carrer *et al.*(2009) reviewed the main studies of indoor air related health effects and prioritized the diseases such as allergic and asthma symptoms, lung cancer, chronic obstructive pulmonary disease (COPD), airborne respiratory infections, cardio vascular

diseases (CVD), odor and irritation ( sick building syndrome symptoms), that are being caused or aggravated by poor Indoor air quality.

A research was undertaken by Gallego *et al.* (2008) to identifying volatile organic compound and origin of odors in indoors. The samples of air were collected using pump samplers by the inhabitants when they perceive odorous or discomfort. The analyses was performed by automatic thermal desorption with gas chromatography mass spectrometer. Results showed that higher total volatile organic compound was detected in indoor air compared to outdoor air. The concentrations of individual VOCs, such as ethanol, acetone was also much higher than the standard dwelling. This methodology was applied to sick building syndrome evaluation in which occupant experienced series of symptoms by the amount of time they spent in building

A study by Martuzevicius *et al.* (2008) made an attempt to find out the contribution of traffic related particulate matter in the indoor aerosols by assessing amount of traffic particles penetrating to indoor from outdoor environment. The concentration of PM<sub>2.5</sub> was measured inside and outside of six houses which were located at the distance 30 -300 mm from highway. The data was collected in spring and fall season and it was analyzed by 3-way method called parafic method. Although the distance from the highway and traffic intensity were generally important for assessing the indoor concentration of traffic-related aerosols, the data collected in this study suggest that specifically for houses located in a close proximity to major highways these two factors may not necessarily play the most important role in differentiating exposure levels between houses.

Meng *et al.* (2008) conducted a study to investigate whether daily and weekly asthma symptoms can be attributed to traffic-related exposures, poverty, and or vulnerabilities. Annual average daily vehicle traffic density within 500 feet of California Health Interview Survey respondents was calculated. Logistic regression analyses were performed to evaluate the association between annual average traffic density and frequent asthma symptoms with income as a confounder and a modifier. After adjustment for age, sex, and race ethnicity, a 92% increase in frequent asthma symptoms was observed among those in high traffic density and a 50% increase among those in medium traffic density compared to those in low traffic density. Adjustment for poverty did not change these

estimates, but individuals in poverty were twice more likely to experience frequent symptoms. Furthermore, delays in care, a poor/fair health status, current/previous smoking, overweight/obese, or unemployment showed independent associations with frequent asthma symptoms. Analyses stratified on income indicated greater estimated traffic effects for asthmatics in poverty, whereas the estimates for asthmatics above the poverty level moved closer toward the null. Traffic-related exposures, poverty and vulnerabilities all increased the risk of frequent asthma symptoms. Those in poverty appeared to be more strongly affected by heavy traffic near their residences.

A research study by Palonen *et al.* (2008) assessed thermal comfort, perceived air quality and ventilation in 102 single family homes in Finland built since 1980. The study group included homes, with passive stack ventilation, mechanical exhaust ventilation, and mechanical supply and exhausts ventilation and mechanical supply and exhaust ventilation with heat recovery. Air change rates were measured in 74 homes over a 3 week period using a passive tracer gas technique. The most common indoor climate related problem was dustiness of surfaces (36% of houses). Stuffy air was a problem in 12 %, insufficient ventilation during summer and ventilation noises were the most common problems related to the ventilation system. One third of the homes were considered to be free from indoor climate problems related but 20 % had at least three problems. Measured air change rates were generally low compared with finish buildings regulation requirements of 0.5 ach, (ach is the unit of measurement for air change rate)with average values of 0.30 ach for passive stack ventilation, 0.34 ach for mechanical exhaust and 0.41 ach mechanical supplies and exhaust ventilation.

Communities and Local Government, London (CLG,2008) summarized evidence for the impact of buildings on human health and safety and identified 33 hazards like Biocides, Carbon monoxide , cockroaches, environmental tobacco smoke, explosion in buildings, fungal growth, house dust mites, Hygrothermal conditions, land contaminations including landfill gas, lead, particles and fibers ,radon, oxides of Nitrogen, Volatile Organic Compounds, and Sulphur dioxide that were associated with Indoor Air Quality. In addition other factors relating to the Indoor environment were identified including noise, lighting, slips, trips, and falls, sources of infections and electromagnetic fields.

A study by Jarnstrom *et al.* (2008) reported on building material emissions and indoor air quality in residential buildings. Indoor air concentration and emission from structures and interior surfaces decreased in six months. Ammonia and formaldehyde remained material were investigated in eight residential buildings during the construction period and first year of occupancy. Volatile organic compounds, formaldehyde, ammonia, as well as temperature, humidity and ventilation were measured. It was found that total volatile organic compounds contribution was same. Results also showed that the ceiling area contribution was more than the surface area. The study confirmed that finishing material was base to provide the good indoor air quality in homes.

Chengappa *et al.* (2007) undertook a comprehensive assessment of the impact of the improved Sukhad stove on indoor air quality. Measurements of carbon monoxide and fine particulate matter PM<sub>2.5</sub> were conducted for a 48-hour period in 60 rural kitchens in Bundelkhand before and after installation of the Sukhad stove. One year after the installation of the Sukhad, 48-hour average CO concentrations were reduced, on average, by 70 % ( $p < 0.001$ ) in the homes of regular users of the improved stove. Similarly, 48-hr average PM<sub>2.5</sub> concentrations were reduced, on average, by 44 % ( $p < 0.01$ ). According to the study the use of the improved cook stoves reduce the indoor air pollution.

Kovesi *et al.* (2007) in their research study found the association between prevalence of reduced ventilation on increased risk of lower respiratory tract infections among Inuit children. Ventilation was measured in 49 homes of Inuit children less than 5 years of age. A standardized questionnaire was used to identify the occurrence of lower respiratory tract infections. Associations between ventilation measures and lower respiratory tract infection were evaluated using logistic regression models. The mean ventilation rates per person were below the recommended rate. The mean indoor CO<sub>2</sub> concentration was higher than the recommended level. Reported respiratory infection was significantly associated with mean CO<sub>2</sub> levels.

Mendel (2007) reviewed 21 research studies that have associated residential chemical emissions from indoor materials and activities with risk of asthma, allergies and pulmonary infections. Risks factors identified most frequently included formaldehyde or

particleboard, phthalates or plastic materials, and recent painting. Other such as aromatic and aliphatic chemical compounds was suggestive. Elevated risks were also reported for renovation and cleaning materials, new furniture and carpets or textile wallpaper. It was concluded that while these risk factors may only be indicators of truly causal factors, the overall evidence suggests a new class of residential risks factors for adverse effects that was ubiquitous in modern residences.

Fisk *et al.* (2007) undertook a meta analysis of 33 studies to investigate the association between occurrence of indoor dampness and mould with adverse health effects. According to this study building dampness and mould were found to be associated with approximately 30 to 50% increase in a variety of respiratory asthma related health outcomes.

Jacobs *et al.* (2007) reviewed knowledge of the links between health and the quality of the indoor environment of homes, to address these risks to health. Indoor air pollution was one of the top four health risks identified by US Environmental Protection Agency (EPA). Indoor air pollution was estimated to cause thousands of Cancer deaths and hundreds of cases of respiratory health problems each year. Millions of children have experienced elevated blood levels of contaminants from exposure to indoor pollutants. Other effects include irritation, and more subtle Neurotoxicological, behavioral and other adverse effects. The associated economic costs are considerable, the Environmental Protection Agency (EPA) estimating that net avoidable costs in 2001 alone were likely to be 150 billion and 200 billion

An investigation by Yoshino *et al.* (2006) reported that indoor air pollution by chemical substances is a serious problem in Japan and that such pollution is associated with sick house syndrome. They investigated 60 houses where occupants were suspected of suffering symptoms caused by indoor pollution. Concentration of VOCs and formaldehyde as well as air exchange rates and air tightness was measured. Only 36% of 14 homes met the 0.5 ach required in the building standard law. The concentration of formaldehyde, toluene, ethyl benzene concentration of formaldehyde, p-dichlorobenzene and TVOC was significantly higher in Sick house syndrome homes. Concentration was higher in new homes or in those with high air tightness and low air change rate, and where there were new furniture or moth crystals were used.

Engvall *et al.* (2006) undertook a questionnaire study on the indoor environment and occupant health of residents in Stockholm and compared the results with studies undertaken in the 1992. The 2006 study focused on homes built after the 1990s and found an increase in the proportion of complaint about thermal comfort as well as the proportion reporting sick building syndrome symptoms. Those reporting fatigue increased from 24 to 29% and eye symptoms increased from 8 to 13%.

Levis (2006) reported to the evidence from studies of schools and offices that demonstrates that improvements to the indoor environmental quality (IEQ) results in improved comfort, satisfaction, health, task performance and productivity of occupants. Each of the four categories of IEQ (thermal conditions, acoustics, illumination, IAQ) has significant implication for energy consumption as well as for other sources use and pollution emission.

Roulet (2006) discussed the relationship between IAQ and the energy performance of a building. The steps to reduce energy use in the 1970s was often involved the use of measures such as weather-stripping to reduce air leakage and this was associated with increased problems of indoor pollution, humidity and mould growth. It was found that with appropriate building design and use it was possible to achieve better IAQ with lower energy use.

According to Roulet (2006) air handing units in mechanically ventilated building were significant sources of indoor pollution. The study of 64 European office buildings showed that fewer sick building syndrome symptoms occurred in newer offices and in those with more floor space per person, near busy road, air traffic and more urban locations were detrimental. Also SBS symptoms were correlated with perceived thermal and acoustical comfort as well as lighting. All the 'healthy' buildings had open able windows and 66% had natural or hybrid ventilation and two thirds of the less healthy had mechanical ventilation.

According to Levin (2006) and Brvinen de Brvien *et al.* (2005) the major pollutants like SO<sub>2</sub>, NO<sub>2</sub>, Ozone, particulates, biological particulates, and benzene enter the building through polluted outdoor air. The air in the building is polluted due to combustion by products such as carbon monoxide, nitrogen dioxide, ozone, allergens including mould

spores, building material and furnishings, cleaning products, personal care products, air fresheners, pesticides used indoors, tobacco smoking, hobbies, cooking, and other occupant activities, as well as dry cleaned clothes, bio effluents and soil gas intrusion including radon. Sulphur dioxide (SO<sub>2</sub>) is produced by sulphur-containing fuels such as coal and oil. Ozone is primarily a pollutant of ambient air produced by photochemical reaction. It undergoes reaction in indoors with surfaces and airborne pollutants to produce new organic compounds and particles.

Gauderman *et al.* (2005) examined the association between traffic-related pollution and childhood asthma in 208 children from 10 southern California communities using multiple indicators of exposure. Study subjects were randomly selected from participants in the Children's Health Study. Outdoor nitrogen dioxide was measured in summer and winter outside the home of each child. Lifetime history of doctor-diagnosed asthma was associated with outdoor NO<sub>2</sub>. Also observed increased asthma associated with closer residential distance to a freeway and with model-based estimates of outdoor pollution from a freeway. These two indicators of freeway exposure and measured NO<sub>2</sub> concentrations were also associated with wheezing and use of asthma medication. Asthma was not associated with traffic volumes on roadways within 150 meters of homes or with model-based estimates of pollution from non freeway roads. These results indicated that respiratory health in children was adversely affected by local exposures to outdoor NO<sub>2</sub> or other freeway-related pollutants.

Bttermann *et al.* (2005) in their study explored whether attached garages may be the important sources of air contaminants in the home. In a study of 15 residential garages, the researchers observed elevated concentration of VOCs in garages air. The calculated emission rates of 34 VOC in the 15 garages, totaled 3.0-4.1 grams/day and were dominated by gasoline related compounds. Although the impact of the concentration of VOC in the garage air upon the indoor air concentration of the residences was not assessed in this study, the researchers concluded that garages were potentially sources of VOCs into air of residences.

Mehta and Shahpur (2004) studied the health benefits of interventions to reduce indoor air pollution from solid fuel use in South and South-east Asia, Africa, and the

America. The three interventions assessed were providing access to cleaner fuels, providing access to improved stoves, and providing part of the population with access to cleaner fuels and part of the population with improved stoves. Two major health outcomes associated with indoor air pollution were addressed, namely acute lower respiratory infections in young children under five years of age and chronic obstructive pulmonary disease in adults over twenty. While providing access to cleaner fuels had a larger health impact on the population than improved stoves, there was considerable health benefits associated with improved stove use. Improved stoves were also much more cost-effective than cleaner fuels. Of the cleaner fuels, kerosene or paraffin was more cost-effective than liquefied petroleum gas.

Hanninen *et al.* (2004) conducted a study to investigate potential determinants of indoor generated particle concentrations including building and family characteristics. Air exchange rate, building materials, building age, an attached garage, and family characteristics were associated with levels of indoor generated particles. Wooden floors and wooden panels were associated with decreased levels of indoor generated particles, while PVC or plastic floors were associated with increased levels of indoor generated particles.

Saijo *et al.* (2004) conducted a study to find out health problems and allergies among occupants of 564 dwellings in the Sapporo region of Japan with a questionnaire survey about health problems and allergies. The houses had been build or refurbished in the previous few years. One hundred and ninety one households gave permission for measurements and of these 67 complained of symptoms and 124 did not report symptoms. Women exhibited more symptoms than men, and they spent more time in the home. Level of VOCs and aldehydes were measured in total dwellings drawn from the two groups. Concentration of some individual VOCs (Toluene, butyl acetate, ethyl benzene, Xylene, alphapiene, noanal, p-dichloro-benzene) and the sum of concentrations of identified VOCs were significantly related to symptoms of residents. There was no relationship between symptoms and formaldehyde and acetaldehyde concentration. Dampness (condensation on window paints and / or walls and mould growth) was significantly related to symptoms and the risks were found to be higher where the number of symptoms of dampness increased.

Leech *et al.* (2004) undertook a telephone administered questionnaire survey to study general and respiratory health of occupants of R-2000™ energy efficient homes and a control group residing in new homes in the same area of Canada. The aim was to compare the change in health status of the two groups during the year before occupancy, with that of one year after occupancy. The primary criterion for R-2000™ certification was a tight building envelope with Mechanical Ventilation by Heat Recovery Ventilation. A further mandatory requirement was the use of material with less potential for volatile emissions to the indoor air. The survey found that 10 % of the R- 2000™ residents did not realize that they had an Heat Recovery Ventilation. Only 76% operated it throughout the winter 58% throughout the summer. Symptoms scores that throat, irritation, cough, fatigue, and irritability improved significantly in the R- 2000™ homes compared with the control home occupants. The other survey (GerES IV) focused on children and involved 1790 randomly selected 3 to 14 year old-the domestic environment of 600 of these children was monitored. VOCs in air were determined as well as phthalates in house dust. Concentration when compared with previous surveys, there was evidence for a decline in benzene and toluene concentrations. A significant correlation was found between di-n-butyl phthalate in house dust and the presence of the metabolite mono butyl phthalate in urine.

According to Crump, (2004) Methane and associated gases, including CO<sub>2</sub>, hydrogen and a wide range of organic compounds, are produced in landfill sites when micro-organisms break down organic material such as vegetable matter, wood, paper, and so on. Chemical vapors may also be present in the ground through pollution of soil and ground water resulting from industrial sites, waste disposal and accidental chemical spillage and leakage. Buildings may be influenced by these vapors if constructed on contaminated land that has not being adequately remediated, or because of the movement of vapor and contaminated groundwater from neighboring sites

Bahera *et al.* (2003) made an attempt to find out the role of indoor air pollution due to domestic fuels as a risk factor for lung cancer in women. The sample had smokers and non smokers among women. Tobacco smoking was the most important risk factor for lung cancer. Among non-smokers out of all the cooking fuels the risk of development of lung cancer was highest for biomass fuel exposure. The result showed that of all cooking fuel the

risk of development of lung cancer was highest for biomass fuel. The study concluded that biomass fuel exposure was an important risk factor in the causation of lung cancer among women along the exposure of tobacco smoke.

Mishra (2003) conducted a study in developing countries including India using data from a nationally representative sample. Effects of exposure to cooking smoke, ascertained by type of fuel used for cooking (biomass fuels, cleaner fuels, or a mix of biomass and cleaner fuels), and on the reported prevalence of asthma were estimated. Results indicated that elderly men and women living in households using biomass fuels had a significantly higher prevalence of asthma than do those living in households using cleaner fuels. Active tobacco smoking was also associated with higher asthma prevalence in the elderly, but not environmental tobacco smoke. Availability of a separate kitchen in the house and a higher living standard of the household were associated with lower asthma prevalence. The effect of cooking smoke on asthma was greater among women than among men.

Venn *et al.* (2003) investigated the relationship between exposure to some indoor air pollutants and the occurrence of childhood wheezing illness in a study of 410 homes in Nottingham. They reported indoor concentration of total measurements of surface dampness and recorded presence of mould. Visible mould was only identified in 11 homes but was significantly associated with an increased risk of wheezing illness. The risk of wheezing was significantly increased by dampness. Among the 193 cases with persistent wheezing, formaldehyde and damp were associated with more frequent nocturnal symptoms.

Wargockj *et al.* (2002) in their research study found out the evidence for the effects of ventilation on health, comfort on health, comfort on productivity in non industrial indoor environments. They concluded that ventilation was strongly associated with comfort, perceived air quality, health, and sick building syndrome symptoms, inflammation, infections, asthma, allergy, and short term sick leave.

Pekkanen *et al.* (2002) conducted a research to study the health effects of fine particulate air pollution. The results of the study showed that the exposures to ultrafine

particles had been associated with adverse health effects. The fine particulate air pollution was found to have adverse health effects on people who were exposed to such air.

Hodgson *et al.* (2002) measured the emission rates of formaldehyde in a new, fully furnished but unoccupied manufactured home. The materials with highest percentage of the total emission rates of formaldehyde were determined to be the particle board cabinetry cases (36%) and the high density fiber board and passages door (32%).

According to estimates by the World Health Organisation (2002) indoor air pollution accounts for more than 5,000 premature deaths a day on a global scale, most of them in developing countries from low quality solid fuels burnt in open fires for heating or cooking. Globally, exposure to these combustions by products is estimated to cause 36% of all lower respiratory infections and 22% of all chronic obstructive pulmonary disease. Even in the “developed “countries where the recourses are available to create safe buildings, there are many more subtle hazards that contribute to unsafe, unhealthy, or uncomfortable buildings.

Tuomainen *et al.* (2001) describe the classification of indoor climate, construction and finishing materials that gave target and design values for thermal conditions, odor intensity, noise levels, ventilations and indoor air quality in new buildings. It included emission rates for building and finishing materials and recommends maximum surface area use of material based on the emission characteristics. There were also three classes of indoor air quality  $S_1$ ,  $S_2$  and  $S_3$  with target values for formaldehyde, TVOC and ammonia concentration as well as temperature, humidity, and air velocity. The authors investigated IAQ in two blocks of flats, one constructed according to the recommended classification and the other using more conventional building technology. After completion, TVOC concentration was about 10 times higher in the control building. The  $S_1$  target values for temperature, RH,  $CO_2$ , formaldehyde and total suspended particles were achieved before occupancy and those for CO, TVOC and ammonia were reached within five months. The  $S_1$  target for odor was not achieved in the allotted time period. The authors concluded that IAQ was better in the flat built to the classification system than in the control building, the

largest measured difference being the TVOC and ammonia levels, and that the system is a useful tool for the design and construction process.

Dennekamp (2001) conducted a study to measure the concentrations of particles less than 100 nm diameter and of oxides of nitrogen generated by cooking with gas and electricity, on possible hazards to health in poorly ventilated kitchens. Experiments with gas and electric rings, grills, and ovens were used to compare different cooking procedures. Nitrogen oxides were measured. High concentrations of particles were generated by gas combustion, by frying, and by cooking of fatty foods. Electric rings and grills may also generate particles from their surfaces. Cooking in a poorly ventilated kitchen gave rise to potentially toxic concentrations of numbers of particles. Very high concentrations of oxides of nitrogen were generated by gas cooking, and with no extraction and poor ventilation, these concentrations reach the level at which adverse health effects were to be expected.

Ezzati *et al.* (2000) conducted research to exposure the particulate matter resulting from bio fuel combustion. A continuous monitoring of indoor air pollution and individual time activity were taken to construct detailed profile for 345 individual in 55 houses. 14-hour days of continuous real-time monitoring of concentrations of particulate matter  $\leq 10 \mu\text{m}$  in aerodynamic diameter and the location and activities of household members. These data were supplemented by data on the spatial dispersion of pollution and from interviews. Young and adult women had not only the highest absolute exposure to particulate matter (2,795 and 4,898  $\mu\text{g}/\text{m}^3$  average daily exposure concentrations, respectively) but also the largest exposure relative to that of males in the same age group (2.5 and 4.8 times, respectively). Exposure during brief high-intensity emission episodes accounted for 31–61% of the total exposure of household members who took part in cooking and 0–11% for those who did not. Simple models that neglect the spatial distribution of pollution within the home, intense emission episodes, and activity patterns underestimate exposure by 3–71% for different demographic subgroups, resulted in inaccurate and biased estimations.

Khoder *et al.* (2000) undertook a research and investigated on the indoor and outdoor concentration of formaldehyde in 7 flats in Greater Cairo residential area. The

daytime formaldehyde concentration measurements were taken from kitchen, bedroom, and living room. Significant positive correlations were found between the concentrations of formaldehyde found in these three rooms. On the other hand, no significant differences were found between the mean formaldehyde concentrations in these three rooms. The maximum mean concentration of formaldehyde (147 ppb) was recorded in a new at, while the minimum concentration (43 ppb) was observed in an old at. The maximum hourly and daytime Concentrations were 350 and 225 ppb, respectively. Air temperature, relative humidity and the age of the flat were factors affecting the emission and concentration of formaldehyde. The maximum indoor and outdoor formaldehyde concentrations were recorded during the summer season. During the spring, 38% of the samples indicated that the concentration of formaldehyde in the seven flats exceeded 0.1 ppm.

A research was conducted by McDonnell *et al.* (2000) to find out whether non malignant respiratory disease contributing to the cause of death. The purpose of the study was to analyze the outcome associated with fine particles  $PM_{2.5}$  or course particles  $PM_{10}$ . Samples were taken who lived near airport. The measurement of  $PM_{2.5}$  was estimated on monthly basis.  $PM_{2.5-10}$  was calculated as difference between  $PM_{2.5}$  and  $PM_{10}$ . Cox proportional hazards model was used to study association between natural deaths, non malignant death, and lung cancer. The model was used to find out the mean of  $PM_{2.5}$ ,  $PM_{10}$  and  $PM_{2.5-10}$ . The results showed that  $PM_{10}$  associations for the male subgroup were similar to those of males in the entire cohort. It was found that  $PM_{2.5}$  remained stable where as  $PM_{2.5-10}$  decreased. Relationship of mortality with fine fraction or course fraction could not be established in the study.

Hodgson *et al.* (2000) reported in a study of new manufactured and site built homes that formaldehyde was by far the most likely of the 12 VOCs evaluated to produce sensory irritation effects. Phenol and acetic acid were also identified as relatively potent irritants. Multiplying the relative irritancy for VOCs by the geometric mean indoor concentration measured in the seven site built homes in the study. Results showed that acetic acid contributed 17 more times sensory irritation than phenol and formaldehyde. The WHO designated formaldehyde as a known human carcinogen.

A study was conducted by Naeher *et al.* (2000) to find out the Indoor and outdoor level of particulate matter and carbon monoxide from traditional and improved wood stoves and gas stoves. 22 hour average carbon monoxide (CO), total suspended particulates (TSP), particles less than 10  $\mu\text{m}$  in diameter ( $\text{PM}_{10}$ ), and particles less than 2.5  $\mu\text{m}$  in diameter ( $\text{PM}_{2.5}$ ) measurements were made in three test homes of highland rural Guatemala in kitchens, bedrooms, and outdoors on a longitudinal basis, before and after introduction of potential exposure-reducing interventions. Four cook stove conditions were studied sequentially background (no stove in use), traditional open woodstove, improved woodstove with flue (plancha), and bottled-gas (LPG) stove. With nine observations each, kitchen  $\text{PM}_{2.5}$  levels were 56  $\text{mg}/\text{m}^3$  under background conditions, 528  $\text{mg}/\text{m}^3$  for open fire conditions, 96  $\text{mg}/\text{m}^3$  for plancha conditions, and 57  $\text{mg}/\text{m}^3$  for gas stove conditions. Corresponding  $\text{PM}_{10}/\text{TSP}$  levels were 173/174, 717/836, 210/276, 186/218  $\text{mg}/\text{m}^3$ . Corresponding CO levels were 0.2, 5.9, 1.4, 1.2 ppm. Comparisons with other studies in the area indicated that the reductions in indoor concentrations achieved by improved wood-burning stoves deteriorate with stove age. Mother and child personal CO and  $\text{PM}_{2.5}$  measurements for each stove condition demonstrate the same trend as area measurements, but with less differentiation.

Liao *et al.* (1999) conducted a study to address the possible mechanisms for PM cardiovascular disease mortality, examined the cardiac autonomic response to daily variations in PM in 26 elderly (mean age 81) individuals for 3 consecutive weeks. Indoor  $\text{PM}_{2.5} > 15 \text{ pg}/\text{m}^3$  was used to define high pollution days. A decline in heart rate variability was associated with adverse cardiovascular events, the lower heart rate variability was associated with increased  $\text{PM}_{2.5}$  concentrations and increased the risk for an acute cardiovascular occurrence in elderly persons.

A study by Kelly *et al.* (1999) was aimed to identify the emission of formaldehyde from material and consumer products in California homes. Formaldehyde was a toxic air contaminant released indoors from wood material and also consumer products. This study determined formaldehyde emission rates from 55 diverse materials and consumer products under two realistic chamber test conditions, using both time-integrated and continuous real-time measurements. Among dry products, relatively high emissions were found from bare

pressed-wood materials made with urea-formaldehyde resins, and from new (unwashed) permanent press fabrics. Urea-formaldehyde materials with paper, vinyl, laminate, and other coatings showed formaldehyde emissions lower by about a factor of 10 than those from bare urea-formaldehyde materials. Among wet products, an acid-cured floor finish showed the highest formaldehyde emissions; greatly exceeding those of any dry product even 24 hour after application. Fingernail polish and hardener showed relatively high emission rates, and latex paint and wallpaper relatively low emission rates, but these products emit similar amounts of formaldehyde because of widely different surface areas of application.

A research was undertaken by Morrison *et al.* (1998) to measure the emission rate of volatile organic compounds and aldehydes from materials typically found in ventilation ducts. The emission rate of VOCs per exposed surface area of materials was found to be low for some duct liners, but high for duct sealing caulk and a neoprene gasket. For a typical duct, the contribution to VOC concentrations was predicted to be only a few percent of common indoor levels. Selected materials were exposed to 100ppb ozone and measured VOC emissions. Exposure to ozone increased the emission rates of aldehydes from a duct liner, duct sealing caulk, and neoprene gasket. The emission of aldehydes from these materials could increase indoor air concentrations by amounts that are as much as 20% of odor thresholds. Also measured the rate of ozone uptake on duct liners and galvanized sheet metal to predict how much ozone might be removed by a typical duct in ventilation systems. For exposure to a constant ozone mole fraction of 37 ppb, a lined duct would initially remove 9% of the ozone, but over a period of 10 days the ozone removal efficiency would diminish to less than 4%. In an unlined duct, in which only galvanized sheet metal is exposed to the airstream, the removal efficiency would be much lower, 0.02%. Therefore, ducts in ventilation systems are unlikely to be a major sink for ozone.

Metzger *et al.* (1998) made an attempt to understand the assurance of indoor environmental quality through building diagnostics at schematic design period. The researcher developed a process for evaluation of building performance in schematic design phase to avoid problems in later stage. The process was developed from the existing procedures of building diagnostic. The result of the study showed that building diagnostic can be effective in preventing health problems. It gave an assurance that indoor

environmental quality can be improved if the building performance is well defined and complied in early stages if consider in early period of construction.

Garett *et al.* (1998) conducted a research to find out the indoor air borne fungal spores, and its association with environmental factors and respiratory health in children. A sample of eighty households with 148 children between 7 to 14 years were taken, among them 36% of children were asthmatic. Six visits were made to each of the houses on two months cycles and samples of air borne fungal spores were collected from bedroom, living room, kitchen, and outdoor. A detailed dwelling characterization was done using questionnaire and inspection survey. Skin prick test was conducted for each child. Results showed that large air borne fungal spores concentration was recorded in association with musty odors, high indoor humidity, and limited ventilation through windows. *Penicillium* exposure was the risk factor for asthma; while *aspergillum* for atopy. Also it was found in the study that fungal allergies were very common in children who were exposed to these spores. Indoor exposure to certain genera in winter was risk factor for asthma, atopy, and respiratory symptoms in children.

According to Lee (1998) one of the considerations when dealing with indoor air quality problems associated with mechanical systems is back drafting. Back drafting is the re-entrainment of combustion fumes into a space through de-pressurization. This de-pressurization causes naturally rising combustion fumes to be drawn down the chimney, in order to achieve indoor/outdoor pressure equilibrium. Negative pressure within a space or building may be caused in several ways. For instance an unbalanced ventilation system where more air is exhausted than supplied. In addition, exhaust hoods, central vacuum cleaners, inadequate combustion air, odor exhaust fans, prevailing winds and stack effect are all potential causes of negative pressure within a building. The sources prone to back draft are naturally vented, fuel burning appliances and equipment, including: domestic hot water tanks; natural gas boilers, fuel-fired hot air furnaces, and wood burning fireplaces and stoves.

Ferrari *et al.* (1988) found an average 'respirable' particle concentration of 86 g/m in eight Sydney dwellings with wood fires compared to 28 g/m found in four dwellings

without wood fires. Short-term concentrations during cooking (fuel unspecified) averaged 420 g/m in seven Sydney dwellings.

A study was undertaken by Brunekreef *et al.* (1997) to evaluate the extent to which the lung function in children who were living near motorways. The study was carried out in six areas located near major motorways in the Netherlands. Measured the lung function in the children and assessed their exposure to traffic related air pollution using separate traffic counts for automobiles and trucks. According to the study, the lung functions was associated with truck traffic density but had a lesser association with automobile traffic density. The association was stronger in children living closest less than 300 meters to the motor ways. Lung function was also associated with the concentration of black smoke, measured inside the schools as a proxy for diesel exhaust particles is related to air pollution generated on the motorways. It was observed that the associations were stronger in girls than in boys. The results indicated that exposure to traffic air pollution, in particular diesel exhaust particles, lead to reduced lung function in children living near major motorways.

Jassen (1997) conducted a study to investigate the validity of outdoor particulate matter (PM<sub>10</sub>) concentrations; the association between personal and outdoor concentrations, within subjects, over time. Repeated measurements of personal, indoor, and outdoor PM<sub>10</sub> were conducted among 37 nonsmoking, 50 to 70year-old adults, living in Amsterdam, Netherlands. Regression analyses were conducted for each subject separately, and the distribution of the individual regression and correlation coefficients was investigated. Furthermore, the extent to which differences among personal, indoor, and outdoor concentrations explained was studied. Outdoor concentrations exceeded indoor concentrations but underestimated personal exposures. The major part of the difference between personal and outdoor concentrations attributed to exposure to environmental tobacco smoke, living along a busy road, and time spent in a vehicle. The results showed a reasonably high correlation between personal and outdoor PM<sub>10</sub> within individuals, providing support for the use of ambient PM<sub>10</sub> concentrations as a measure of exposure in epidemiologic studies linking the day to day variation in particulate matter air pollution to the day to day variation in health.

Relation between air pollution and the exacerbation of childhood asthma was studied in a panel of 71 children aged 5 to 7 years with mild asthma by Romieu *et al.* (1996). During the follow up ambient measures of particulate matter less than 10mm (PM<sub>10</sub>, 24 hr average) and ozone (1 hr maximum) frequently exceeded the Mexican standards for these contaminants. The peak expiratory flow rate was associated with PM<sub>10</sub> levels and marginally with ozone levels. Respiratory symptoms (coughing, phlegm production, wheezing, and difficulty breathing) were associated with both PM<sub>10</sub> and ozone levels. An increase of 20mg/m<sup>3</sup> of PM<sub>10</sub> were related to an 8% increase in lower respiratory illness among children on the same day and an increase of 10mg/m<sup>3</sup> in the weekly mean of particulate matter less than 2.5m (PM<sub>2.5</sub>) was related to a 21% increase in lower respiratory illness on the same day. According to the study children with mild asthma were affected by the high ambient levels of particulate matter and ozone observed in the northern part of Mexico.

According to Levin (1995) Modern buildings generally fail to provide all their occupants with the safety, health, and comfort that are expected. A significant fraction of building occupants is uncomfortable, dissatisfied, or even ill from the effects of modern building. On average, roughly 30% of office workers report experiencing frequently one or more symptoms of the sick building syndrome. The situation in schools appears even worst as they are under increasing financial pressures to reduce construction, operation, and maintenance costs as well as energy consumption. In the design of many modern buildings indoor environmental parameters must be carefully controlled to within the limits established in the prevalent codes, standards, and guidelines. The indoor environment is influenced by lighting either through windows or by electrical means that affects thermal condition and energy consumption; thermal condition that affects air quality and its perception by occupants; ventilation system that produce noise that can be beneficial or harmful, depending on the system and the building context.

According to Pearson (1994) and Baggs (1996) several basic strategies can be employed in the design, construction, and operation of buildings to reduce the presence and concentrations of indoor air pollutants. The first line of attack should always be the avoidance of products that contain solvents, glues, and plastics. There is an increasing

number of commercial sources of natural paints, glues, materials, and systems that can be economically substituted for the most dangerous building material, e.g. particle board, wafer board, carpet, foams, paint. The use of natural (and unpainted) lime cement plasters and solid wood as wall finishes and concrete, linoleum, solid wood, and ceramic tiles for floor finishes can reduce total VOC concentration by an order of magnitude.

According to Dockery and Pope (1994) Ingress of outdoor respirable particulates into indoor air due to air infiltration may also contribute to indoor particulates but these may vary significantly (e.g. amount of soot and acid aerosols) from those generated indoors

Rowe and Wilke (1994) investigated occupant perception of thermal comfort and indoor air quality vectors in eight office buildings in Sydney and suburbs. They found that more than 45 % of occupants of each building were dissatisfied with either vector, the greatest dissatisfaction being found in six buildings that were mechanically ventilated.

Kemp and Dingle (1994) described a range of SBS symptoms in 20-40 % of occupants complained of strong chemical odors. Rabone *et al.* (1994) found no association between recent occupant mental distress and work related symptoms in 401 occupants of a sick office building in Sydney. Instead, the symptoms were strongly associated with “stuffiness” of the air supporting a role of building factors rather than human factors in cause of symptoms.

Dingle and Olden, (1992) investigated new four level offices building in Perth where occupants complained of strong chemical odors and SBS symptoms. They applied a self response questionnaire to 44 occupants selected randomly and their indices were dry eyes (65%), tired and strained eyes (54%), reflection and glare(41%), fatigue (57%), sore throat (28%), migraine (36%). Factors that were identified as possible contributors to these symptoms were window glare and high indoor temperature.

According to Samet and Spengler (1991) Respirable suspended particulates (RSP) also arise in indoor air from fuel-based heating appliances and cooking stoves. Wood-burning heaters and kerosene heaters can elevate RSP concentrations to short-term levels. Airtight wood heaters will limit indoor leakage but still contribute substantially to outdoor air pollution.

Norback *et al.* (1990) conducted a research to find out relationships between indoor air quality and personal factors related to the sick building syndrome symptoms such as eye, skin and upper airway irritation, headache, and fatigue. A multi factorial study was performed to investigate relationships between such symptoms, and its exposure to environmental factors, and personal factors. The results showed that the total indoor hydrocarbon concentration was significantly related to symptoms. Other indoor exposures such as room temperature, air humidity, and formaldehyde or carbon dioxide concentration did not correlate with the symptoms. Personal factors such as hyper reactivity and airway diseases were strongly related to the sick building syndrome. It was concluded that the sick building syndrome was of multi factorial origin and depending on both personal factors and environmental factors such as the indoor hydrocarbon concentration. Although some types of hydrocarbons might also contributed to the irritative symptoms.

Spengler *et al.* (1983) measured nitrogen dioxide average concentrations over a one-year period in 137 US dwellings from a rural community where outdoor annual mean concentrations were 20–30 ppb. Annual mean indoor concentrations were higher than outdoors by 100 ppb in kitchens and 60 ppb in bedrooms for dwellings with gas cooking (seldom vented in the US). Ten per cent of the dwellings exhibited concentrations exceeding the US National Ambient Air Quality Standard of 200 ppb. Concentrations in dwellings with electric cooking were lower than outdoor concentrations (Brauer and Spengler 1994). The major indoor sources of nitrogen oxides (NO<sub>x</sub>) including nitrogen dioxide (NO<sub>2</sub>), are gas-fuelled cookers, fires, water heaters and space heaters, and oil fired space heaters.

Willaird. *et al.* (1975) conducted a study to investigate indoor sources of air pollution on indoor air quality. The four houses chosen for study represented different surrounding land use, life styles, and house age and layout. The pollutant gases were measured simultaneously at three indoor locations and one outdoor location. Emissions from gas stoves contribute NO<sub>2</sub>, NO, and CO to indoor atmosphere of houses where such stoves are used. Kitchen concentrations of these gases responded rapidly to stove use, and for a given house during a given season. There was a correlation between average NO<sub>2</sub> concentrations and average stove use. NO<sub>2</sub> and NO were produced in roughly equal amounts by the stoves in the homes where testing was conducted. Indoor concentrations of these pollutants were invariably higher than those outside. Normal stove operations frequently resulted in NO<sub>2</sub> concentrations in the kitchens. Comparison of samplings carried out in the spring-summer of 1973 and the fall-winter of 1973-74 showed that the more closed up mode of the house in the colder weather produced more uniform concentrations within the various rooms of the house as compared with the warmer months. A diffusion experiment conducted in one of the houses showed that the half-life of NO<sub>2</sub> was only % of that for CO and NO, indicating that NO<sub>2</sub> decays through reaction or absorption in addition to normal dilution from air exchange. This effect was observed in some of the other houses by comparing the relative concentrations of NO<sub>2</sub> and the other pollutants in various parts of the house. The results of the study showed that indoor levels of NO and NO<sub>2</sub> are directly related to stove use in the homes tested. These stoves often produced more NO<sub>2</sub> than NO. In some instances, the levels of NO<sub>2</sub> and CO in the kitchen exceeded the air quality standards for these pollutants. A diffusion experiment conducted in one of the houses showed that the half-life for NO<sub>2</sub> was less than one-third that for either NO or CO. Oxidation of NO to NO<sub>2</sub> (based upon comparing the half-life of NO to CO) does not appear to occur to a significant degree indoors.

An extensive review of literature research related to the broad area of research Indoor air quality and building design was carried out. The research in the past focused on understanding the concentration of various pollutants in indoors and their impact on health of the building occupant.

Vast research was done to explore the affect of Indoor pollution on various diseases like asthma, bronchitis, headache, and fatigue, cardio vascular diseases, lung infection and so on. Few researchers focused on understanding the accumulation of indoor air pollutants in residential houses due to various activities like cooking with various fuels, use of electrical gadgets, ventilation levels.

From the literature survey it was understood that, indoor air quality as a topic of research attracted the attention of researchers forty years back and still continue to be a prime area of research. However, the architectural and interior building design features on Indoor air quality was found to be unexplored. Hence, to fill the existing research gap the present study was designed and undertaken.

## Chapter III

# MATERIALS AND METHODS

The aim of the research is to establish the relation between indoor air quality in residential buildings and (i) Selected design aspects of residential buildings such as building location characteristics, building design features, and construction material (ii) Household maintenance practices (iii) Extent of use of electrical gadgets (iv) Extent of use of personal care products.

The methodology adopted for conducting the research study is discussed under the following headings

3.1 Research design

3.2 Sampling procedures

3.3 Variables and their measurements

3.4 Research tool

3.5 Pilot study

3.6 Data collection

3.7 Data analyses

### **3.1 Research design**

Research design is invented to enable researcher to answer research questions validly, objectively, accurately and economically as possible (Kerlinger, 1995). Exploratory research was adopted as the focus of the research study was to measure the indoor air quality parameters, and explore its relation with selected independent variables.

### **3.2 Sampling procedures**

The sample method involves taking a representative selection of the population and using the data collected as research information. A sample is a “subgroup of a population” (Frey *et al*,2000). The purposive sampling procedure was adopted to select the study

location initially. Using random sampling technique the houses from study location were selected to measure the indoor air quality parameters and to collect data on independent variables.

### **3.2.1 Selection of area of the study**

Hyderabad and Secunderabad the twin cities of Telangana were selected to draw the sample for conducting the study. Hyderabad and Secunderabad are highly urbanized cities. Air pollution due to traffic and other developmental activities has increased to a level that can have an adverse effect on the health of the people. The highly polluted zones as per the records available with Pollution Control Board (PCB) of Telangana viz, Abids, Kukatpally, Panjagutta, M.G road, and Zoo Park were selected purposively to draw the households for conducting the research.

### **3.2.2 Selection of the sample**

From the five selected highly polluted locations viz., Abids, Kukatpally, Panjagutta, M.G road, and Zoo park, 30 households were selected at random. The criteria for selecting the households was that the house should be located within one kilometer radius from the main traffic road. The other criteria followed was the willingness of inmates to participate in the study.

### **3.2.3 Size of the sample**

The size of the sample was 30 houses selected at randomly from the study area.

## **3.3 Variable and their measurements**

Variable is something that varies. It takes on any justifiable set of values. Variable is a symbol to which numerals or values are assigned (Kerlinger, 1995). Keeping in view the focus of the research the variables for the study were identified and are primarily categorized as Dependent and Independent variables.

### 3.3.1 Dependent variable

The measures that are used to observe a possible effect are called as dependent variable (Shaughnessy, 2000). Indoor Air Quality was the Dependent variable of the study. Indoor Air Quality was studied in terms of presence of (i) Carbon dioxide (ii) Volatile organic compounds (iii) PM<sub>10</sub> (iv) PM<sub>4</sub> (iv) PM<sub>2.5</sub> (v) Relative humidity (vi) Temperature and (vii) Dew point. Each of these parameters was considered as separate variable in the data analyses. The parameters Carbon dioxide, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative humidity, Temperature, and Dew point were measured using environmental monitor EVM-7(Fig-1) and the parameter Volatile organic compounds, was measured using Tiger VOC detector (Fig-2).



**Plate-1 Environmental monitor (EVM-7)**



**Plate-2 Tiger VOC detector**

#### 3.3.1.1. Carbon dioxide (CO<sub>2</sub>)

Carbon dioxide is a normal constituent of exhaled breath and is commonly measured as a screening tool to evaluate whether adequate volumes of fresh outdoor air are being introduced into indoor air. If indoor carbon dioxide levels are more than 1,000 ppm, there is probably inadequate ventilation, and complaints such as headaches, fatigue, and eye and throat irritation may be prevalent (White, 1994). A high level of carbon dioxide may indicate that other contaminants in the building also may be present at elevated levels and could be responsible for occupant complaint. Hence, CO<sub>2</sub> is identified as one of the parameters contributing to the indoor air quality of the household. CO<sub>2</sub> is treated as a variable and explored its relation with independent variables of the study.

### **3.3.1.2. Volatile organic compounds (VOCs)**

The World Health Organisation defined an organic compound as volatile if it had a melting point below room temperature and a boiling point between 50–100°C and 240–260°C (WHO, 2003). The majority of VOCs found in the indoor environments originate from building materials, indoor furnishings, cleaning supplies, consumer products and processes, such as printing, cooking, hobbies, cleaning, interior renovations and pesticide applications (Brown, 1994). Volatile organic compounds can cause many symptoms, such as headache, eye, nose, and throat irritations, dry cough, dizziness and nausea, tiredness, also have bad effects on respiration systems, blood vessel systems, and nerve systems, and VOCs may be carcinogenic (Huang and Haghghat, 2002). Hence, the presence of VOCs was treated as one of the parameters to measure Indoor air quality. VOCs in selected households were measured using the Tiger VOC detector.

### **3.3.1.3. Particulate matter 10 (PM<sub>10</sub>)**

Particulate matter less than 10 micrometers in diameter are called as PM<sub>10</sub>. Particulate matter in the air includes a mixture of solids and liquid droplets. Some particles are emitted directly, others are formed in the atmosphere when other pollutants react. Particles come in a wide range of sizes. Those less than 10 micrometers in diameter (PM<sub>10</sub>) are so small that they can get into the lungs, potentially causing serious health problems (Abbey, 1991). Ten micrometers is smaller than the width of a single human hair. PM<sub>10</sub> in selected households were measured using the EVM-7 monitor. As presence of PM<sub>10</sub> in indoors contributes to the air quality it is identified as a variable that can affect the Indoor air quality of the household.

### **3.3.1.4. Particulate matter 4 (PM<sub>4</sub>)**

Particulate matter of 4 micrometers in diameter is called as PM<sub>4</sub>. These particles are slightly bigger than PM<sub>2.5</sub>. These particles can get into the throat and can cause irritation in throat that may lead to continuous cough. Presence of PM<sub>4</sub> in indoor environment was not explored much. Hence, in the present investigation apart from PM<sub>10</sub> and PM<sub>2.5</sub>, PM<sub>4</sub> was also identified as indoor air quality parameter and explored its relation with the selected independent variables of the study.

### **3.3.1.5. Particulate matter 2.5 (PM<sub>2.5</sub>)**

Very small particles that are less than 2.5 micrometers in width are known as fine particulate matter or PM<sub>2.5</sub>. These particles are so small they can be detected only with an electron microscope. The width of these particles are less than 1/30 the width of a human hair. Fine particulates can play a role in causing serious illnesses and death because they are small enough to be inhaled deep into the lungs. Once fine particles are in the lungs, they can affect the heart, blood vessels, and lungs (Dockery, 1992). PM<sub>2.5</sub> is one of the dependent variable of the study.

### **3.3.1.6. Relative humidity (RH %)**

Relative Humidity is a measure of the amount of moisture in the air compared to what the maximum amount of moisture in the air could be. The maximum amount of moisture that can be in the air depends on the temperature. As air warms it can have more moisture. Elevated relative humidity can promote the growth of mold, bacteria, and dust mites, which can aggravate allergies and asthma (Sundell, 2004). Hence Relative humidity is identified as one of the parameters to study the Indoor air quality.

### **3.3.1.7. Temperature (t ° C)**

There is no and ideal temperature suitable for all building occupants. The location of building site, its orientation and the design aspects of the building structure can affect the concentration of temperature in indoors (Sundell, 2004). In the present research temperature inside the household was identified as a variable and its relation with selected independent variable was studied.

### **3.3.1.8. Dew point (%)**

The dew point is the temperature at which the water vapor in a sample of air at constant barometric pressure condenses into liquid water at the same rate at which it evaporates( Peat, 1998). Moisture in the air can be produced by people during activities such as cooking, cleaning, and washing, as well as through normal respiration. The amount of water vapor in the air had direct effect on health and comfort and is also important in

relation to the occurrence of biological pollutants in indoors. Dew point is treated as one of the variable.

### **3.3.2 Independent variable**

The factors which are controlled or manipulated by the experimenter are called the independent variable (Shaughnessy, 2000). The independent variables of the study are categorized under the following six major heads

3.3.2.1 Building location characteristics

3.3.2.2 Building design features

3.3.2.3 Construction material

3.3.2.4 Household maintenance practices

3.3.2.5 Extent of use of electrical gadgets and

3.3.2.6 Extent of use of personal care products

#### **3.3.2.1 Building location characteristics**

One of the assumptions of the study is that selected building location orientation may have the influence on the indoor air quality of residential buildings. Each of these factors is treated as independent variable and explored its impact on selected indoor air quality parameters such as CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, RH, temperature, and dew point of residential buildings.

##### **3.3.2.1.1 Geographical location of the building**

Geographical location of the building **is** the demarcated area on the land where the building is located. The quality of the outdoor environment is determined by local geography (Thatcher, 1995). In the present investigation geographical location of the building was selected as an independent variable and its relation and its contribution to each of the indoor air quality parameter was studied.

### **3.3.2.1.2 Site orientation**

Orientation is a fundamental step to ensure that buildings work with the passage of the sun across the sky. Knowing of sun paths for any site is fundamental in designing building facades to let in light and passive solar gain, as well as reducing glare and overheating the building interior (Brown and Decay, 2000). Orientation of the building may have influence on the air flow. Role of site orientation on indoor air quality of the building was not found to be explored much. Hence, in the present investigation an attempt was made to find the relation and contribution of site orientation to indoor air quality of residential buildings.

### **3.3.2.1.3 Height of the base of the building with reference to main road**

Heavy traffic as a source of air pollution was found out in the previous research (Gertler, 2000). An attempt was made in the present investigation to find the relation and contribution of height of the base of the building with reference to main traffic road on indoor air quality of residential buildings. The height of the main road is taken as a base. The height of the base of the building was compared with the height of the main road and judged whether it is above the main road, below the main road or on the same level with main road.

### **3.3.2.1.4 Height of the base of the building with reference to road in front of the house**

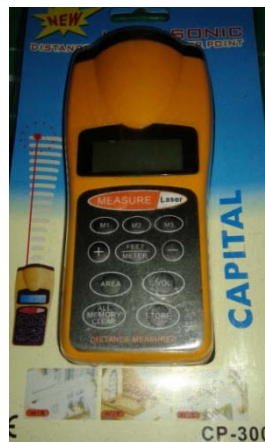
In the present study the height of the base of the building whether above, below or at the same level with the road in front of the house was treated as a variable and an attempt was made to find relation and contribution of this variable to indoor air quality of residential buildings. The height of the road in front of the house is taken as a base. The height of the base of the building was compared with the height of the road in front of the house and judged whether it is above the road in front of the house, below the road in front of the house or on the same level with road in front of the house.

### **3.3.2.1.5 Side of the building facing the main road**

An attempt was made in the study to explore whether the side of the building in the heavy traffic zones either front, back, left or right that was facing towards the main traffic road had any impact on indoor air quality of the residential buildings.

### **3.3.2.2 Building design features**

The study is intended to find out the relation between selected building design features and indoor air quality of residential buildings. After identifying the research gap building design features such as plot area, plinth area, landscape area, floor area ratio, open area on the wall of the building facing the main road, open area on the outer wall of the building, height of the building, ceiling height, and number of rooms were identified as variables and their influence on indoor air quality of residential building was studied. The measurement essential for the study were taken with the laser distance measurer.



**Plate-3 Laser distance measurer.**

### **3.3.2.2.1 Plot area**

An area of the land that has been measured and is considered as a unit is called plot area. An attempt was made in the present investigation to find the relation and contribution of plot area to indoor air quality of residential buildings.

#### **3.3.2.2.2 Plinth area**

Plinth area or built up covered area of a building is measured at floor level at any storey (Joseph and Demkin, 2007). Plinth area is calculated by taking the external dimension of the building at the floor level. An attempt was made in the present investigation to find the relation and contribution of plinth area to indoor air quality of residential buildings.

#### **3.3.2.2.3 Landscape area**

Landscape area is the plot area minus plinth area and it is used for vegetation. An attempt was made in the present investigation to find the relation and contribution of landscape area to indoor air quality of residential buildings.

#### **3.3.2.2.4 Floor area ratio**

The total square feet of the building divided by total site square feet of the building is called the floor area ratio. Floor area ratio was treated as an independent variable and its relation and contribution to indoor air quality was studied.

#### **3.3.2.2.5 Open area on the wall of the building facing the main road**

The total open area on the wall in the form of doors and windows which was facing the main traffic road was calculated. One of the assumptions of the study was that the amount of open area on the wall facing the main road may influence the indoor air quality of the building. Hence, this is considered as an independent variable.

#### **3.3.2.2.6 Open area on the outer wall of the building**

The total open area in the outer wall in the form of doors, windows, ventilators, was measured and treated as a variable. Further explored its relation and contribution to indoor air quality.

#### **3.3.2.2.7 Height of the building**

The height of the building was identified as variable and studied its relation and contribution to indoor air quality. The height of the building was measured in feet and inches.

### **3.3.2.2.8 Ceiling height**

One of the variables under building design feature was the ceiling height of the building. The ceiling height of the building was treated as an independent variable in the present study.

### **3.3.2.2.9 Number of rooms**

The total number of rooms was considered as a variable and studied its impact on indoor air quality. Each enclosed area was considered as a separate room.

### **3.3.2.2.10 Extent of dust accumulation feature**

Some of the construction features like nooks and corners, top of storage cabinets, window sills, furniture, furnishings, lighting fixtures, and electrical gadgets give scope for the dust to accumulate on them. The amount of dust in indoors may serve as a source of indoor air pollution. There was no evidence of research in this area. Hence, the extent of dust accumulation features was identified as a variable in the present investigation. The extent of presence of dust accumulation feature was categorized as high, moderate, and low depending on the number of such features in the house.

### **3.3.2.3 Construction and finishing material**

Construction techniques and building material may affect the quality of the indoor air. The construction techniques that may create air quality problems are the use of chemically based adhesives for fastening, the use of asbestos, on site floor finishing, the use of chemically impregnated building material, such as pressed wood, particle boards, the use synthetic material, such as plastics, the use of solvent based paints (Lee, 1998). In the present study construction material used for walls, floors and ceiling and their relation and contribution to indoor air quality was explored.

#### **3.3.2.3.1 Wall material**

Certain wall material may act as breeding ground or storage sink for pollution. Hence, in the present study an attempt was made to find the relation and contribution of wall material on indoor air quality of the residential buildings.

### **3.3.2.3.2 Floor material**

Flooring material and moisture sealing of concrete floors may influence the quality of indoor air. Hence, in the present study an attempt is made to find the relation and contribution of flooring material on indoor air quality of the residential households.

### **3.3.2.3.3 Finishing material**

Certain finishes may act as breeding ground or storage sinks for pollutants, which may later be release into the indoor environment (Lee, 1998). In the present study the relation and contribution of finishing material to indoor air quality of the residential households was studied.

### **3.3.2.3.4 Ceiling type**

Different kinds of ceiling finishes are available. The influence of ceiling type whether RCC slab or false roofing on indoor air quality of the residential households was studied.

### **3.3.2.4 Household maintenance practices**

It was hypothesized that the practices followed to keep the house clean itself may act as source of indoor air pollution. In view of the existing research gap. Presence of dust in the house, frequency of household cleaning, feeling of congestedness, frequency of use of cleaning reagent were identified as variables and then relation to indoor air quality was explored.

#### **3.3.2.4.1 Extent of presence of dust in the house**

The presence of dust on floors, wall, ceiling, carpets, foot mats, rugs, curtains, furniture, lighting fixtures, home accessories, equipment, storage almarahs, and windows was observed. Depending on the density of accumulated dust on each of the features scores 3,2,1 were given for high, moderate, low dust accumulation respectively. The judgment of density of dust was based on perception of investigator while collecting data. Based on the total score the houses were categorized as highly dust accumulated house, moderately dust accumulated house and low dust accumulated house.

#### **3.3.2.4.2 Frequency of household cleaning**

Frequency of household cleaning was measured in terms of daily, alternate days, weekly once, once in fortnight, once in a month, twice in month, and yearly. The scores allotted were 7,6,5,4,3,2,1 for daily, alternate days, once in a week, once in a fortnight, once in a month, twice in a month, yearly respectively. Higher the score higher the frequency of household cleaning.

#### **3.3.2.4.3 Feeling of congestedness**

Feeling of congestedness may result due to lack of ventilation, excess and huge furniture, heavy storage units, overloaded loft, lack of space for internal circulation so on. The extent of feeling of congestedness as perceived by the investigator was measured in terms of high, moderate, low based on the presence of the above feature. High score was given when the researcher experienced the feeling of congestedness in the house due the above features. Relatively medium and low scores were given based on the investigator's perception.

#### **3.3.2.4.4 Frequency of use of cleaning reagent**

The use of cleaning reagent and its influence and contribution to indoor air quality was explored. The frequency of use of cleaning reagent was measured in terms of regularly, sometimes, occasionally, rarely, never and the scores allotted were 5,4,3,2,1 respectively. Higher the score higher the use of reagent for cleaning.

#### **3.3.2.4.5 Extent of use of electrical gadgets**

An attempt was made in the present investigation to find out the influence of extent of use of electrical gadgets on indoor air quality. The extent of use of electrical gadgets was measured in terms of frequency of use viz., regularly, sometimes, occasionally, rarely and never and the scores allotted were 5,4,3,2,1 respectively. Higher the score higher the frequency of use of electrical gadgets.

### **3.3.2.5 Use of personal care products**

Personal care products may have impact on the indoor air due to the emission of toxic substances. Hence extent of use of personal care products was treated as an independent variable.

## **3.4 Research tool**

Interview cum observation schedule was the tool used to collect the information from the respondent. The schedule consisted of six sections. The section one was designed to collect personal information of the respondent. The second section of the tool was designed to gather information on the building location characteristics, the third section of schedule was intended to collect data on building design parameters. The details of construction and finishing material, information on the household maintenance practices and personal care practices of the inmates were other section of the tool (Appendix-A).

## **3.5 Pilot study**

Pilot study was conducted to test the feasibility of research tool. Necessary modifications were made in the tool before data collection.

## **3.6 Data collection**

The data on indoor air quality parameters was collected using EVM7 and tiger VOC detector. In each house the reading were recorded in three different rooms viz., bedroom, living room, and kitchen. In each area the readings were recorded three times. The time gap for each reading was three hours. In each house presence of CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity, Temperature, Dew point were measured. The first reading was taken at 12'O clock in the afternoon followed by second and third reading at 3pm and 6pm respectively. Information on Building design parameters, were collected using a interview cum observation schedule.

### **3.7 Data analyses**

The aim of the study was to establish the relationship between indoor air quality and selected independent variable. Data was analyzed. Frequency and percentages were calculated for all the variable of the study. Spearman correlations were calculated to find the correlation between each of the indoor air quality parameter and independent variable. ANOVA was carried out to find the variation in indoor air quality parameter with reference to independent variable. Where 'f' value was found significant; multiple comparison tests were carried out to find out the significant variation between groups. Stepwise regression was used to study the contribution of each of the independent variable towards each indoor air quality parameter.

## Chapter IV

# RESULTS AND DISCUSSION

The analyses of research data was done to present it in interpretable form so that the relations of research problems can be studied and tested. The frequency distributions of data on study variables that can be used primarily for descriptive purpose and the results obtained by analyzing the data through appropriate statistical methods are present in this chapter under the following heads.

4.1 Frequency distributions

4.2 Hypothesis testing

### **4.1 Frequency distributions**

Frequencies and percentages were calculated for the study variables and presented under the following heads.

4.1.1 Family information

4.1.2 Building location characteristics

4.1.3 Building design parameters

4.1.4 Construction and finishing material

4.1.5 Household maintenance practices

4.1.6 Extent of use of electrical gadgets

4.1.7 Extent of use of personal care products

4.1.8 Indoor air quality parameters

#### **4.1.1 Family information**

The household was the unit of analysis in the investigation. Data regarding number of family members, males, adults, children, and age of the building is presented below.

#### 4.1.1.1 Number of family members

Data regarding number of family members living in the house at the time of data collection was gathered. The mean number of family members was 5.9 with a standard deviation of 2.5. Taking mean and SD, the families were divided into large, medium, small. Slightly more than three fourth (76.6%) of the sample had 3 to 8 members in the family. Small families below three members were only 13.3 percent .

**Table 4.1. Distribution of households by Number of family members**

N=30

Number of family members	Number	Percentage( %)
Above 8 members	3	10 %
Between 3-8 members	23	76.6 %
Below 3 members	4	13.3 %
Total	30	100%
Mean		5.9
SD		2.5

The mean family size was found to be high among the study sample with relatively high SD. The difference among the sample regarding the number of family members was found to be more.

#### 4.1.1.2 Sex wise and age wise number of males, females, children and adults

Details of members in the family are presented below

**Table 4.2. Distribution of households by sex and age of family members**

N=30

Number of males	Number	Percentage( %)
1	4	13.3 %
2	16	53.33 %
Above 3	10	33.33 %
Total	30	100 %
Number of females	Number	Percentage( %)
1	4	13.33 %
2	6	20.0 %
Above 3	20	66.6 %
Total	30	100%
Number of children	Number	Percentage (%)
1	6	20.0 %
2	8	26.66 %
Above 3	6	20.0 %
Total	20	100 %
Number of adults	Number	Percentage (%)
1	-	-
2	3	5 %
Above 3	27	90 %
Total	30	100 %

Families with two male were 53.33 per cent. Comparatively more families (66.6%) had more than three female members in family. More or less equal distribution was observed in case of number of children in the family and majority of the families (90%) had more than three adults in the family.

#### **4.1.1.3 Age of the building**

Data on age of the building was collected. Slightly more than half (57%) of the houses included in the study were built ten years ago and the remaining 43 percent of the households were built above 5 years and below 10 years.

#### **4.1.2 Building location characteristics**

The variables included under the category of building location characteristics were (i) Geographical location of building site, (ii) Site orientation, (iii) Height of the base of the building site with reference to main traffic road, (iv) Height of the base of the building site with reference to road in front of the house and (v) Side of the building facing the main road.

#### 4.1.2.1 Geographical location of building site

The houses included in the study were drawn from five residential areas identified under the study according to the set criteria.

**Table 4.3. Distribution of households by geographical location of building site**

N =30

Building Location	Number	Percentage %
Abids	5	16.6 %
Kukatpally	7	23.3 %
M.G road	6	20.0 %
Panjagutta	5	16.6 %
Zoopark	7	23.3 %
Total	30	100%

Slight variation in the number was due to the availability and willingness of respondents to participate in the study.

#### 4.1.2.2 Site orientation

The data on orientation of the building site whether towards east, west, north, or south was gathered. The contribution of site orientation to indoor air quality (IAQ) was studies.

**Table 4.4 Distribution of households by site orientation**

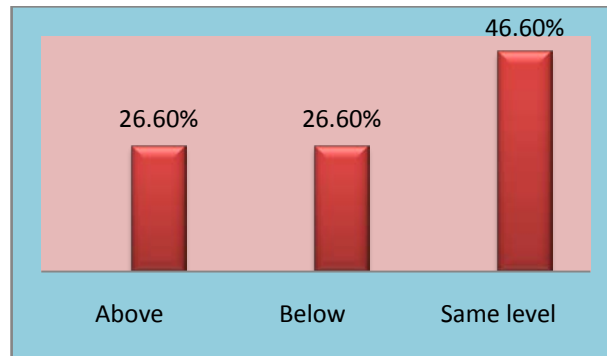
N =30

Site Orientation	Number	Percentage(%)
East	3	10.0 %
West	6	20.0 %
North	16	53.3 %
South	5	16.6 %
Total	30	100%

More number of houses (53.3 %) were facing towards north, and least number of houses had east facing. One of the limitations of the study was to select the houses near the main traffic road; probably this could be one of the reason for large majority falling in one category.

#### 4.1.2.3 Height of the base of the building site with reference to the main road

An attempt was made in the study to find out the relation between height of the building site with reference to main traffic road and its influence on indoor air quality of residential interiors.

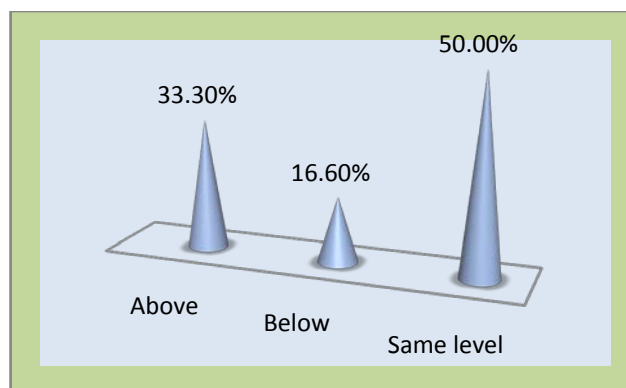


**Figure 4.1 Distribution of households by height of the base of the building site with reference to the main road**

According to the data relatively more number of houses (46.6 %) were on the same level with reference to the height of the main traffic road. Houses below or above the height of the main traffic road were found to be one fourth of the sample each.

#### 4.1.2.4 Height of the base of the building site with reference to road in front of the house

Apart from the main traffic road, the road just in front of the house can also add pollution in the house.

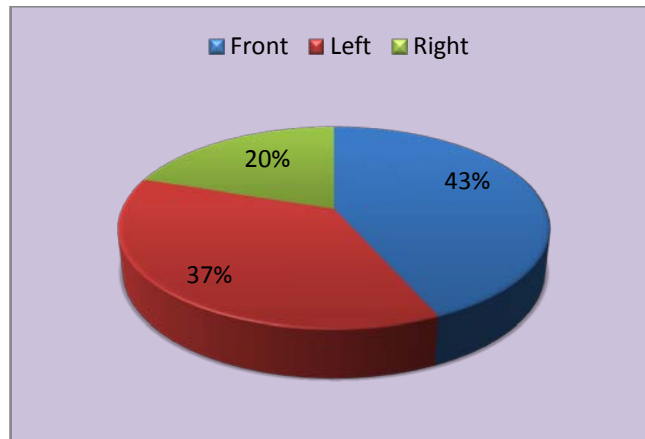


**Figure 4.2 Distribution of households by height of the base of the building site with reference to the road in front of the house**

One third of the buildings selected for the study were above the level of road in front of the house. Fifty per cent were at the same level with the road in front of the house.

#### 4.1.2.5 Side of the building facing the main road

Side of the building facing the main road was one of the variables of the study. An attempt was made to find its contribution to the indoor air quality in the house.



**Figure 4.3 Distribution of households by the side of the building facing the main road**

For relatively more number of houses (43%) the front side of the building was facing the main road.

#### 4.1.3 Building design parameters

The building design parameters selected for the study were (i) plot area (ii) plinth area (iii) landscape area (iv) floor area ratio (v) open area on the wall of the building facing the main traffic road (vi) open area on the outer wall of the building (vii) height of the building (viii) ceiling height (ix) number of rooms (x) extent of dust accumulation features.

**Table 4.5. Distribution of households by building design parameters**

N =30

Building design parameter	Mean Sq.ft	SD	Small	Medium	Large
Plot area(sq.ft)	1683.3	424.92	Below 900 sq.ft 4 (13.3 %)	1258 – 2108 sq.ft 21 (70.0 %)	Above 2108 sq.ft 5(16.6 %)
Plinth area (sq.ft)	1350.83	374.76	Below 650 sq.ft 5 (16.6 %)	976 – 1726 sq.ft 21(70.0%)	Above 1726 sq.ft 4 (13.3 %)
Landscape area (sq.ft)	325.96	168.75	Below 75 sq.ft 4(13.3 %)	157 – 495 sq.ft 22(73.3 %)	Above 495 sq.ft 4(13.3 %)
Floor area ratio	0.80	0.09	Below 0.54 5(16.6%)	0.7 - 0.9) 21(70 %)	Above 0.9 4(13.3%)
Open area on the wall of the building facing the main road (sq.ft)	37.93	19.91	Below 8 sq.ft 3(11.1 %)	18 – 58 sq.ft 19(70.37 %)	Above 58 sq.ft 5(18.51 %)
Open area on the outer wall of the building (sq.ft)	75.49	34.14	Below 27 sq.ft 2(6.6 %)	42 – 110 sq.ft 22(73.3 %)	Above 110 sq.ft 6(20 %)
Height of the building (ft)	21.6	6.97	Above 12 Ft. 6(20.0 %)	16 – 29 ft 20(66.6 %)	Above 29 ft 4(13.3 %)
Ceiling height (ft)	10.02	1.29	Below 8ft 4(13.3 %)	10 – 11ft 22(73.3 %)	Above 11ft 4(13.3 %)
No. of rooms	4.93	0.70	Below 4 -	4 - 6 23(76.66%)	Above 6 7(23.33%)

\*percentages in parenthesis

**4.1.3.1 Plot area**

The mean plot area was 1683.3 sq.ft. Majority (70%) of the houses had plot area between 1258 and 2108 sq.ft. Negligible proportion had either small or large plot area.

**4.1.3.2 Plinth area**

Plinth area is the built up area of the house. The mean plinth area was 1350.83 sq.ft with a SD 374.7 sq.ft. Seventy per cent of the houses had plinth area between 976 and 1726 sq.ft.

#### **4.1.3.3 Landscape area**

The mean landscape area was 325.96 sq.ft. About 73.3 per cent houses had landscape area between 157 and 495 sq.ft. Only 13.3 per cent had landscape area below 75 sq.ft.

#### **4.1.3.4 Floor area ratio**

The total area of the building divided by total area of the building site is called the floor area ratio. The mean floor area ratio was 0.80 sq.ft with SD 0.09.

#### **4.1.3.5 Open area on the wall of the building facing the main road**

The total open area on the wall which was facing the main traffic road in the form of doors, windows, ventilators was taken. The mean open area was 37.93 sq.ft. The majority of the houses (70.37 %) had open area between 18 and 58 sq.ft.

#### **4.1.3.6 Open area on the outer wall of the building**

The total open area on the four outer walls in the form of doors, windows, ventilators was calculated. 73.3 per cent of the houses had open area between 42 and 110 sq.ft.

#### **4.1.3.7 Height of the building**

The mean height of the building was 21.6ft. Majority of the houses had height between 16 and 29 ft.

#### **4.1.3.8 Ceiling height**

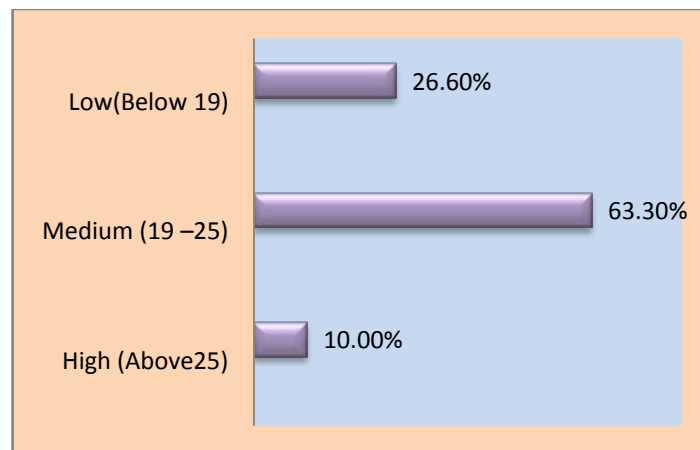
The mean ceiling height was 10.02 ft with SD 1.29. Majority of the houses (73.3%) had ceiling height between 10 and 11ft.

#### **4.1.3.9 No. of rooms**

Majority of the houses had rooms between 4 and 6. Houses with or below 4 rooms were not found. Only 23.33 percent of the houses had more than 6 rooms.

#### 4.1.3.10 Extent of dust accumulation features

The amount of dusts in the house may be in proportion to the extent of dust accumulation features present in the house. The dust can accumulate in nooks and corners of the house, on furniture, storage almarahas, window sills and so on. The presence of these construction features were identified. Each of the feature was given a score. Higher the presence of dust accumulation features higher the score. The mean score was 22.1 with a SD of 2.81. Taking mean and SD the sample was divided into three categories.



**Figure 4.4 Distribution of households by extend of dust accumulation features**

The mean presence of dust accumulation score was 22.1 with a SD of 2.81. The extent of presence of dust accumulation features were relatively more in only 10 percent of the households and moderate in 63.3 percent of the households.

#### 4.1.4 Construction and finishing material

The material used for (i) construction of walls and(ii) finishing material used for walls; (iii) flooring material and the (iv) type of ceiling were taken as variables in the study.

##### 4.1.4.1 Wall material

The wall construction material may contribute to the indoor air quality of the houses. Hence it is treated as one of the variables.

**Table 4.6. Distribution of households by material used for construction wall construction**

N =30		
Material for wall construction	N	%
Traditional brick, lime mortar, cement plaster	2	6.66%
Traditional brick, lime mortar, lime plaster	3	10.0%
Traditional brick, cement mortar, cement plaster	19	63.33%
Traditional brick, cement mortar, lime plaster	5	16.66%
Cement brick, cement mortar, cement plaster.	1	3.33%
Total	30	100%

Different materials were observed in different houses. More number of the houses used the traditional brick, cement mortar, and cement plaster for wall construction. Only 3.33 percent used cement brick, cement mortar and cement plaster.

#### **4.1.4.2 Finishing material for wall**

Finishing material may also contribute to the indoor air quality and hence it was considered as a variable in the investigation.

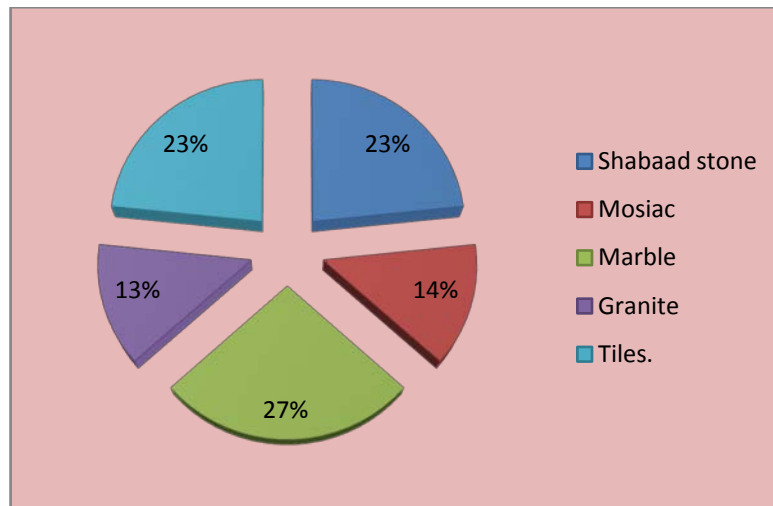
**Table 4.7. Distribution of households by finishing material used for walls**

N =30		
Finishing Material for walls	N	%
Cement plastering, Luppum	9	30%
Cement plastering, Luppum, paint	9	30%
Cement plastering, whitewash, distemper	5	16.66 %
Cement plastering, whitewash, paint	7	23.33 %
Total	30	100%

Equal percent (30.0%) of the houses used cement plastering with luppum and cement plastering with paint as wall finish. Only 16.6 percent of the households used cement plastering, whitewash and distemper.

#### **4.1.4.3 Flooring material**

The flooring material used in each of the house was recorded.

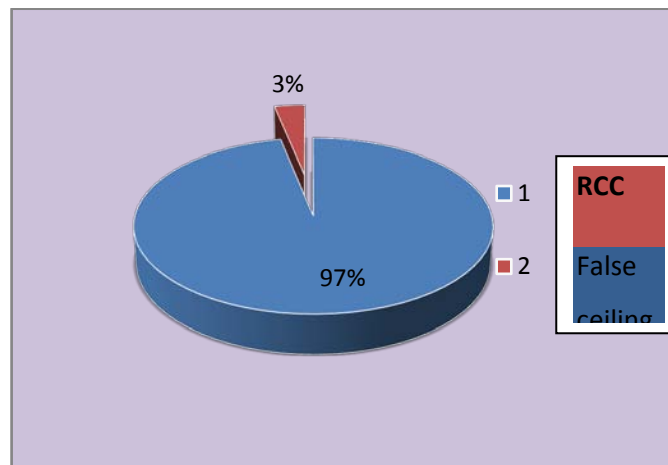


**Figure 4.5 Distribution of households by flooring material**

Relatively more number of houses (27%) had marble as the flooring material followed by shabaad stone (23.33 %). Only about 13.3 per cent of houses had either mosaic or granite for flooring.

#### 4.1.4.4 Ceiling type

The type of the ceiling found was either RCC or false ceiling with RCC. Majority of the houses had RCC ceiling. Only 3 percent of the houses had false ceiling along with RCC roof.



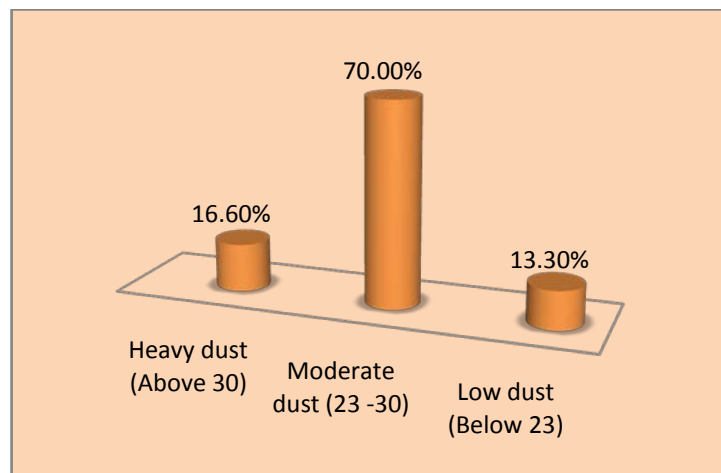
**Figure 4.6 Distribution of households by ceiling type**

#### 4.1.5 Household maintenance practices

One of the assumption of the study was that household maintenance practices may have impact on the indoor air quality, since the household practices includes the use of cleaning reagents which are chemical products. Household maintenance practices included in the study were (i) extent of presence of dust, (ii) frequency of household cleaning, (iii) feeling of congestedness, and (iv) extent of use of cleaning reagents for household maintenance.

##### 4.1.5.1 Extent of Presence of dust in the house

The presence of dust in the house was physically examined. Depending on the density of the visible dust on floors, walls, lighting fixtures, furniture, doors and window sills. The houses were categorized as houses with heavy dust, moderate dust and low dust depending on the total scored earned. The scores 3,2,1 were given for high, moderate and low dust respectively.



**Figure 4.7 Distribution of households by extent of presence of dust in the house**

The estimated mean score was 26.86 with SD of 3.57. Taking mean and SD the sample was divided into three categories. About 70 per cent of the samples were found to have moderate dust where as only 13.3 per cent were found to have low dust.

##### 4.1.5.2 Frequency of household cleaning

The frequency of household cleaning in terms of daily, alternate days, weakly once, once in fortnight, in a month, twice in month, yearly was measured, and scores

7,6,5,4,3,2, 1 were given respectively. Higher the frequency of cleaning higher was the score. Households earned very high score were grouped under the category highly regular, the houses who were cleaning the house in a more desirable way were categorized as regular and the houses who were cleaning the house less frequently were categorized as less regular.

**Table 4.8. Distribution of households by frequency of household cleaning**

N =30

Frequency of cleaning	Number	Percentage %
Highly regular	5	16.6 %
Regular	18	60.0 %
Less regular	7	23.3 %
Total	30	100%
Mean		43.13
SD		5.13

The estimated mean was 43.13 with SD 5.13. About 60 percent of the houses were found to have regular household cleaning, where as only 5 percent were found to have highly regular household cleaning.

#### 4.1.5.3 Feeling of Congestedness

Feeling of congestedness is due to excess and huge furniture, heavy storage units, overloaded loft, lack of space for internal circulation, lack of ventilation and so on. Based on the presence of these features in the house, the extent of feeling of congestedness was measured. High score was given when the researcher experienced the feeling of congestedness in the house due the above features. Taking mean and SD the sample was divided in three categories as heavy, moderate and low.

**Table 4.9. Distribution of households by feeling of Congestedness**

N =30

Feelig of congestedness	Number	Percentage %
Heavy(Above 20 )	2	6.6 %
Moderate(11 – 20)	20	66.6 %
Low(Below 11)	8	26.6 %
Total	30	100%
Mean		15.43
SD		4.07

The estimated mean was 15.43 with SD 4.0. Relatively more number of the houses (66.6%) were found to have moderate feeling of congestedness in the houses.

#### 4.1.5.4 Extent of use of cleaning reagent for household maintenance Practices

The cleaning reagents can be one of the factors causing the poor air quality due to chemicals used in the products. Hence it was taken as a variable to study its impact on indoor air quality. The frequency of use of cleaning reagent was measured in terms of regularly, sometimes, occasionally, rarely, never and scores 5,4,3,2,1 were allotted respectively.

**Table 4.10. Distribution of households by extent of use of cleaning reagent**

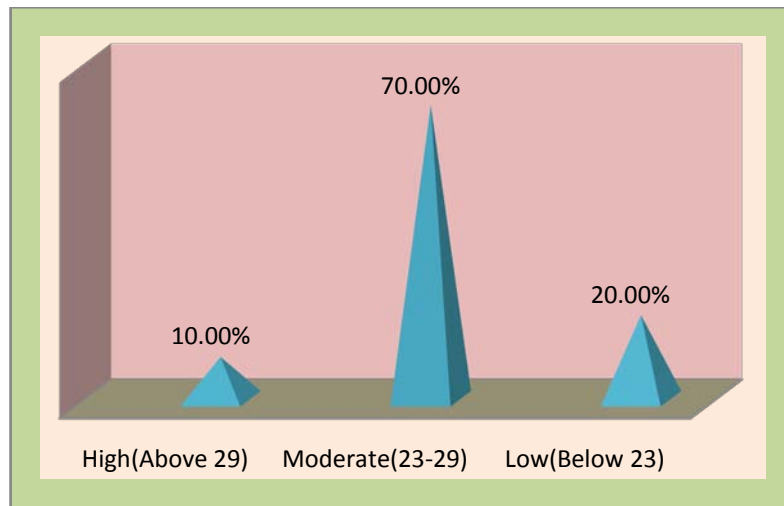
N =30

Extent of use of cleaning reagent	Number	Percentage %
Highly regular(Above 125)	3	10 %
Regular(106 – 125)	23	76.6%
Less regular(Below 106)	4	13.3 %
Total	30	100%
Mean		115.6
SD		9.82

The estimated mean was 115.6 with SD 9.82. About 76.6 percent of the houses were found using of cleaning reagent regularly. Whereas only 10 percent of the houses were found using cleaning reagents highly regularly.

#### 4.1.6 Extent of use of electrical gadgets

Electrical gadgets may have impact on the indoor air quality of the house and hence it is treated as a variable. The extent of use of electrical gadgets was measured in terms of frequency of use viz., regularly, sometimes, occasionally, rarely and never with scores of 5,4,3,2,1 respectively. The mean score was 26.3 with a SD of 0.70. Taking mean and SD the sample was divided into three categories.



**Figure 4.8 Distribution of households by the extent of use of electrical gadgets.**

About 70 percent houses were found to have moderate use of electrical gadgets and only 20 percent of the houses were found to have less usage of electrical gadgets.

#### 4.1.7 Extent of use of personal care products

Personal care products may have impact on the indoor air due to the emission of toxic substances by these products. The personal care products may act as a source of indoor air pollution. The extent of use of personal care products like body lotion, deodorant, body spray, perfumes, powders, nail polish, nail polish remover, hair dye, shampoo, conditioner, and medicines were measured in terms of regular, sometimes, occasionally, rarely, never and scores 5,4,3,2,1 were given respectively.

**Table 4.11. Distribution of households by extent of use of personal care product**

N =30

Extent of use of Personal care	Number	Percentage %
High(Above 53)	6	20.0 %
Moderate(44 – 50)	19	63.3 %
Low(Below 4)	5	16.3 %
Total	30	100%
Mean	47.43333	
SD	3.276703	

About 63.3 per cent of the houses were found using personal care products moderately and only 16.3 percent were found using the same less frequently.

#### 4.1.8 Indoor air quality parameters

The most common indoor air pollutants according to previous research were particulate matter (Massey et al, 2009), CO<sub>2</sub> (Maier et al, 2009), VOCs (Gallego et al ,2008) moisture and temperature (Brvinen de Brvien et al ,2005). Hence in the present investigation the eight parameters viz., CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, RH, temperature, and dew point were considered to measure IAQ.

##### 4.1.8.1 Carbon dioxide (CO<sub>2</sub>)

Carbon dioxide concentration has been used as an alternate measure of ventilation rate relative to its influence on indoor air quality (Reardon and Shaw 1993). Concentration of CO<sub>2</sub> in air was one of the parameters considered while assessing IAQ.

**Table.4.12. Distribution of household by CO<sub>2</sub> level in the indoors**

N =30

Level of CO <sub>2</sub> indoors	Number	Percentage %
Below 999.89 ppm	1	3.33 %
Between 999.89 –1532.91ppm	24	80.0 %
Above 1532.91ppm	4	13.3 %
Total	30	100%
Mean		1266.40
SD		266.51

The acceptable CO<sub>2</sub> level according to the ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) was below 1000 ppm which indicates that there is adequate air circulation for indoor environments. In the study it was observed that majority (80 %) of the houses had CO<sub>2</sub> levels above 1000 ppm. Only about 3.3 percent had below 999.89ppm. The level of CO<sub>2</sub> in indoors of the houses households near heavy traffic areas was found to be more than the accepted levels.

According to White (1994) CO<sub>2</sub> levels above 1000ppm in indoors is an indication of inadequate ventilation. The houses near to heavy traffic roads were found with inadequate ventilation due to closing of windows to prevent the entry of outdoor polluted air. This resulted in high concentration of CO<sub>2</sub> in indoors. High CO<sub>2</sub> levels can cause headaches, eye irritations in inmates.

#### 4.1.8.2 Volatile organic compounds (VOCs)

VOCs are emitted over periods of weeks or years from construction and finishing products and have the potential to change indoor air quality. The major sources of VOCs in indoor air are wet construction products like paints, adhesives sealant in new buildings and a mixture of wet household products and other materials in established buildings (Brown, 1994).

**Table. 4.13. Distribution of household by VOCs level in the indoors**

N =30

Level of VOC	Number	Percentage %
Below 14.91ppm	27	90.0 %
Between 14.91 – 27.35ppm	-	-
Above 27.35ppm	3	10.0 %
Total	30	100%
Mean		6.22
SD		21.13

The concentration of VOCs in the selected households was categorized as low, medium, high taking mean and SD in consideration. The level of VOCs in the households was either very low or high. The release of VOCs in indoor was mainly when the residents were using cleaning reagents and personal care products. Use of cleaning reagent for floor cleaning and bathroom cleaning were found to contribute to the level of VOCs in indoors. Relatively more amount of VOCs were released in indoors where residents were using cosmetics, like body lotion, nail polish, perfumes, deodorants, lipsticks and so on.

The VOCs concentration was high at the time of use of cleaning reagents and cosmetics. Slowly the concentration reduced within a short time after the use of these products. Probably this could be the reason for high variation in the level of VOCs in indoors. According to Huang and Haghghat (2002) high concentration of VOCs in indoors can cause dizziness, nausea, head ache, eye, and nose and throat irritation.

#### 4.1.8.3 Particulate matter 10 (PM<sub>10</sub>)

The dust particles those less than 10 micrometers in diameter are called as (PM<sub>10</sub>) are so small that they can get into the lungs, potentially causing serious health problems (Abbey, 1991). They are known as respirable particulates, as they are capable of reaching

the lower region of the respiratory track and are responsible for adverse health effects. According to the ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) the acceptable level of particulate matter in indoors is  $3\text{mg}/\text{m}^3$ .

**Table. 4.14 Distribution of household by PM<sub>10</sub> level in the indoors**

N=30

Level of PM <sub>10</sub>	Number	Percentage %
Below $2.1\text{ mg}/\text{m}^3$	2	6.66%
Between $2.1 - 3.1\text{ mg}/\text{m}^3$	27	90.0%
Above $3.1\text{ mg}/\text{m}^3$	1	3.33 %
Total	30	100%
Mean		2.6
SD		0.5

Respiratory symptoms like coughing, phlegm production, wheezing, and difficulty breathing were associated with PM<sub>10</sub> levels (Romieu et.al ,1996). The release of particulate matter in indoors can have adverse health effects (Abbey, 1991). The mean concentration of PM<sub>10</sub> in the households was  $2.6\text{ mg}/\text{m}^3$ . In majority of the households the PM<sub>10</sub> concentration was between 2.1 and  $3.3\text{ mg}/\text{m}^3$ . Only in case of 3.33 percent household the PM<sub>10</sub> level was high. Very few houses (6.66%) had low PM<sub>10</sub> concentration. Majority ((93.33%) of the households had PM<sub>10</sub> above  $2.1\text{ mg}/\text{m}^3$ , which may cause respiratory irritations and lung related diseases. The houses near to heavy traffic roads were found to have health risks due to PM<sub>10</sub>.

#### 4.1.8.4 Particulate matter 4 (PM<sub>4</sub>)

Particulate matter of 4 micrometers in diameter is called as PM<sub>4</sub>. These particles are slightly less than PM<sub>10</sub>. These particles can get into the throat and can cause irritation in throat that may lead to continuous cough.

**Table. 4.15 Distribution of household by PM<sub>4</sub> level in the indoors**

N =30

Level of PM <sub>4</sub>	Number	Percentage %
Below $1.3\text{ mg}/\text{m}^3$	-	-
Between $1.3 - .3.1\text{ mg}/\text{m}^3$	27	90.0 %
Above $3.1\text{ mg}/\text{m}^3$	6	20.0 %
Total	30	100%
Mean		2.9
SD		0.9

The PM<sub>4</sub> levels in 90 percent of the houses were found between 1.3 – .3.1 mg/m<sup>3</sup>. None of the houses were found to have PM<sub>4</sub> levels below 1.3 mg/m<sup>3</sup>. The PM<sub>4</sub> level in indoors of houses in heavy traffic areas was found to be relatively high. The traffic pollution might be the reason for high concentration of PM<sub>4</sub> in indoors.

**4.1.8.5 Particulate matter 2.5 (PM<sub>2.5</sub>)**

Particulate matter of 2.5 micrometers are very fine dust that can be detected only with an electron microscope. Once these fine particles enter in the lungs, they can affect the heart, blood vessels, and lungs (Dockery, 1992).

**Table. 4.16. Distribution of household by PM<sub>2.5</sub> level in the indoors**  
N =30

Level of PM <sub>2.5</sub>	Number	Percentage %
Below 1.3 mg/m <sup>3</sup>	-	-
Between 1.3 – .3.1 mg/m <sup>3</sup>	27	90.0 %
Above 3.1 mg/m <sup>3</sup>	6	20.0 %
Total	30	100%
Mean	2.9	
SD	0.9	

The majority of the houses (90 %) were found to have PM<sub>2.5</sub> levels between 1.3 – .3.1 mg/m<sup>3</sup>. One fifth of the households were with concentration of PM<sub>2.5</sub> above the permitted limits. None of the households were with less or negligible level of PM<sub>2.5</sub>. According to the present study the households near to heavy traffic zones had the threat of PM<sub>2.5</sub> in indoor air.

**4.1.8.6 Relative humidity (RH)**

Elevated humidity in indoors can promote the growth of mold, bacteria, and dust mites, which can aggravate allergies and asthma (Sundell, 2004).

**Table. 4.17. Distribution of household by RH level in the indoors**

N=30

Level of RH	Number	Percentage %
Low (Below 39.34)%	5	16.6 %
Medium (39.34 – 47.74)%	22	73.3 %
High (Above 47.74)%	3	10.0 %
Total	30	100%
Mean		43.54
SD		4.20

According to the ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) the acceptable level of RH in indoors should be between 30 - 60 per cent. Level of RH above 45 % is not desirable. About 73.3 percent of the houses were found to have RH levels more than the acceptable levels. As high concentration of RH aggravates allergies and asthma, according to the study, the residential houses near heavy traffic zones were with a risk of promoting allergies and asthma.

#### 4.1.8.7 Temperature

There is no ideal temperature suitable for all building occupants. The location of building site, its orientation and the design aspects of the building structure can affect the concentration of temperature in indoors (Sundell, 2004). According to the ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) the acceptable level of indoor temperature for indoor environment is 20-27 °C.

**Table. 4.18. Distribution of household by temperature level in the indoors**

N =30

Level of temperature	Number	Percentage %
Below 28.31 °C	5	16.6 %
Between 28.31 – 30.37) °C	22	73.3 %
Above 30.37 °C	3	10.0 %
Total	30	100%
Mean		29.25
SD		1.12

The mean indoor temperature was found to be higher than the standard acceptable indoor temperature. None of the households were found with comfortable indoor temperature. The houses in heavy traffic zone were found to have relatively more indoor temperature. The reasons could be many. The households were found with closed windows

and doors most of the time to prevent the entry of outdoor polluted air. Lack of air circulation, and openings to escape the hot air in indoors might have contributed to high level of indoor temperature. The other reason could be as the outdoor air was hot the heat was transferred to indoors also.

#### 4.1.8.8 Dew point

The dew point is the temperature at which the water vapor in a sample of air at constant barometric pressure condenses into liquid water at the same rate at which it evaporates( Peat, 1998). The amount of water vapor in indoor is important in relation to the occurrence of biological pollutants in indoors. Higher the dew point higher the chances of accumulation of biological pollutants in indoors and higher the health risk. The physical comfort is directly related to level of dew point.

**Table.4.19 Distribution of household by dew point level in the indoors**

n =30

Level of dew point	Number	Percentage %
Below 14.5 %	1	33.3 %
Between 14.5 – 16.72 %	25	83.3 %
Above 16.72 %	4	13.3 %
Total	30	100%
Mean	15.61	
SD	1.11	

Majority of the households (83.3%) had dew point levels between 14.5 – 16.72 % in indoor air. The chances of accumulation of biological pollutants in households near heavy traffic zones was found to be high and the physical comfort was found to be low.

## 4.2 Hypothesis Testing

One of the objectives of the research study is to establish the relation between indoor air quality and selected (i) Building location characteristics (ii) Building design parameters (iii) Construction and finishing material (iv) Household maintenance practices (v) Extent of use of electrical gadgets and (vi) Extent of use of personal care products.

Accordingly the following main null hypotheses with corresponding sub null hypothesis are formulated and presented below.

H<sub>01</sub> There exists no relation between selected building location characteristics and indoor air quality

H<sub>0 1.1</sub> There exists no relation between selected geographical location of building and indoor air quality

H<sub>0 1.2</sub> There exists no relation between site orientation and indoor air quality

H<sub>0 1.3</sub> There exists no relation between height of the base of the building with reference to main road and indoor air quality

H<sub>0 1.4</sub> There exists no relation between height of the base of the building with reference to road in front of the house and indoor air quality

H<sub>0 1.5</sub> There exists no relation between side of the building facing the main road and indoor air quality

H<sub>02</sub> There exists no relation between selected building design features and indoor air quality

H<sub>0 2.1</sub> There exists no relation between plot area and indoor air quality

H<sub>0 2.2</sub> There exists no relation between plinth area and indoor air quality

H<sub>0 2.3</sub> There exists no relation between landscape area and indoor air quality

H<sub>0 2.4</sub> There exists no relation between floor area ratio and indoor air quality

H<sub>0 2.5</sub> There exists no relation between open area on the wall of the building facing the main road and indoor air quality

H<sub>0 2.6</sub> There exists no relation between open area on the outer wall of the building and indoor air quality

H<sub>0 2.7</sub> There exists no relation between height of the building and indoor air quality

H<sub>0 2.8</sub> There exists no relation between ceiling height and indoor air quality

H<sub>0 2.9</sub> There exists no relation between number of rooms and indoor air quality

H<sub>0</sub> 2.10 There exists no relation between extent of dust accumulation features and indoor air quality

H<sub>0</sub> 3 There exists no relation between selected building construction material and indoor air quality

H<sub>0</sub> 3.1 There exists no relation between wall material and indoor air quality

H<sub>0</sub> 3.2 There exists no relation between finishing material for walls and indoor air quality

H<sub>0</sub> 3.3 There exists no relation between floor material and indoor air quality

H<sub>0</sub> 3.4 There exists no relation between ceiling type and indoor air quality

H<sub>0</sub> 4 There exist no relation between household maintenance practices and indoor air quality

H<sub>0</sub> 4.1 There exists no relation between extent of presence of dust in the house and indoor air quality

H<sub>0</sub> 4.2 There exists no relation between frequency of household cleaning and indoor air quality

H<sub>0</sub> 4.3 There exists no relation between feeling of congestedness and indoor air quality

H<sub>0</sub> 4.4 There exists no relation between extent of use of cleaning reagent and indoor air quality

H<sub>0</sub> 5 There exists no relation between extent of use of electrical gadgets and indoor air quality

H<sub>0</sub> 6 There exists no relation between extent of use of personal care products

H<sub>0</sub> 7 There is no difference in the extent of influence exerted by selected variable on indoor air quality

H<sub>0</sub> 7.1 There is no difference in the extent of influence exerted by selected variable on CO<sub>2</sub> level in indoor air

H<sub>0</sub> 7.2 There is no difference in the extent of influence exerted by selected variable on VOCs level in indoor air

H<sub>0</sub> 7.3 There is no difference in the extent of influence exerted by selected variable on PM<sub>10</sub> level in indoor air

H<sub>0</sub> 7.4 There is no difference in the extent of influence exerted by selected variable on PM<sub>4</sub> level in indoor air

H<sub>0</sub> 7.6 There is no difference in the extent of influence exerted by selected variable on RH level in indoor air

H<sub>0</sub> 7.7 There is no difference in the extent of influence exerted by selected variable on temperature level in indoor air

H<sub>0</sub> 7.8 There is no difference in the extent of influence exerted by selected variable on dew point level in indoor air

To test the hypothesis statistically analysis of variance was computed between the dependent and independent variables. A significant 'f' in an analysis of variance is an indication that not all the population means are equal. Where significant 'f' values were found, multiple comparison test was applied to determine which means differ.

To ascertain the order in the influence of the selected independent variables on indoor air quality, stepwise regression was carried out. From the stepwise regression contribution of selected independent variables on each indoor air quality parameter was found out.

#### **4.2.1 Relation between building location characteristics and indoor air quality**

In the present investigation the five building location characteristics selected were (i) geographical location of building (ii) site orientation (iii) height of the base of the building site with reference to main road (iv) height of the base of the building site with reference to road in front of the house (v) side of the building facing the main road.

Accordingly under the null hypothesis H<sub>0</sub>1, five sub null hypotheses H<sub>0</sub> 1.1, H<sub>0</sub> 1.2, H<sub>0</sub> 1.3, H<sub>0</sub> 1.4 and H<sub>0</sub> 1.5 were formulated and discussed below.

H<sub>0</sub> 1.1 There exists no relation between geographical location of building site and indoor air quality

According to spearman correlation significant correlation between geographical location of building site and indoor air temperature ( $r = 0.58$ ) was found. No significant correlation was found between geographical location of building and other indoor air quality parameters such as CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, RH, temperature and dew point (Appendix-B, Table-1)

**Table 4.20. Analysis of variation in indoor air quality parameters with regard to Geographical location of building site**

IAQ Parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Geographical location	4	730082	182520.5	2.77*	0.03
	Error	85	5591184	65778.64	–	–
	Total	89	6321266	–	–	–
VOC	Geographical location	4	1156.171	289.0428	0.6	0.63
	Error	85	38571.43	453.7816	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Geographical location	4	0.238165	0.059541	0.58	0.67
	Error	85	8.681764	0.102138	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Geographical location	4	0.011687	0.002922	4.07**	0.00
	Error	85	0.060873	0.000716	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Geographical location	4	0.053107	0.013277	1.49	0.20
	Error	85	0.752592	0.008854	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Geographical location	4	241.0712	60.2678	3.86**	0.00
	Error	85	1326.195	15.60229	–	–
	Total	89	1567.266	–	–	–
Temperature	Geographical location	4	25.73379	6.433447	6.30**	0.00
	Error	85	86.7123	1.020145	–	–
	Total	89	112.4461	–	–	–
Dew point	Geographical location	4	7.512523	1.878131	1.55	0.19
	Error	85	102.9327	1.210973	–	–
	Total	89	110.4452	–	–	–

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant variation was found in the level of CO<sub>2</sub>, PM<sub>4</sub>, RH, and Temperature in indoor air according to geographical location of building site. Geographical location of building site was found to be an influencing factor in determining the level of CO<sub>2</sub>, PM<sub>4</sub>, RH and temperature in indoors of residential households. The presence of VOCs, PM<sub>10</sub>,

PM<sub>2.5</sub> and dew point in residential indoors was not influenced by the geographical location of building site. Further to understand the significant difference in the level of CO<sub>2</sub> in residential interior multiple comparison test was done.

**Table 4.21. Mean comparison and significant probabilities between Geographical location of building site with respect to CO<sub>2</sub>**

S.no	Geographical location of the building site	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Abids	1256.20	1-2	100.64	1.16	0.24
2.	Kukatpally	1155.56	1-3	169.23	1.88	0.06
3.	M.G road	1425.43	1-4	20.51	0.21	0.82
4.	Panjagutta	1276.71	1-5	15.34	0.17	0.85
5.	Zoopark	1240.86	2-3	269.87	3.27**	0.00
			2-4	121.15	1.39	0.16
			2-5	85.3	1.07	0.28
			3-4	148.72	1.65	0.10
			3-5	184.57	2.24*	0.02
			4-5	35.85	0.41	0.68

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

The difference in the level of CO<sub>2</sub> in indoor air was highly significant between the households located in Kukatpally and M.G road. Significant difference in the level of CO<sub>2</sub> was found between the households located in M.G Road and Zoo Park. Geographical location of the building site was found to be a variable that can influence the level of CO<sub>2</sub> in residential indoors.

**Table 4.22. Mean comparison and significant probabilities between Geographical location of building site with respect to PM<sub>4</sub>**

S.no	Geographical location of the building site	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Abids	0.11	1-2	0.01	1.17	0.24
2.	Kukatpally	0.10	1-3	0	0.76	0.44
3.	M.G road	0.11	1-4	0.01	0.81	0.41
4.	Panjagutta	0.12	1-5	0.02	2.33*	0.02
5.	Zoopark	0.09	2-3	0.01	2.06*	0.04
			2-4	0.02	2.06*	0.04
			2-5	0.01	1.26	0.20
			3-4	0.01	0.09	0.92
			3-5	0.02	3.28**	0.00
			4-5	0.03	3.22**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference in the level of PM<sub>4</sub> in residential indoors located in Abids and Zoo park; Kukatpally and M.G Road; Kukatpally and Panjagutta was found. The mean difference in the level of PM<sub>4</sub> was highly significant between the houses located in M.G Road and Zoo Park; Panjagutta and Zoo Park.

Geographical location of building site was found to be a factor that influence the level of PM<sub>4</sub> in residential interiors.

**Table 4.23. Mean comparison and significant probabilities between Geographical location of building site with respect to Relative Humidity**

S.no	Geographical location of the building site	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Abids	42.15	1-2	0.31	0.23	0.81
2.	Kukatpally	41.84	1-3	1.08	0.78**	0.43
3.	M.G road	43.23	1-4	4.41	3.05	0.00
4.	Panjagutta	46.56	1-5	2.19	1.63	0.10
5.	Zoopark	44.34	2-3	1.39	1.09	0.27
			2-4	4.72	3.53**	0.00
			2-5	2.5	2.04*	0.04
			3-4	3.33	2.41*	0.01
			3-5	1.11	0.87	0.38
			4-5	2.22	1.66	0.09

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference in the level of Relative Humidity in indoors was found between the houses located in Kukatpally and Zoo Park; M.G Road and Panjagutta. The difference was highly significant between the houses located in Abids and M.G Road; Kukatpally and Panjagutta.

Location of the building site was found to be a factor in determining the level of Relative Humidity in residential interiors.

**Table 4.24. Mean comparison and significant probabilities between Geographical location of building site with respect to Temperature**

S.no	Geographical location of the building site	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Abids	29.92	1-2	0.11	0.32	0.74
2.	Kukatpally	29.81	1-3	0.85	2.39*	0.01
3.	M.G road	29.07	1-4	1.5	4.05**	0.00
4.	Panjagutta	28.42	1-5	0.95	2.77**	0.00
5.	Zoopark	28.97	2-3	0.74	2.26*	0.02
			2-4	1.39	4.05**	0.00
			2-5	0.84	2.68**	0.00
			3-4	0.65	1.84	0.06
			3-5	0.1	0.30	0.75
			4-5	0.55	1.60	0.11

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

According to multiple comparison test significant difference in the level of indoor temperature was found between the houses located in Abids and M.G road; Kukatpally and M.G Road. Highly significance difference was found between houses located in Abids and Panjagutta; Abids and Zoo Park; Kukatpally and Zoo Park.

Geographical location of building site was found to be an influencing the indoor temperature.

According to the present study the level of CO<sub>2</sub>, PM<sub>4</sub>, RH and temperature in residential indoors was influenced by the geographical location of residential building. Whereas geographical location of building site had no influence on the level of VOCs, PM<sub>10</sub>, PM<sub>2.5</sub> and dew point in residential interiors.

Hence, the null hypothesis was partially rejected.

H<sub>0</sub> 1.2 There exists no relation between site orientation and indoor air quality

No significant correlation existed between indoor air quality parameters and site orientation (Appendix-B, Table-1)

**Table 4.25. Analysis of variance in indoor air quality parameters with regard to Site orientation**

IAQ Parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Site orientation	3	502195.2	167398.4	2.47*	0.05
	Error	86	5819071	67663.62	–	–
	Total	89	6321266	–	–	–
VOC	Site orientation	3	504.1124	168.0375	0.36	0.77
	Error	86	39223.49	456.0871	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Site orientation	3	0.135155	0.045052	0.44	0.72
	Error	86	8.784774	0.102149	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Site orientation	3	0.00453	0.00151	1.90	0.13
	Error	86	0.06803	0.000791	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Site orientation	3	0.066209	0.02207	2.56*	0.05
	Error	86	0.73949	0.008599	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Site orientation	3	125.7375	41.91248	2.50*	0.05
	Error	86	1441.529	16.76196	–	–
	Total	89	1567.266	–	–	–
Temperature	Site orientation	3	0.926031	0.308677	0.23	0.86
	Error	86	111.5201	1.296745	–	–
	Total	89	112.4461	–	–	–
Dew point	Site orientation	3	10.52897	3.509658	3.02*	0.03
	Error	86	99.91628	1.161817	–	–
	Total	89	110.4452	–	–	–

p < 0.01 significant at 1 percent \*\* p < 0.05 significant at 5 percent\*

Significant variation in the level of CO<sub>2</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point in residential indoors was found according to site orientation.

**Table 4.26. Mean comparison and significant probabilities between Site orientation with respect to CO<sub>2</sub>**

S.no	Site orientation	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	East	1079.56	1-2	128.48	1.20	0.22
2.	West	1208.04	1-3	236.59	2.50*	0.01
3.	North	1316.15	1-4	209.8	1.91*	0.05
4.	South	1289.36	2-3	108.11	1.50	0.13
			2-4	81.32	0.89	0.37
			3-4	26.79	0.34	0.72

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

According to multiple comparisons test significant mean difference was found between the houses with east and north; east and south site orientation on CO<sub>2</sub> levels in indoors.

**Table 4.27. Mean comparison and significant probabilities between Site orientation with respect to PM<sub>2.5</sub>**

S.no	Site orientation	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	East	1-2	0.01	0.01	0.39	0.69
2.	West	1-3	0.06	0.06	1.76	0.08
3.	North	1-4	0.01	0.01	0.02	0.98
4.	South	2-3	0.15	0.15	1.73	0.08
		2-4	0.02	0.02	0.49	0.62
		3-4	0.07	0.07	2.19*	0.03

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

The houses with north and south site orientation differed significantly on PM<sub>2.5</sub> levels in indoors.

**Table 4.28. Mean comparison and significant probabilities between Site orientation with respect to Relative Humidity**

S.no	Site orientation	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	East	41.37	1-2	1	0.59	0.55
2.	West	42.37	1-3	3.22	2.16*	0.03
3.	North	44.59	1-4	1.54	0.89	0.37
4.	South	42.91	2-3	2.22	1.96*	0.05
			2-4	0.54	0.37	0.70
			3-4	1.68	1.38	0.16

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant mean difference in the level of RH in indoors was found between the houses with east and north site orientation; west and north site orientation.

**Table 4.29. Mean comparison and significant probabilities between Site orientation with respect to Dew point**

S.no	Site orientation	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	East	14.74	1-2	0.78	1.76	0.08
2.	West	15.52	1-3	1.12	2.85**	0.00
3.	North	15.86	1-4	0.67	1.47	0.14
4.	South	15.41	2-3	0.34	1.14	0.25
			2-4	0.11	0.28	0.77
			3-4	0.45	1.40	0.16

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant mean difference on dew point levels in indoors was found between the houses with east and north site orientation.

Among the eight IAQ parameters CO<sub>2</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point levels in residential interiors were found to be influenced by site orientation. In case of CO<sub>2</sub> east facing houses differed significantly with north and south facing houses. In case of PM<sub>2.5</sub> houses with north and south orientation differed significantly. With reference to Relative Humidity north facing houses differed significantly with east facing houses and west facing houses. Highly significant variation in Dew point level was found between the houses with east and north facing houses.

Site orientation was found to be influencing the level of CO<sub>2</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point and not influencing the level of VOCs, PM<sub>10</sub>, PM<sub>4</sub>, and Temperature in indoor environment of residential households.

Hence, the null hypothesis was partially rejected.

H<sub>0</sub> 1.3 There exists no relation between height of the base of the building site with reference to main road and indoor air quality

According to the spearman correlation no significant correlation existed between indoor air quality parameters and height of the base of the building site with reference to main road (Appendix-B, Table-1).

**Table 4.30. Analysis of variance in indoor air quality parameters with regard to Height of the base of the building site with reference to main traffic road**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Ht. of the base of the building with reference to main road	2	211316.2	105658.1	1.50	0.22
	Error	87	6109950	70229.31	–	–
	Total	89	6321266	–	–	–
VOC	Ht. of the base of the building with reference to main road	2	712.9282	356.4641	0.79	0.45
	Error	87	39014.68	448.4446	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Ht. of the base of the building with reference to main road	2	0.126713	0.063356	0.62	0.53
	Error	87	8.793216	0.101071	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Ht. of the base of the building with reference to main road	2	0.003807	0.001904	2.40	0.09
	Error	87	0.068753	0.00079	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Ht. of the base of the building with reference to main road	2	0.073388	0.036694	4.35*	0.01
	Error	87	0.732311	0.008417	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Ht. of the base of the building with reference to main road	2	28.96007	14.48004	0.81	0.44
	Error	87	1538.306	17.68168	–	–
	Total	89	1567.266	–	–	–
Temperature	Ht. of the base of the building with reference to main road	2	3.556402	1.778201	1.42	0.24
	Error	87	108.8897	1.251606	–	–
	Total	89	112.4461	–	–	–
Dew point	Ht. of the base of the building with reference to main road	2	4.539204	2.269602	1.86	0.16
	Error	87	105.906	1.217311	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

According to analyses of variance significant–difference in the level of PM<sub>2.5</sub> in indoors was found according to the height of the building site with reference to main traffic road.

**Table 4.31. Mean comparison and significant probabilities between Height of the base of the building site with reference to main traffic road with respect to PM<sub>2.5</sub>**

S.no	Ht. of the base of the building with reference to main road	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Above	0.11	1-2	0.05	1.86	0.06
2.	Below	0.16	1-3	0.01	0.67	0.50
3.	Same level	0.10	2-3	0.06	2.92**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in the level of PM<sub>2.5</sub> in indoors was found between the houses below the height of the main traffic road and same level of height with the main traffic road.

The concentration of PM<sub>2.5</sub> in residential interiors was influenced by building site height with reference to main traffic road. Except PM<sub>2.5</sub> none of the IAQ parameters such as CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, Relative Humidity, Temperature and Dew point were found effected by building site height with reference to main road.

Hence, the null hypothesis was partially rejected.

H<sub>0</sub> 1.4 There exists no relation between height of the building site with reference to road in front of the house and indoor air quality

According to the spearman correlation no significant correlation existed between indoor air quality parameters and height of the building site with reference to height of the road in front of the house.

**Table 4.32. Analysis of variance in indoor air quality parameters with regard to Height of the base of the building with reference to road in front of the house**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Ht of the base building site with reference to road in front of the house	2	207041.4	103520.7	1.47	0.23
	Error	87	6114225	70278.45	–	–
	Total	89	6321266	–	–	–
VOC	Ht of the base building site with reference to road in front of the house	2	1374.795	687.3974	1.55	0.21
	Error	87	38352.81	440.8369	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Ht of the base building site with reference to road in front of the house	2	0.361818	0.180909	1.83	0.16
	Error	87	8.558111	0.098369	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Ht of the base building site with reference to road in front of the house	2	0.002272	0.001136	1.40	0.25
	Error	87	0.070288	0.000808	–	–
	Total	89	0.07256	–	–	–
PM <sub>25</sub>	Ht of the base building site with reference to road in front of the house	2	0.021549	0.010774	1.19	0.3075
	Error	87	0.78415	0.009013	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Ht of the base building site with reference to road in front of the house	2	63.87162	31.93581	1.84	0.16
	Error	87	1503.394	17.2804	–	–
	Total	89	1567.266	–	–	–
Temperature	Ht of the base building site with reference to road in front of the house	2	1.421978	0.710989	0.55	0.57
	Error	87	111.0241	1.276139	–	–
	Total	89	112.4461	–	–	–
Dew point	Ht of the base building site with reference to road in front of the house	2	4.815618	2.407809	1.98	0.14
	Error	87	105.6296	1.214134	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

No significant variation existed between the indoor air quality parameters and height of the base of the building site with reference to the height of the road in front of the house.

The height of the base of the building either below, above or same level with reference to the height of the road in front of the house had no influence on any of the IAQ parameters.

Hence, the null hypothesis was accepted.

H<sub>0</sub> 1.5 There exist no relation between side of the building facing the main road and indoor air quality

No significant correlation were found between side of the building facing the main road and IAQ parameters selected for the study ( Appendix B, Table-1 ).

**Table 4.33. Analysis of variance in indoor air quality parameters with regard to Side of the building facing the main road quality**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Side of the building facing the main road	2	96859.93	48429.97	0.67	0.51
	Error	87	6224406	71544.9	–	–
	Total	89	6321266	–	–	–
VOC	Side of the building facing the main road	2	2374.489	1187.245	2.76*	0.06
	Error	87	37353.12	429.3462	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Side of the building facing the main road	2	0.462698	0.231349	2.37	0.09
	Error	87	8.457231	0.09721	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Side of the building facing the main road	2	0.008383	0.004191	5.68**	0.00
	Error	87	0.064177	0.000738	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Side of the building facing the main road	2	0.093412	0.046706	5.70**	0.00
	Error	87	0.712286	0.008187	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Side of the building facing the main road	2	191.9327	95.96637	6.07**	0.00
	Error	87	1375.333	15.80843	–	–
	Total	89	1567.266	–	–	–
Temperature	Side of the building facing the main road	2	9.344584	4.672292	3.94*	0.02
	Error	87	103.1015	1.185075	–	–
	Total	89	112.4461	–	–	–
Dew point	Side of the building facing the main road	2	17.98279	8.991396	8.4602**	0.00
	Error	87	92.46246	1.062787	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant variation in the level of PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point in indoor air according to the side of the building facing the main road was found. Significant variation was found in case of VOCs and indoor temperature according to the side of the building facing the main road.

**Table 4.34. Mean comparison and significant probabilities between Side of the building facing the main road with respect to VOC**

S.no	Side of the building facing the main road	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Front	3.10	1-2	9.78	1.99*	0.04
2.	left	12.88	1-3	2.31	0.39	0.69
3.	right	0.79	2-3	12.09	1.99*	0.04

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

According to multiple comparison test significant difference in the level of VOC in indoor was found between the houses with front side facing the main road and left side facing the main road. Similarly significance difference in the level of VOC in indoor air existed between the houses with left side facing the main road and right side facing the main road.

**Table 4.35. Mean comparison and significant probabilities between Side of the building facing the main road with respect to PM<sub>4</sub>**

S.no	Side of the building facing the main road	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Front	0.11	1-2	0.02	3.37**	0.00
2.	left	0.09	1-3	0.01	1.26	0.20
3.	right	0.10	2-3	0.01	1.49	0.13

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant difference in the levels of PM<sub>4</sub> in indoors was found between the houses with front side of the building facing the main road and left side facing the main road.

**Table 4.36. Mean comparison and significant probabilities between Side of the building facing the main road with respect to PM<sub>2.5</sub>**

S.no	Side of the building facing the main road	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Front	0.13	1-2	0.04	1.81	0.07
2.	left	0.17	1-3	0.08	3.32*	0.00
3.	right	0.17	2-3	0.04	1.76	0.08

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference in the levels of PM<sub>2.5</sub> in indoors was found between the houses with front side of the building facing the main road and right side of the building facing the main road.

In case of particulate matter PM<sub>10</sub> in indoors was not influenced by the side of the building facing the main road. The concentration of PM<sub>4</sub>, and PM<sub>2.5</sub> in indoor air was found to be influenced by the side of the building facing the main road. The houses with front side facing the main road were found to be having relatively more concentration of PM<sub>4</sub>, and PM<sub>2.5</sub> in indoors.

**Table 4.37. Mean comparison and significant probabilities between Side of the building facing the main road with respect to Relative Humidity**

S.no	Side of the building facing the main road	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Front	41.87	1-2	3.2	3.20**	0.00
2.	left	44.89	1-3	2.82	2.48*	0.01
3.	right	44.69	2-3	0.2	0.16	0.86

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Variations in the level of Relative Humidity in indoor was highly significant between the houses with front and left side facing the main road and significant between the houses with front and right side facing the main road. The houses with left side facing the main road were found to be with relatively high indoor humidity.

**Table 4.38. Mean comparison and significant probabilities between Side of the building facing the main road with respect to Temperature**

S.no	Side of the building facing the main road	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Front	29.56	1-2	0.37	1.42	0.15
2.	left	29.19	1-3	0.86	2.78**	0.00
3.	right	28.70	2-3	0.49	1.55	0.12

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in the levels of temperature in indoors was found between the houses with front side of the building facing the main road and right side of the building facing the main road. The houses facing the main road were found to be with relatively high indoor temperature.

**Table 4.39. Mean comparison and significant probabilities between Side of the building facing the main road with respect to Dew point**

S.no	Side of the building facing the main road	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Front	15.18	1-2	1	4.07**	0.00
2.	left	16.18	1-3	0.3	1.00	0.316
3.	right	15.48	2-3	0.7	2.30*	0.023

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in the level of dew point in indoors was found between the houses with front and left side of the building facing the main road. Significant difference was found between the houses with left and right side facing the main road with reference to dew point levels in indoors.

The side of the building facing the main road was found to be a factor that influence the level of indoor pollutants such as VOC, PM<sub>4</sub>, PM<sub>2,5</sub>, Relative Humidity, Temperature and Dew point. Level of CO<sub>2</sub> and PM<sub>10</sub> in indoor air were not influenced by the side of the building facing the main road.

The houses with front side facing the main road were found to be with relatively more concentration of PM<sub>4</sub>, and Relative Humidity. Similarly houses with left side facing the main road were found to have more concentration of PM<sub>2,5</sub> and Dew point.

According to the present study the side of the building facing the main road was found to be an influential factor in maintaining the indoor air quality.

Hence, the null hypothesis was rejected.

The building location characteristics selected for the study were found to be affecting the IAQ of residential buildings.

CO<sub>2</sub> was found to be influenced by geographical location of building site and site orientation.

VOC was found to be influenced by only side of the building facing the main road.

None of the building site location characteristics were found influencing the level of PM<sub>10</sub> in indoor air of residential buildings.

PM<sub>4</sub> was found to be influenced by geographical location of building site and side of the building facing the main road.

PM<sub>2.5</sub> was found to be influenced by site orientation, height of the building with reference to main traffic road, side of the building facing the main road.

Relative Humidity was found to be influenced by geographical location of building site, site orientation, and side of the building facing the main road.

Temperature was found to be influenced by geographical location of building site, and side of the building facing the main road.

Dew point was found to be influenced by site orientation and side of the building facing the main road.

Side of the building facing the main road was found to be a major factor that influences the IAQ.

Height of the building with reference to road in front of the house had not shown any impact on IAQ.

#### 4.2.2 Relation between Building Design Parameters and indoor air quality

An attempt was made in the present research to explore the relation between the selected building design parameters such as (i) plot area (ii) plinth area (iii) landscape area (iv) floor area ratio (v) open area on the wall of the building facing the main road (vi) open area on the outer wall of the building (vii) height of the building (viii) ceiling height (ix) number of rooms (x) extent of dust accumulation features and indoor air quality.

Accordingly under the null hypothesis  $H_0$  2 sub hypotheses  $H_0$  2.1,  $H_0$  2.2,  $H_0$  2.3,  $H_0$  2.4,  $H_0$  2.5,  $H_0$  2.6,  $H_0$  2.7,  $H_0$  2.8,  $H_0$  2.9, and  $H_0$  2.10 were formulated and discussed below.

$H_0$  2.1 There exists no relation between plot area and indoor air quality

Highly significant correlation was found between plot area and  $CO_2$ . ( $r = 0.46$ ) (Appendix-B, Table-1)

**Table 4.40. Analysis of variance in indoor air quality parameters with regard to Plot area**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Plot area	2	880441.1	440220.6	7.03**	0.00
	Error	87	5440825	62538.22	—	—
	Total	89	6321266	—	—	—
VOC	Plot area	2	301.3792	150.6896	0.33	0.71
	Error	87	39426.23	453.175	—	—
	Total	89	39727.61	—	—	—
PM <sub>10</sub>	Plot area	2	0.047775	0.023888	0.23	0.79
	Error	87	8.872154	0.101979	—	—
	Total	89	8.919929	—	—	—
PM <sub>4</sub>	Plot area	2	0.008006	0.004003	5.39**	0.00
	Error	87	0.064554	0.000742	—	—
	Total	89	0.07256	—	—	—
PM <sub>2.5</sub>	Plot area	2	0.120425	0.060213	7.64**	0.00
	Error	87	0.685273	0.007877	—	—
	Total	89	0.805699	—	—	—
Relative Humidity	Plot area	2	221.9869	110.9934	7.17**	0.00
	Error	87	1345.279	15.46298	—	—
	Total	89	1567.266	—	—	—
Temperature	Plot area	2	5.191187	2.595593	2.10	0.12
	Error	87	107.2549	1.232815	—	—
	Total	89	112.4461	—	—	—
Dew point	Plot area	2	6.143428	3.071714	2.56	0.08
	Error	87	104.3018	1.198871	—	—
	Total	89	110.4452	—	—	—

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

High significant variations in the level of CO<sub>2</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, and Relative Humidity in indoor air according to plot area was found.

**Table 4.41. Mean comparison and significant probabilities between Plot area with respect to CO<sub>2</sub>**

S.no	Plot area	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Large	1070.78	1 - 3	197.13	3.75**	0.00
2.	Medium	1453.72	1 - 2	382.94	2.51*	0.01
3.	Small	1267.91	3 - 2	185.81	2.36*	0.02

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

According to multiple comparison test significant difference was found in the level of CO<sub>2</sub> in indoor air between the houses with large and medium plot areas and small and medium size plot area. Highly significant difference in the level of CO<sub>2</sub> in indoor air was found between the houses with large and small size plot area. As the area of the plot increased, the concentration of CO<sub>2</sub> in indoor air decreased.

**Table 4.42. Mean comparison and significant probabilities between Plot area with respect to PM<sub>4</sub>**

S.no	Plot area	Mean score	Mean Contrast	Mean difference	t- value	Level of significance
1.	Large	0.11	1 - 3	0.01	1.27	0.20
2.	Medium	0.12	1 - 2	0.01	1.47	0.14
3.	Small	0.10	3 - 2	0.02	3.12**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant difference in the level of PM<sub>4</sub> in indoor air was found between the houses with large plot area and small plot area.

**Table 4.43. Mean comparison and significant probabilities between Plot area with respect to PM<sub>2.5</sub>**

S.no	Plot area	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Large	0.09	1 - 3	0.02	3.28**	0.00
2.	Medium	0.21	1 - 2	0.21	0.53	0.59
3.	Small	0.11	3 - 2	0.1	3.745**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant difference in the levels of  $PM_{2.5}$  in indoors was found between the houses with large and small plot area, small and medium plot area. No difference in the level of  $PM_{2.5}$  in indoor air was found between the houses with large and medium plot area.

**Table 4.44. Mean comparison and significant probabilities between Plot area with respect to Relative Humidity**

S.no	Plot area	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Large	39.87	1 – 3	3.95	3.62**	0.00
2.	Medium	45.68	1 – 2	5.81	3.20**	0.00
3.	Small	43.82	3 – 2	1.86	1.50	0.13

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in the levels of Relative Humidity in indoors was found between the houses with large and small plot area, and between the houses with large and medium plot area. The size of the plot area was found influencing the level of  $CO_2$ ,  $PM_4$ ,  $PM_{2.5}$  and Relative Humidity in the indoor air of residential building.

Hence, the null hypothesis was partially rejected.

$H_0$ 2.2 There exists no relation between plinth area and indoor air quality

There exist a significant correlation between plinth area and  $CO_2$  in indoor air ( $r = 0.44$ ) (Appendix-B, Table-1).

**Table 4.45. Analysis of variance in indoor air quality parameters with regard to Plinth area**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Plinth area	2	533316.2	266658.1	4.00*	0.02
	Error	87	5787950	66528.16	–	–
	Total	89	6321266	–	–	–
VOC	Plinth area	2	710.6677	355.3339	0.79	0.45
	Error	87	39016.94	448.4706	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Plinth area	2	0.052805	0.026403	0.25	0.77
	Error	87	8.867123	0.101921	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Plinth area	2	710.6677	355.3339	0.79	0.45
	Error	87	39016.94	448.4706	–	–
	Total	89	39727.61	–	–	–
PM <sub>2.5</sub>	Plinth area	2	0.079265	0.039633	4.74*	0.01
	Error	87	0.726434	0.00835	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Plinth area	2	200.9498	100.4749	6.39**	0.00
	Error	87	1366.316	15.70479	–	–
	Total	89	1567.266	–	–	–
Temperature	Plinth area	2	3.921477	1.960738	1.57	0.21
	Error	87	108.5246	1.247409	–	–
	Total	89	112.4461	–	–	–
Dew point	Plinth area	2	12.69523	6.347613	5.64**	0.00
	Error	87	97.75002	1.123563	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Among eight IAQ parameters selected for the study, significant variation according to the plinth area with regard to indoor air quality was found in the level of CO<sub>2</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point.

**Table 4.46. Mean comparison and significant probabilities between Plinth area with respect to CO<sub>2</sub>**

S.no	Plinth area	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Large	1070.78	1 – 3	228.96	3.28**	0.00
2.	Medium	1282.87	1 – 2	212.09	0.53	0.59
3.	Small	1299.74	3 – 2	16.87	3.74**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant difference in the levels of CO<sub>2</sub> in indoors was found between the houses with large and small plinth area; small and medium plinth area. No significant difference in the levels of CO<sub>2</sub> was found between the houses with large and medium size plinth area. The concentration of CO<sub>2</sub> decreased with an increase in plinth area of the house.

**Table 4.47. Mean comparison and significant probabilities between Plinth area with respect to PM<sub>2.5</sub>**

S.no	Plinth area	Mean score	Mean Contrast	Mean difference	t- value	Level of significance
1.	Large	0.09	1 - 3	0.02	2.59*	0.01
2.	Medium	0.19	1 - 2	0.1	0.56	0.57
3.	Small	0.11	3 - 2	0.08	2.88**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference in the level PM<sub>2.5</sub> in indoor air was found between houses with large and small size plinth area; small and medium size plinth area. There exists no significant difference in the level of PM<sub>2.5</sub> in indoors in case of houses with large and medium size plinth area.

**Table 4.48. Mean comparison and significant probabilities between Plinth area with respect to RH**

S.no	Plinth area	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Large	39.87	1 - 3	4.44	2.19*	0.03
2.	Medium	43.24	1 - 2	3.37	3.56**	0.00
3.	Small	44.31	3 - 2	1.07	0.94	0.34

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference in the level Relative Humidity in indoor air was found between houses with large and small size plinth area; large and medium size plinth area. There exists no significant difference in the level of Relative Humidity in indoors in case of houses with small and medium size plinth area.

**Table 4.49. Mean comparison and significant probabilities between Plinth area with respect to Dew point**

S.no	Plinth area	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Large	14.94	1 - 3	0.91	0.41	0.67
2.	Medium	15.11	1 - 2	0.17	2.71**	0.00
3.	Small	15.85	3 - 2	0.74	2.42*	0.01

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant difference in the level of Dew point in indoor air was found between houses with large and medium size plinth area; small and medium size plinth area. There exists no significant difference in the level of Dew point in indoors in case of houses with large and small size plinth area.

Significant variation according to plinth area was found in the level of CO<sub>2</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point in residential indoors.

The level of CO<sub>2</sub> in indoors was found to be influenced by the size of the plinth area. As the size of the plinth area increased mean score of CO<sub>2</sub> decreased.

The size of the plinth area showed impact on the level of PM<sub>2.5</sub>, Relative Humidity, and Dew point in indoor air of residential buildings. Level of Relative Humidity and Dew point decreased with increased plinth area.

Hence, the null hypothesis was partially rejected.

H<sub>0</sub>2.3 There exists no relation between landscape area and indoor air quality

There existed no significant correlation between landscape area and indoor air quality parameters (Appendix-B, Table-1)

**Table 4.50. Analysis of variance in indoor air quality parameters with regard to Landscape area**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	landscape area	2	125305.5	62652.74	0.87	0.41
	Error	87	6195961	71217.94	–	–
	Total	89	6321266	–	–	–
VOC	landscape area	2	592.9529	296.4765	0.65	0.51
	Error	87	39134.65	449.8236	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	landscape area	2	0.001892	0.000946	0.00	0.99
	Error	87	8.918037	0.102506	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	landscape area	2	0.001719	0.000859	1.05	0.35
	Error	87	0.070841	0.000814	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	landscape area	2	0.005268	0.002634	0.28	0.75
	Error	87	0.80043	0.0092	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	landscape area	2	73.56127	36.78064	2.14	0.12
	Error	87	1493.705	17.16902	–	–
	Total	89	1567.266	–	–	–
Temperature	landscape area	2	2.127838	1.063919	0.83	0.43
	Error	87	110.3183	1.268026	–	–
	Total	89	112.4461	–	–	–
Dew point	landscape area	2	3.317211	1.658605	1.34	0.26
	Error	87	107.128	1.231357	–	–
	Total	89	110.4452	–	–	–

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

No significant variation existed in the levels of indoor air quality parameters with reference to landscape area.

The results of the present investigation revealed that the size of landscape area around the residential building had no impact on indoor air quality.

Hence, the null hypothesis was accepted.

H<sub>0</sub> 2.4 There exists no relation between floor area ratio and indoor air quality

There existed no significant correlation between floor area ratio and indoor air quality parameters (Appendix-B, Table-1)

**Table 4.51. Analysis of variance in indoor air quality parameters with regard to Floor area ratio**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	floor area ratio	2	172352.9	86176.46	1.21	0.30
	Error	87	6148913	70677.17	–	–
	Total	89	6321266	–	–	–
VOC	floor area ratio	2	819.5231	409.7616	0.91	0.40
	Error	87	38908.08	447.2193	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	floor area ratio	2	0.015803	0.007901	0.07	0.92
	Error	87	8.904126	0.102346	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	floor area ratio	2	0.00452	0.00226	2.88*	0.05
	Error	87	0.06804	0.000782	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	floor area ratio	2	0.021131	0.010566	1.17	0.31
	Error	87	0.784568	0.009018	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	floor area ratio	2	10.84342	5.421708	0.30	0.73
	Error	87	1556.423	17.88992	–	–
	Total	89	1567.266	–	–	–
Temperature	floor area ratio	2	1.270376	0.635188	0.49	0.61
	Error	87	111.1757	1.277882	–	–
	Total	89	112.4461	–	–	–
Dew point	floor area ratio	2	3.744361	1.872181	1.52	0.22
	Error	87	106.7009	1.226447	–	–
	Total	89	110.4452	–	–	–

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

According to the analysis of variance significant difference was found on PM<sub>4</sub> levels in indoor air according to the floor area ratio.

**Table 4.52. Mean comparison and significant probabilities between Floor area ratio with respect to PM<sub>4</sub>**

S.no	Floor area ratio	Mean score	Mean Contrast	Mean difference	t- value	Level of significance
1.	Large	0.11	1 – 3	0.01	0.15	0.87
2.	Medium	0.11	1 – 2	0	1.58	0.11
3.	Small	0.10	3 – 2	0.01	2.08*	0.04

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Variations in the levels of PM<sub>4</sub> in indoor air with reference to floor area ratio was significant between the residential buildings with small and medium floor area ratio

No significant correlation existed between floor area ratio of a residential buildings and IAQ parameters such as CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point. Out of all these IAQ parameters significant mean difference in the level of PM<sub>4</sub> in indoor environment was found between the houses with relatively small and medium floor area ratio.

Hence, the null hypothesis was partially rejected.

H<sub>0</sub> 2.5 There exists no relation between open area on the wall of the building facing the main road and indoor air quality

There existed no significant correlation between open area on the wall of the building facing the main road and indoor air quality parameters.

**Table 4.53. Analysis of variance in indoor air quality parameters with regard to Open area on the wall of the building facing the main traffic road**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Open area on the wall of the building facing the main traffic road.	2	175641.5	87820.76	1.24	0.29
	Error	87	6145625	70639.37	–	–
	Total	89	6321266	–	–	–
VOC	Open area on the wall of the building facing the main traffic road.	2	1041.272	520.63	1.17	0.31
	Error	87	38686.33	444.67	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Open area on the wall of the building facing the main traffic road.	2	0.50623	0.25	2.61*	0.07
	Error	87	8.413699	0.09	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Total open area on the wall of the building facing the main traffic road.	2	0.000224	0.00	0.13	0.87
	Error	87	0.072336	0.00	–	–
	Total	89	0.07256	–	–	–
PM <sub>25</sub>	Open area on the wall of the building facing the main traffic road.	2	0.042119	0.02	2.39	0.09
	Error	87	0.76358	0.00	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Open area on the wall of the building facing the main traffic road.	2	14.97222	7.48	0.41	0.65
	Error	87	1552.294	17.84	–	–
	Total	89	1567.266	–	–	–
Temperature	Open area on the wall of the building facing the main traffic road.	2	11.52324	5.76	4.96**	0.00
	Error	87	100.9229	1.16	–	–
	Total	89	112.4461	–	–	–
Dew point	Open area on the wall of the building facing the main traffic road.	2	3.618992	1.80	1.47	0.23
	Error	87	106.8263	1.22	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Variations in the level of temperature in indoor air with reference to open area on the wall of the building facing the main traffic road was found highly significant. Except the indoor temperature none of the IAQ parameters revealed variations in their presence in indoors with reference to open area on the wall of the building facing the main road.

**Table 4.54. Mean comparison and significant probabilities between Open area on the wall of the building facing the main traffic road with respect to Temperature**

S.no	open area on the wall of the building facing the main traffic road	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Large	28.81	1 - 3	0.71	0.25	0.79
2.	Medium	28.70	1 - 2	0.11	2.71**	0.00
3.	Small	29.52	3 - 2	0.82	2.12*	0.03

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant difference in the level of temperature in indoors was found between the houses with small and medium open area on the wall of the building facing the main traffic road. Highly significant difference was found with reference to temperature in indoor environment between the houses with large and medium open area on the wall of the building facing the main road.

Open area in the form of windows, doors and ventilators had impact only on the level of indoor air temperature in residential buildings and it had not shown any impact on the level of CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub> Relative Humidity and Dew point in indoor environment of households.

Hence the null hypothesis was partially rejected.

H<sub>0</sub> 2.6 There exists no relation between open area on the outer wall of the building and indoor air quality

There existed no significant correlation between floor area ratio and indoor air quality parameters.

**Table 4.55. Analysis of variance in indoor air quality parameters with regard to Open area on the outer wall of the building**

IAQ parameter	Source of variation	Df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Open area on the outer wall of the building.	2	698716.4	349358.2	5.40*	0.00
	Error	87	5622550	64627.01	–	–
	Total	89	6321266	–	–	–
VOC	Open area on the outer wall of the building.	2	636.4178	318.2089	0.70	0.49
	Error	87	39091.19	449.324	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Open area on the outer wall of the building.	2	0.47058	0.23529	2.42	0.09
	Error	87	8.449349	0.097119	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Open area on the outer wall of the building.	2	0.000691	0.000345	0.41	0.65
	Error	87	0.071869	0.000826	–	–
	Total	89	0.07256	–	–	–
PM <sub>25</sub>	Open area on the outer wall of the building.	2	0.033255	0.016628	1.87	0.15
	Error	87	0.772444	0.008879	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Open area on the outer wall of the building.	2	4.668579	2.334289	0.13	0.87
	Error	87	1562.598	17.96089	–	–
	Total	89	1567.266	–	–	–
Temperature	Open area on the outer wall of the building.	2	2.339362	1.169681	0.92	0.40
	Error	87	110.1067	1.265595	–	–
	Total	89	112.4461	–	–	–
Dew point	Open area on the outer wall of the building.	2	2.675639	1.33782	1.08	0.34
	Error	87	107.7696	1.238731	–	–
	Total	89	110.4452	–	–	–

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Variations in the level of CO<sub>2</sub> in indoor air with reference to open area on the outer wall of the building was significant. None of the other IAQ parameters showed variation in their levels in indoor environment based on open area on the outer wall of the building.

**Table 4.56. Mean comparison and significant probabilities between Open area on the outer wall of the building with respect to CO<sub>2</sub>**

S.no	open area on the outer wall of the building	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	Large	1395.43	1 - 3	186.65	0.15	0.87
2.	Medium	1411.67	1 - 2	16.24	2.74**	0.00
3.	Small	1208.78	3 - 2	202.89	2.23*	0.02

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant mean difference in the level of CO<sub>2</sub> in indoors was found between the houses with medium and small open area on the outer wall of the building, Highly significant mean difference was found between houses with large and medium open area on the outer wall of the building with reference to CO<sub>2</sub> in indoors. Open area on the outer wall of the building in terms of doors, windows, and ventilators was taken as a building design variable explored its relation to IAQ. According to the study open area on the outer wall of the building affected the concentration of CO<sub>2</sub> in indoors environments of residential households. The concentration of CO<sub>2</sub> in indoors increased with an increase in the open area on the outer wall of the building. Hence, the null hypothesis partially rejected.

H<sub>0</sub> 2.7 There exists no relation between height of the building and indoor air quality

Spearman correlation revealed significant correlation between height of the building and VOCs (r = 0.46). (Appendix –B, Table -1)

**Table 4.57. Analysis of variance in indoor air quality parameters with regard to Height of the building**

IAQ parameter	Source of variation	Df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Ht of the building	2	207041.4	103520.7	1.47	0.23
	Error	87	6114225	70278.45	–	–
	Total	89	6321266	–	–	–
VOC	Ht of the building	2	539.1377	269.5688	0.59	0.55
	Error	87	39188.47	450.4422	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Ht of the building	2	0.488364	0.244182	2.51	0.08
	Error	87	8.431565	0.096915	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Ht of the building	2	0.001368	0.000684	0.83	0.43
	Error	87	0.071192	0.000818	–	–
	Total	89	0.07256	–	–	–
PM <sub>25</sub>	Ht of the building	2	0.032694	0.016347	1.83	0.16
	Error	87	0.773005	0.008885	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Ht of the building	2	38.78914	19.39457	1.10	0.33
	Error	87	1528.477	17.5687	–	–
	Total	89	1567.266	–	–	–
Temperature	Ht of the building	2	2.368622	1.184311	0.93	0.39
	Error	87	110.0775	1.265258	–	–
	Total	89	112.4461	–	–	–
Dew point	Ht of the building	2	1.285817	0.642909	0.51	0.60
	Error	87	109.1594	1.254706	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

No significant variation existed in the level of selected indoor air quality parameters such as CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub> Relative Humidity and Dew point with reference to the height of the building. According to the present study height of the building had no impact on indoor air quality.

Hence, the null hypothesis was accepted.

H<sub>0</sub> 2.8 There exists no relation between ceiling height and indoor air quality

Spearman correlation revealed significant correlation between ceiling height of the building and temperature (r = 0.37) (Appendix –B, Table -1).

**Table.4.58 Analyses of variance in indoor air quality parameters with regard to Ceiling height**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Ceiling height	2	175521.9	87760.93	1.24	0.29
	Error	87	6145745	70640.74	–	–
	Total	89	6321266	–	–	–
VOC	Ceiling height	2	161.9896	80.9948	0.17	0.83
	Error	87	39565.62	454.7772	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Ceiling height	2	0.004311	0.002156	0.02	0.97
	Error	87	8.915618	0.102478	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Ceiling height	2	0.009409	0.004704	6.48**	0.00
	Error	87	0.063151	0.000726	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Ceiling height	2	0.120967	0.060483	7.68**	0.00
	Error	87	0.684732	0.00787	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Ceiling height	2	88.38525	44.19263	2.59	0.08
	Error	87	1478.881	16.99863	–	–
	Total	89	1567.266	–	–	–
Temperature	Ceiling height	2	36.20252	18.10126	20.6**	0.00
	Error	87	76.24357	0.876363	–	–
	Total	89	112.4461	–	–	–
Dew point	Ceiling height	2	15.16353	7.581764	6.92**	0.00
	Error	87	95.28172	1.095192	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

According to analysis of variance highly significant variation in the levels of PM<sub>4</sub>, PM<sub>2.5</sub>, Temperature, and Dew point in indoor air was found according to the ceiling height of the building.

**Table 4.59. Mean comparison and significant probabilities between Ceiling height with respect to PM<sub>4</sub>**

S.no	Ceiling height	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.12	1 - 3	0.02	2.42*	0.01
2.	Medium	0.08	1 - 2	0.04	3.37**	0.00
3.	Low	0.10	3 - 2	0.02	0.97	0.32

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

According to multiple comparisons test highly significant difference in the level of PM<sub>4</sub> was found between the houses with high and medium ceiling height. Similarly significant difference between the homes with high and low ceiling height with respect to PM<sub>4</sub> was found.

**Table 4.60. Mean comparison and significant probabilities between Ceiling height with respect to PM<sub>2.5</sub>**

S.no	Ceiling height	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.20	1 - 3	0.09	2.49*	0.01
2.	Medium	0.06	1 - 2	0.14	3.73**	0.00
3.	Low	0.11	3 - 2	0.05	0.87	0.38

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

According to multiple comparisons test highly significant difference in the level of PM<sub>2.5</sub> was found between the houses with high and medium ceiling height. Similarly significant difference between the homes with high and low ceiling height with respect to PM<sub>2.5</sub> was found.

**Table 4.61. Mean comparison and significant probabilities between Ceiling height with respect to Temperature**

S.no	Ceiling height	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	28.17	1 - 3	1.21	5.90**	0.00
2.	Medium	31.67	1 - 2	3.5	4.54**	0.00
3.	Low	29.38	3 - 2	2.29	4.15**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in the level of temperature in residential indoors according to the ceiling height of the building was found. Residential buildings with medium ceiling height were found to have high indoor temperature.

**Table 4.62. Mean comparison and significant probabilities between Ceiling height with respect to Dew point**

S.no	Ceiling height	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	15.61	1 - 3	0.09	3.32**	0.00
2.	Medium	17.81	1 - 2	2.2	0.30	0.75
3.	Low	15.52	3 - 2	2.29	3.72**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significance difference existed in the level of Dew point in residential interiors according to ceiling height. Buildings with low ceiling height differed significantly with buildings with high and medium ceiling height on the level of Dew Point in interiors. No significant difference was found between high and medium ceiling height buildings on the level of Dew Point in interiors.

Ceiling height of the building had an impact on the level of  $PM_{4,}$   $PM_{2.5,}$  Temperature and Dew point in residential interiors.

Hence, the null hypothesis was partially rejected.

$H_0$  2.9 There exists no relation between number of rooms and indoor air quality

There exists no correlation between number of rooms and any of the indoor air quality parameters selected under the study.

**Table 4.63. Analysis of variance in indoor air quality parameters with regard to Number of rooms**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	No. of rooms	3	952750.1	317583.4	5.08**	0.00
	Error	86	5368516	62424.61	–	–
	Total	89	6321266	–	–	–
VOC	No. of rooms	3	141.161	47.05367	0.10	0.95
	Error	86	39586.44	460.3075	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	No. of rooms	3	0.236431	0.07881	0.78	0.50
	Error	86	8.683498	0.100971	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	No. of rooms	3	0.005937	0.001979	2.55	0.06
	Error	86	0.066623	0.000775	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	No. of rooms	3	0.044841	0.014947	1.68	0.17
	Error	86	0.760858	0.008847	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	No. of rooms	3	142.2655	47.42184	2.86*	0.04
	Error	86	1425.001	16.56977	–	–
	Total	89	1567.266	–	–	–
Temperature	No. of rooms	3	5.925209	1.97507	1.59	0.19
	Error	86	106.5209	1.238615	–	–
	Total	89	112.4461	–	–	–
Dew point	No. of rooms	3	9.740854	3.246951	2.77*	0.04
	Error	86	100.7044	1.170981	–	–
	Total	89	110.4452	–	–	–

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

According to the analysis of variance highly significant difference was found in levels of CO<sub>2</sub>, Relative Humidity and Dew point in residential interiors with regard to number of rooms.

**Table 4.64. Mean comparison and significant probabilities between Number of rooms with respect to CO<sub>2</sub>**

S.no	Number of rooms	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	4	1380.94	4- 5	228.48	3.76**	0.00
2.	5	1152.46	4-6	72.57	0.97	0.33
3.	6	1308.37	4-7	30.61	0.20	0.84
4.	7	1350.33	5-6	155.91	2.18*	0.03
			5-7	197.87	1.32	0.18
			6-7	41.96	0.26	0.78

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference was found between houses with 4 and 5 rooms in the level of CO<sub>2</sub> in indoor air and significant difference between houses with 5 and 6 rooms on CO<sub>2</sub> levels in indoors.

**Table 4.65. Mean comparison and significant probabilities between Number of rooms with respect to Relative Humidity**

S.no	Number of rooms	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	4	44.31	4- 5	1.37	1.37	0.17
2.	5	42.94	4-6	0.19	0.15	0.87
3.	6	44.50	4-7	6.38	2.5*	0.01
4.	7	37.93	5-6	1.56	1.33	0.18
			5-7	5.01	2.05*	0.04
			6-7	6.57	2.58*	0.011

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant mean difference in the level of Relative Humidity in indoor air of residential building was found to be significant between houses with 4 and 7 rooms; 5 and 7 rooms; 6 and 7 rooms.

**Table 4.66. Mean comparison and significant probabilities between Number of rooms with respect to Dew point**

S.no	Number of rooms	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	4	15.91	4- 5	0.43	1.64	0.10
2.	5	15.48	4-6	0.3	0.92	0.35
3.	6	15.61	4-7	1.75	2.67**	0.00
4.	7	14.16	5-6	0.13	0.43	0.66
			5-7	1.32	2.04*	0.04
			6-7	1.45	2.16*	0.03

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly Significant mean difference in the level of Dew point in indoor air of residential building was found between houses with 4 and 7 rooms, significant mean difference between houses with 5 and 7 rooms; 6 and 7 rooms; 6 and 7 rooms.

The relation between the number of rooms in the residential buildings and indoor air quality was studied. Variation in the level of CO<sub>2</sub>, Relative Humidity, and Dew point according to the number of rooms in the house was found out. The concentration of CO<sub>2</sub> levels in houses with 5 rooms was found to be less. The difference in the level of CO<sub>2</sub> in

indoor air was significantly different from houses with 4 and 5 rooms and 5 and 6 rooms. Relative Humidity and Dew point in the indoor air decreased with an increase in the number of rooms probably the air circulation was better and helped in reduction of Humidity and Dew point.

Hence, the null hypothesis was partially rejected.

H<sub>0</sub> 2.10 There exists no relation between extent of dust accumulation features and indoor air quality

Significant correlation existed between dust accumulation feature and CO<sub>2</sub>, Dew point (r = 0.45) (r = 0.4) (Appendix-b, Table-1).

**Table 4.67. Analysis of variance in indoor air quality parameters with regard to Extent of dust accumulation features**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Extend of Dust accumulation features	2	823978.2	411989.1	6.52*	0.00
	Error	87	5497288	63187.22	–	–
	Total	89	6321266	–	–	–
VOC	Extend of Dust accumulation features	2	449.8508	224.9254	0.49	0.60
	Error	87	39277.76	451.4684	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Extend of Dust accumulation features	2	0.046261	0.02313	0.22	0.79
	Error	87	8.873668	0.101996	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Extend of Dust accumulation features	2	0.004059	0.002029	2.57	0.08
	Error	87	0.068501	0.000787	–	–
	Total	89	0.07256	–	–	–
PM <sub>25</sub>	Extend of Dust accumulation features	2	0.010614	0.005307	0.58***	0.56
	Error	87	0.795084	0.009139	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Extend of Dust accumulation features	2	169.2957	84.64785	5.2**	0.00
	Error	87	1397.97	16.06863	–	–
	Total	89	1567.266	–	–	–
Temperature	Extend of Dust accumulation features	2	22.12205	11.06102	10.6**	0.00
	Error	87	90.32404	1.038207	–	–
	Total	89	112.4461	–	–	–
Dew point	Extend of Dust accumulation features	2	5.519536	2.759768	2.28	0.10
	Error	87	104.9257	1.206043	–	–
	Total	89	110.4452	–	–	–

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant variation according to the extent of dust accumulation features in residential households was found with reference to CO<sub>2</sub>, Relative Humidity, Temperature and Dew point.

**Table 4.68. Mean comparison and significant probabilities between Extent of dust accumulation features with respect to CO<sub>2</sub>**

S.no	Extent of dust accumulation features	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	1114.07	1 - 3	161.45	3.57**	0.00
2.	Medium	1449.28	1 - 2	335.21	2.38*	0.01
3.	Low	1275.52	3 - 2	173.76	2.18*	0.03

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in the level of CO<sub>2</sub> was found between the houses with high and low dust accumulation features. Significant difference in the level of CO<sub>2</sub> in indoors was found between the houses with high and medium extent of dust accumulation features; low and medium extent of dust accumulation features.

**Table 4.69. Mean comparison and significant probabilities between Extent of dust accumulation features with respect to RH**

S.no	Extent of dust accumulation features	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	41.45	1 - 3	3.06	0.27	0.78
2.	Medium	41.85	1 - 2	0.4	2.84**	0.00
3.	Low	44.51	3 - 2	2.66	2.09*	0.03

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in the level of RH was found between the houses with high and medium dust accumulation features. Significant difference in the level of Relative Humidity in indoors was found between the houses with low and medium extent of dust accumulation features.

**Table 4.70. Mean comparison and significant probabilities between Extent of dust accumulation features with respect to Temperature**

S.no	Extent of dust accumulation features	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	29.25	1 - 3	0.25	3.27*	0.00
2.	Medium	30.49	1 - 2	1.24	0.88	0.37
3.	Low	29.00	3 - 2	1.49	4.61**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in indoor temperature was found between the houses with low and medium dust accumulation features. Significant difference in the level of Temperature in indoors was found between the houses with high and low extent of dust accumulation features where as The effect of extent of dust accumulation features in residential households on the IAQ parameters selected for the study was analyzed statistically.

Variations in the level of CO<sub>2</sub>, Relative Humidity, Temperature and Dew point according to the presence of dust accumulation features were found. Significance mean differences were found in the level of CO<sub>2</sub>, Relative Humidity and Temperature based on the extent of dust accumulation features.

Hence, the null hypothesis was partially rejected.

#### **4.2.3 Relation between building construction material and indoor air quality**

In the present research the impact of building construction material on indoor air quality was explored. The building construction materials included in the study were (i) wall material (ii) finishing material for wall (iii) flooring material (iv) ceiling type.

H<sub>0</sub>3.1 There exists no relation between wall material and indoor air quality

There exists no significant correlation between wall material and IAQ parameters (Appendix-B, Table-1)

**Table 4.71. Analysis of variance in indoor air quality parameters with regard to Wall material**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Wall material	4	692521.9	173130.5	2.61*	0.04
	Error	85	5628745	66220.52	–	–
	Total	89	6321266	–	–	–
VOC	Wall material	4	4672.322	1168.081	2.83*	0.02
	Error	85	35055.28	412.4151	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Wall material	4	0.063024	0.015756	0.15	0.96
	Error	85	8.856905	0.104199	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Wall material	4	0.015273	0.003818	5.66**	0.00
	Error	85	0.057287	0.000674	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Wall material	4	0.348556	0.087139	16.20**	0.00
	Error	85	0.457143	0.005378	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Wall material	4	331.9959	82.99896	5.71**	0.00
	Error	85	1235.27	14.53259	–	–
	Total	89	1567.266	–	–	–
Temperature	Wall material	4	18.43522	4.608804	4.16**	0.003
	Error	85	94.01087	1.10601	–	–
	Total	89	112.4461	–	–	–
Dew point	Wall material	4	14.87788	3.719469	3.30*	0.014
	Error	85	95.56737	1.124322	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant variations in the levels of most of the IAQ parameters such as CO<sub>2</sub>, VOCs, PM<sub>4</sub>, PM<sub>2.5</sub>, RH, Temperature, Dew point in residential interiors according to the material used for wall construction was found.

**Table 4.72. Mean comparison and significant probabilities between Wall material with respect to CO<sub>2</sub>**

S.no	Wall material*	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	1020.61	1-2	303.09	2.23*	0.02
2.	2	1323.70	1-3	209.42	2.62*	0.01
3.	3	1311.03	1-4	134.79	1.08	0.28
4.	4	1155.40	1-5	272.39	1.49	0.13
5.	5	1293.00	2-3	12.67	0.13	0.89
			2-4	168.3	1.55	0.12
			2-5	30.7	0.17	0.85
			3-4	155.63	2.08*	0.04
			3-5	18.03	0.11	0.90
			4-5	137.6	0.84	0.40

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\* **Wall material:** 1. Traditional brick, lime mortar, cement plaster. 2. Traditional brick, lime mortar, lime plaster. 3. Traditional brick, cement mortar, cement plaster. 4. Traditional brick, cement mortar, lime plaster. 5. Cement brick, cement mortar, cement plaster.

According to multiple comparison test the level of CO<sub>2</sub> in indoor air of residential households differed significantly between the houses with walls constructed out of traditional brick, lime mortar, cement plaster and the houses with walls constructed out of traditional brick, lime mortar and lime plaster. The major difference between these two types of houses was cement plaster and lime plaster.

There exist a significant difference in the level of CO<sub>2</sub> between the houses with wall constructed out of traditional brick, lime mortar, cement plaster and houses with walls constructed out of traditional brick, cement mortar and cement plaster. The difference between these two types of houses was cement mortar and lime mortar.

Significant difference in the level of CO<sub>2</sub> was found between the houses with wall constructed out of traditional brick, cement mortar and cement plaster and the houses with walls constructed out of traditional brick, cement mortar, and lime plaster. The major difference between these two types of houses was cement plaster and lime plaster.

**Table 4.73. Mean comparison and significant probabilities between Wall material with respect to VOC**

S.no	Wall material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	1.23	1-2	15.86	1.48	0.14
2.	2	17.09	1-3	3	0.34	0.73
3.	3	4.23	1-4	1.66	0.16	0.86
4.	4	2.89	1-5	36.97	2.57	0.01
5.	5	38.20	2-3	12.86	1.76*	0.08
			2-4	14.2	1.65	0.10
			2-5	21.11	1.55	0.12
			3-4	1.34	0.22	0.82
			3-5	33.97	2.82**	0.00
			4-5	35.31	2.74**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\* **Wall material:** 1. Traditional brick, lime mortar, cement plaster.2. Traditional brick, lime mortar, lime plaster.3. Traditional brick, cement mortar, cement plaster.4. Traditional brick, cement mortar, lime plaster.5. Cement brick, cement mortar, cement plaster.

Significant difference in the level of VOC in residential interiors was found between the houses with wall constructed out of Traditional brick, lime mortar, lime plaster and the houses with wall constructed out of Traditional brick, cement mortar, cement plaster. Similarly highly significant difference in the level of VOC was found between houses with wall constructed out of Traditional brick, cement mortar, cement plaster and cement brick, cement mortar, cement plaster.

Significant difference in the level of VOC in indoors was found in the houses with walls constructed out of traditional brick, cement mortar and lime plaster and the houses with walls constructed out of cement brick, cement mortar and cement plaster.

The major building material responsible for the presence of VOC in indoors was cement mortar, lime mortar, traditional brick and cement brick.

**Table 4.74. Mean comparison and significant probabilities between Wall material with respect to PM<sub>4</sub>**

S.no	Wall material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	0.09	1-2	0.02	1.66	0.09
2.	2	0.11	1-3	0	0.27	0.78
3.	3	0.09	1-4	0.04	2.84**	0.00
4.	4	0.13	1-5	0.03	1.36	0.17
5.	5	0.12	2-3	0.02	2.11*	0.03
			2-4	0.02	1.17	0.24
			2-5	0.01	0.12	0.89
			3-4	0.04	4.32**	0.00
			3-5	0.03	1.42	0.15
			4-5	0.01	0.64	0.51

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\* **Wall material:** 1. Traditional brick, lime mortar, cement plaster.2. Traditional brick, lime mortar, lime plaster.3. Traditional brick, cement mortar, cement plaster.4. Traditional brick, cement mortar, lime plaster.5. Cement brick, cement mortar, cement plaster.

Significant difference in the level of PM<sub>4</sub> in indoor air was found between the houses built with walls out of Traditional brick, lime mortar, lime plaster and the houses with walls constructed out of Traditional brick, cement mortar, cement plaster. The houses built with walls from traditional brick, cement mortar, lime plaster differed significantly from the houses built with two types of wall material composition such as traditional brick, lime mortar and cement plaster and traditional brick, cement mortar, cement plaster with reference to concentration of indoor PM<sub>4</sub>.

**Table 4.75. Mean comparison and significant probabilities between Wall material with respect to PM<sub>2.5</sub>**

S.no	Wall material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	0.11	1-2	0.01	0.37	0.70
2.	2	0.12	1-3	0	0.03	0.96
3.	3	0.11	1-4	0.01	0.33	0.73
4.	4	0.10	1-5	0.34	6.62**	0.00
5.	5	0.45	2-3	0.01	0.59	0.55
			2-4	0.02	0.85	0.39
			2-5	0.33	6.72**	0.00
			3-4	0.01	0.50	0.61
			3-5	0.34	7.93**	0.00
			4-5	0.35	7.66**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\* **Wall material:** 1. Traditional brick, lime mortar, cement plaster.2. Traditional brick, lime mortar, lime plaster.3. Traditional brick, cement mortar, cement plaster.4. Traditional brick, cement mortar, lime plaster.5. Cement brick, cement mortar, cement plaster.

Highly significant difference in the level of PM<sub>2.5</sub> in indoor air was found between the houses built with walls out of Traditional brick, lime mortar, cement plaster and the houses with walls constructed with Cement brick, cement mortar, and cement plaster. The houses built with walls from Cement brick, cement mortar, and cement plaster differed significantly on level of PM<sub>2.5</sub> in indoor air from the houses built with three types of wall material composition such as Traditional brick, lime mortar, lime plaster, Traditional brick, cement mortar, cement plaster, and Traditional brick, cement mortar, lime plaster.

**Table 4.76. Mean comparison and significant probabilities between Wall material with respect to Relative Humidity**

S.no	Wall material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	41.75	1-2	2.49	1.23	0.21
2.	2	44.24	1-3	1.98	1.17	0.24
3.	3	43.68	1-4	0.25	0.13	0.89
4.	4	41.50	1-5	10.83	4.01**	0.00
5.	5	52.58	2-3	0.56	0.40	0.68
			2-4	2.74	1.70	0.09
			2-5	8.34	3.28**	0.00
			3-4	2.18	1.96	0.05
			3-5	8.9	3.94**	0.00
			4-5	11.08	4.59**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

\* **Wall material:** 1. Traditional brick, lime mortar, cement plaster.2. Traditional brick, lime mortar, lime plaster.3. Traditional brick, cement mortar, cement plaster.4. Traditional brick, cement mortar, lime plaster.5. Cement brick, cement mortar, cement plaster.

Highly significant difference in the level of Relative Humidity in indoor air was found between the houses built with walls constructed out of Traditional brick, lime mortar, cement plaster and the houses with walls constructed with Cement brick, cement mortar, and cement plaster. The houses built with walls from Cement brick, cement mortar, and cement plaster differed significantly from the houses built with three types of wall material composition such as Traditional brick, lime mortar, cement plaster, Traditional brick, lime mortar, lime plaster, Traditional brick, cement mortar, cement plaster, Traditional brick, cement mortar, lime plaster with reference to concentration of indoor Relative Humidity.

**Table 4.77. Mean comparison and significant probabilities between wall material with respect to Temperature**

S.no	Wall material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	29.75	1-2	1.39	2.50*	0.01
2.	2	28.36	1-3	0.37	0.80	0.42
3.	3	29.38	1-4	0.38	0.63	0.52
4.	4	29.42	1-5	2.17	2.91	0.00
5.	5	27.58	2-3	1.02	2.71*	0.00
			2-4	1.06	2.39	0.01
			2-5	0.78	1.11	0.26
			3-4	0.04	0.12	0.89
			3-5	1.8	2.89**	0.00
			4-5	1.84	2.76**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\* **Wall material:** 1. Traditional brick, lime mortar, cement plaster.2. Traditional brick, lime mortar, lime plaster.3. Traditional brick, cement mortar, cement plaster.4. Traditional brick, cement mortar, lime plaster.5. Cement brick, cement mortar, cement plaster.

Highly significant difference in the level of Temperature in indoor air was found between the houses built with walls constructed out of Cement brick, cement mortar, cement plaster and from the houses with walls constructed out of Traditional brick, cement mortar, cement plaster, and the houses with walls constructed out of Traditional brick, cement mortar, lime plaster. The houses built with walls from Traditional brick, lime mortar, lime plaster differed significantly from the houses with walls built from Traditional brick, lime mortar, cement plaster and Traditional brick, cement mortar, cement plaster with reference to indoor air temperature.

**Table 4.78. Mean comparison and significant probabilities between Wall material with respect to Dew point**

S.no	Wall material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	15.37	1-2	0.03	0.06	0.94
2.	2	15.40	1-3	0.42	0.92	0.36
3.	3	15.79	1-4	0.47	0.91	0.36
4.	4	14.90	1-5	1.5	2.00*	0.04
5.	5	16.87	2-3	0.39	1.00	0.31
			2-4	0.5	1.13	0.25
			2-5	1.47	2.07**	0.04
			3-4	0.89	2.89**	0.00
			3-5	1.08	1.72	0.08
			4-5	1.97	2.93**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\* **Wall material:** 1. Traditional brick, lime mortar, cement plaster.2. Traditional brick, lime mortar, lime plaster.3. Traditional brick, cement mortar, cement plaster.4. Traditional brick, cement mortar, lime plaster.5. Cement brick, cement mortar, cement plaster.

Highly significant difference in the level of Dew point in indoor air was found between the houses built with walls constructed out of Traditional brick, lime mortar, cement plaster and the houses with walls constructed out of Cement brick, cement mortar, and cement plaster. The houses built with walls from Cement brick, cement mortar, cement plaster differed significantly from the houses built with three types of wall material composition such as Traditional brick, lime mortar, lime plaster, the houses built with Traditional brick, cement mortar, cement plaster, Traditional brick, cement mortar, lime plaster with reference to concentration of indoor Dew point.

Highly significant and significant difference in the level of indoor air pollutants like CO<sub>2</sub>, VOC, PM<sub>4</sub>,PM<sub>2.5</sub>, Relative Humidity, Temperature and dew point was found between the residential buildings used different combinations for wall construction. The major difference found could be due to the use of either cement or lime as a mortar or plastering material and use of either traditional brick or cement brick for wall construction.

Level of CO<sub>2</sub> was found to be more in the houses with walls constructed with traditional brick, lime mortar and lime plaster. Concentration of VOC, PM<sub>2.5</sub>, Relative Humidity, and Dew point in the houses used cement brick, cement mortar and cement plaster for wall construction. Indoor temperature was relatively high in the houses used traditional brick, lime mortar and cement plaster for wall construction .Wall material was found to be influencing the quality of indoor air.

Hence, the null hypothesis was rejected.

H<sub>0</sub> 3.2 There exists no relation between finishing material for walls and indoor air quality

There exists no significant correlation between finishing material for walls and IAQ parameters (Appendix-B, Table-1)

**Table 4.79. Analysis of variance in indoor air quality parameters with regard to Finishing material for walls**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Finishing material	3	854010.8	284670.3	4.47**	0.00
	Error	86	5467256	63572.74	–	–
	Total	89	6321266	–	–	–
VOC	Finishing material	3	3060.183	1020.061	2.39	0.07
	Error	86	36667.42	426.3654	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Finishing material	3	0.194341	0.06478	0.63	0.59
	Error	86	8.725588	0.10146	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Finishing material	3	0.014087	0.004696	6.90**	0.00
	Error	86	0.058473	0.00068	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Finishing material	3	0.078444	0.026148	3.09*	0.03
	Error	86	0.727255	0.008456	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Finishing material	3	332.3395	110.7798	7.71**	0.00
	Error	86	1234.927	14.35961	–	–
	Total	89	1567.266	–	–	–
Temperature	Finishing material	3	19.73561	6.578537	6.10**	0.00
	Error	86	92.71048	1.078029	–	–
	Total	89	112.4461	–	–	–
Dew point	Finishing material	3	17.14747	5.715822	5.26**	0.00
	Error	86	93.29778	1.084858	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant and significant variations were found in the levels of CO<sub>2</sub>, , PM<sub>4</sub>, PM<sub>2.5</sub>, RH, Temperature, Dew point in residential indoors according to various finishing materials used for walls.

The four types of wall finishes found in residential interiors were type-1 Cement plastering, Luppum, Whitewash, type-2 Cement plastering, Luppum, paint, type- 3. Cement plastering, whitewash and distemper type- 4. Cement plastering, whitewash, and paint. Cement plastering was the common factor for all four types; therefore type-1 is luppum with white wash, type-2 luppum with paint, type-3 whitewash with distemper and type-4 whitewash with paint.

**Table 4.80. Mean comparison and significant probabilities between Finishing material with respect to CO<sub>2</sub>**

S.no	Finishing material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	1272.72	1-2	-120.34	1.75	0.08
2.	2	1393.06	1-3	155.03	1.90*	0.05
3.	3	1117.69	1-4	71.07	0.96	0.33
4.	4	1201.65	2-3	275.37	3.39**	0.00
			2-4	191.41	2.60*	0.01
			3-4	-83.96	0.98	0.32

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

**\*Finishing material:** 1.Cement plastering, Luppum, Whitewash. 2. Cement plastering, Luppum, paint 3. Cement plastering, whitewash, distemper. 4. Cement plastering, whitewash, paint.

Highly significant difference in the level of CO<sub>2</sub> in indoor air was found between houses used luppum with paint as wall finish and houses used whitewash with distemper as wall finish.

Significant difference was found in the level of CO<sub>2</sub> in indoor air between the houses used luppum with white wash as wall finish and houses used whitewash with distemper as wall finish.

Significant difference was found in the level of CO<sub>2</sub> in indoor air between the houses used luppum with paint as wall finish and houses used whitewash with paint as wall finish

**Table 4.81. Mean comparison and significant probabilities between Finishing material with respect to VOC**

S.no	Finishing material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	2.02	1-2	13.1	2.33*	0.02
2.	2	15.12	1-3	0.79	0.11	0.90
3.	3	2.81	1-4	0.61	0.10	0.91
4.	4	2.63	2-3	12.31	1.85	0.06
			2-4	12.49	2.07*	0.04
			3-4	0.18	0.02	0.97

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

**\*Finishing material:** 1.Cement plastering, Luppum, Whitewash. 2. Cement plastering, Luppum, paint 3. Cement plastering, whitewash, distemper. 4. Cement plastering, whitewash, paint.

Significant difference in the level of VOC in indoor air was found between the residential buildings used luppum with white wash, as wall finish and the buildings used luppum with paint as wall finish

Significant difference was found in the level of VOC in indoor air between the houses used luppum with paint as wall finish and houses used whitewash with paint as wall finish

**Table 4.82. Mean comparison and significant probabilities between Finishing material with respect to PM<sub>4</sub>**

S.no	Finishing material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	0.09	1-2	0	0.26	0.79
2.	2	0.09	1-3	0.04	3.72**	0.00
3.	3	0.13	1-4	0.02	2.22*	0.02
4.	4	0.11	2-3	0.04	3.94**	0.00
			2-4	0.02	2.46*	0.01
			3-4	0.02	1.63	0.10

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

**\*Finishing material:** 1. Cement plastering, Luppum, Whitewash. 2. Cement plastering, Luppum, paint 3. Cement plastering, whitewash, distemper. 4. Cement plastering, whitewash, paint.

Highly significant difference in the level of PM<sub>4</sub> in indoor air was found between the residential buildings used luppum with white wash as wall finish and residential buildings used whitewash with distemper as wall finish.

Similarly Highly significant difference in the level of PM<sub>4</sub> in indoor air was found between the residential buildings used luppum with paint as wall finish and residential buildings used whitewash with distemper as wall finish.

Significant difference in the level of PM<sub>4</sub> in indoor air was found between the residential buildings used luppum with whitewash as wall finish and residential buildings used whitewash with paint as wall finish

Similarly significant difference in the level of PM<sub>4</sub> in indoor air was found between the residential buildings used luppum with paint as wall finish and residential buildings used whitewash with paint as wall finish

**Table 4.83. Mean comparison and significant probabilities between Finishing material with respect to PM<sub>2.5</sub>**

S.no	Finishing material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	0.10	1-2	0.06	2.66**	0.00
2.	2	0.16	1-3	0.01	0.50	0.61
3.	3	0.11	1-4	0	0.02	0.98
4.	4	0.10	2-3	0.05	1.74	0.08
			2-4	0.06	2.51*	0.01
			3-4	0.01	0.49	0.61

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

**\*Finishing material:** 1.Cement plastering, Luppum, Whitewash. 2. Cement plastering, Luppum, paint 3. Cement plastering, whitewash, distemper. 4. Cement plastering, whitewash, paint.

Significant difference in the level of PM<sub>2.5</sub> in indoor air was found between the residential buildings used luppum with whitewash as wall finish and the buildings used Luppum with paint as wall finish

Similarly significant difference in the level of PM<sub>2.5</sub> in indoor air was found between the residential buildings used luppum with paint as wall finish and residential buildings used whitewash with paint as wall finish

**Table 4.84. Mean comparison and significant probabilities between Finishing material with respect to Relative Humidity**

S.no	Finishing material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	42.59	1-2	3.86	3.73**	0.00
2.	2	46.45	1-3	0.29	0.23	0.81
3.	3	42.30	1-4	0.69	0.63	0.52
4.	4	41.90	2-3	4.15	3.39**	0.00
			2-4	4.55	4.12**	0.00
			3-4	0.4	0.31	0.75

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

**\*Finishing material:** 1.Cement plastering, Luppum, Whitewash. 2. Cement plastering, Luppum, paint 3. Cement plastering, whitewash, distemper. 4. Cement plastering, whitewash, paint.

Significant difference in the level of RH in indoor air was found between the residential buildings used luppum with whitewash as wall finish and the buildings used Luppum with paint as wall finish

Similarly Highly significant difference in the level of RH in indoor air was found between the residential buildings used, luppum with paint as wall finish and residential buildings used whitewash with distemper as wall finish.

Similarly significant difference in the level of RH in indoor air was found between the residential buildings used luppum with paint as wall finish and residential buildings used whitewash with paint as wall finish

**Table 4.85. Mean comparison and significant probabilities between Finishing material with respect to Temperature**

S.no	Finishing material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	29.62	1-2	0.72	2.56*	0.01
2.	2	28.90	1-3	1.08	3.24**	0.00
3.	3	28.54	1-4	0.12	0.39	0.69
4.	4	29.74	2-3	0.36	1.07	0.28
			2-4	0.84	2.78**	0.00
			3-4	1.2	3.42**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\***Finishing material:** 1.Cement plastering, Luppum, Whitewash. 2. Cement plastering, Luppum, paint  
3. Cement plastering, whitewash, distemper. 4. Cement plastering, whitewash, paint.

Significant difference in the level of temperature in indoor air was found between the residential buildings used luppum with Whitewash as wall finish and the buildings used luppum with paint as wall finish

Significant difference was found in the level of temperature in indoor air between the houses used luppum with white wash as wall finish and houses used whitewash with distemper as wall finish.

Significant difference was found in the level of temperature in indoor air between the houses used luppum with paint as wall finish and houses used whitewash with paint as wall finish

Significant difference in the level of temperature in indoor air was found between the residential buildings used whitewash with distemper as wall finish and residential buildings used whitewash with paint as wall finish

**Table 4.86. Mean comparison and significant probabilities between Finishing material with respect to Dew point**

S.no	Finishing material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	1	15.68	1-2	-0.49	1.72	0.08
2.	2	16.17	1-3	0.65	1.95	0.05
3.	3	15.03	1-4	0.47	1.56	0.12
4.	4	15.21	2-3	1.14	3.41**	0.00
			2-4	0.96	3.18**	0.00
			3-4	-0.18	0.51	0.60

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\***Finishing material:** 1.Cement plastering, Luppum, Whitewash. 2. Cement plastering, Luppum, paint 3. Cement plastering, whitewash, distemper. 4. Cement plastering, whitewash, paint.

Highly significant difference in the level of Dew point in indoor air was found between houses used luppum with paint as wall finish and houses used whitewash with distemper as wall finish.

Significant difference was found in the level of Dew point in indoor air between the houses used luppum with paint as wall finish and houses used whitewash with paint as wall finish

The finishing material used on the walls of the residential buildings was found to be affecting the concentration levels of air pollutants such as CO<sub>2</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity, Temperature and Dew point in indoor air. Wall finished with luppum finish and paint were found to be contributing for relatively high level of CO<sub>2</sub>, and VOC in indoor air. There was huge variations in the levels of VOC in interiors between the walls finished with luppum and paint and the walls finished with other finishes such as luppum and white wash and distemper and white wash with paint.

Wall finished with white wash and distemper contributed for relatively high level of PM<sub>4</sub> and walls finished with luppum and paint contributed for high indoor temperature.

According to the study there exists a relation between finishing material used for walls and indoor air quality.

Hence, the null hypothesis was rejected.

H<sub>0</sub> 3.3 There exists no relation between floor material and indoor air quality

Significant correlation existed between floor material and Dew point (r =0.37)  
(Appendix-B, Table-1)

**Table 4.87. Analysis of variance in indoor air quality parameters with regard to Flooring material**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Floor material	4	457493.3	114373.3	1.65	0.16
	Error	85	5863773	68985.57	–	–
	Total	89	6321266	–	–	–
VOC	Floor material	4	337.4527	84.36318	0.18	0.94
	Error	85	39390.15	463.4136	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Floor material	4	0.753266	0.188317	1.96	0.10
	Error	85	8.166662	0.096078	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Floor material	4	0.002644	0.000661	0.80	0.52
	Error	85	0.069916	0.000823	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Floor material	4	0.16141	0.040353	5.32**	0.00
	Error	85	0.644289	0.00758	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Floor material	4	61.34202	15.33551	0.86	0.48
	Error	85	1505.924	17.71675	–	–
	Total	89	1567.266	–	–	–
Temperature	Floor material	4	16.14737	4.036842	3.56**	0.00
	Error	85	96.29872	1.132926	–	–
	Total	89	112.4461	–	–	–
Dew point	Floor material	4	22.05497	5.513742	5.30**	0.00
	Error	85	88.39028	1.039886	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant variation was found in the level of PM<sub>2.5</sub> Temperature and Dew point in indoors with reference to the variation in the use of flooring material.

**Table 4.88. Mean comparison and significant probabilities between Flooring material with respect to PM2.5**

Flooring material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1	0.09	1-2	0	0.11	0.90
2	0.09	1-3	0.01	0.25	0.79
3	0.10	1-4	0.13	4.06**	0.00
4	0.22	1-5	0.04	1.41	0.15
5	0.13	2-3	0.01	0.33	0.73
		2-4	0.13	3.70**	0.00
		2-5	0.04	1.32	0.18
		3-4	0.12	3.93**	0.00
		3-5	0.03	1.20	0.23
		4-5	0.09	2.852**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\*Flooring material: 1.Shabaad stone, 2.Mosaic.3.Marble, 4.Granite, 5.Tiles

According to multiple comparison test highly significant difference in the level of PM<sub>2.5</sub> in indoor air was found between the houses used Shabaad stone and granite for flooring; between the houses used mosaic and granite for flooring; between the houses used marble and granite for flooring; between the houses used granite and tiles for flooring;

**Table 4.89. Mean comparison and significant probabilities between Flooring material with respect to temperature**

Flooring material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1	29.18	1-2	0.31	0.79	0.42
2	29.49	1-3	0.51	1.59	0.11
3	29.69	1-4	0.88	2.28*	0.02
4	28.30	1-5	0.05	0.14	0.88
5	29.23	2-3	0.2	0.53	0.59
		2-4	1.19	2.72**	0.00
		2-5	0.26	0.66	0.50
		3-4	1.39	3.68**	0.00
		3-5	0.46	1.43	0.15
		4-5	0.93	2.40*	0.01

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\*Flooring material: 1.Shabaad stone, 2.Mosaic.3.Marble, 4.Granite, 5.Tiles.

Highly significant and significant difference in indoor temperature level was found between the houses that used shahbad stones and granite as flooring material; marble and granite as flooring material and granite and tiles as flooring material.

**Table 4.90. Mean comparison and significant probabilities between Flooring material with respect to Dew point**

Flooring material	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1	0.09	1-2	0	0.11	0.90
2	0.09	1-3	0.01	0.25	0.79
3	0.10	1-4	0.13	4.06**	0.00
4	0.22	1-5	0.04	1.41	0.15
5	0.13	2-3	0.01	0.33	0.73
		2-4	0.13	3.70**	0.00
		2-5	0.04	1.32	0.18
		3-4	0.12	3.93**	0.00
		3-5	0.03	1.20	0.23
		4-5	0.09	2.85**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

\*Flooring material: 1.Shabbaad stone, 2.Mosiac.3.Marble, 4.Granite, 5.Tiles

Highly significant difference in indoor dew point level was found between the houses that used shahbad stones and granite as flooring material; Mosiac and granite as flooring material ; Marble and granite as flooring material and Granite and Tiles as flooring material.

According to the results of the present research variation in the levels of indoors PM<sub>2.5</sub>, Temperature and Dew point was found according to the flooring material. The houses used granite as flooring material were found to be with relatively high level of PM<sub>2.5</sub> in indoor air. The houses with granite flooring were found significantly different from the houses used shahbad stone, mosaic, marble, and tiles as floor material in the level of PM<sub>2.5</sub> in indoor air.

The houses used granite as flooring material were found to be with relatively low indoor air temperature and differed significantly with the houses used flooring material such as shahbad stone, mosaic, marble, and tiles in the level of indoor temperature. The concentration of PM<sub>2.5</sub> was found to be relatively more in the houses used granite for flooring. The flooring material contributed for accumulation of pollutants in indoor air.

Hence, the null hypothesis was partially rejected.

H<sub>0</sub>3.4 There exists no relation between ceiling type and indoor air quality

**Table 4.91. Analysis of variance in indoor air quality parameters with regard to Ceiling type**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Ceiling material	1	159713.7	159713.7	2.28	0.13
	Error	88	6161553	70017.64	–	–
	Total	89	6321266	–	–	–
VOC	Ceiling material	1	258.0414	258.0414	0.57	0.45
	Error	88	39469.56	448.5178	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Ceiling material	1	0.00064	0.00064	0.00	0.93
	Error	88	8.919289	0.101356	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Ceiling material	1	0.001661	0.001661	2.06	0.15
	Error	88	0.070899	0.000806	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Ceiling material	1	0.003956	0.003956	0.43	0.51
	Error	88	0.801743	0.009111	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Ceiling material	1	1.839457	1.839457	0.10	0.74
	Error	88	1565.427	17.78894	–	–
	Total	89	1567.266	–	–	–
Temperature	No. of rooms	3	5.925209	1.97507	1.59	0.19
	Error	86	106.5209	1.238615	–	–
	Total	89	112.4461	–	–	–
Dew point	Ceiling material	1	2.956943	2.956943	2.42	0.12
	Error	88	107.4883	1.221458	–	–
	Total	89	110.4452	–	–	–

p < 0.01 significant at 1 percent \*\* p < 0.05 significant at 5 percent\*

No significant variation existed in the levels of indoor air quality parameters between the houses with RCC ceiling and RCC ceiling treated with false ceiling.

The type of ceiling had not shown any impact on indoor air pollution

Hence, the null hypothesis was accepted

#### 4.2.4 Relation between household maintenance practices and indoor air quality

Household maintenance practices were studied in terms of (i) extent of presence of dust in the house (ii) frequency of household cleaning (iii) feeling of congestedness (iv) extent of use of cleaning reagents

H<sub>0</sub> 4.1 There exists no relation between extent of presence of dust in the house and indoor air quality

Significant correlation exists between extent of presence of dust in the house and PM<sub>4</sub> parameters (r=0.39) (Appendix-B, Table-1)

**Table 4.92. Analysis of variance in indoor air quality parameters with regard to Extent of presence of dust in the house**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Extend of Presence of dust in the house	2	47406.54	23703.27	0.32	0.72
	Error	87	6273860	72113.33	–	–
	Total	89	6321266	–	–	–
VOC	Extend of Presence of dust in the house	2	1509.593	754.7963	1.71	0.18
	Error	87	38218.01	439.2875	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Extend of Presence of dust in the house	2	0.019248	0.009624	0.09	0.91
	Error	87	8.900681	0.102307	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Extend of Presence of dust in the house	2	0.006349	0.003174	4.17*	0.01
	Error	87	0.066211	0.000761	–	–
	Total	89	0.07256	–	–	–
PM <sub>25</sub>	Extend of Presence of dust in the house	2	0.129744	0.064872	8.34**	0.00
	Error	87	0.675955	0.00777	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Extend of Presence of dust in the house	2	208.9658	104.4829	6.69**	0.00
	Error	87	1358.3	15.61265	–	–
	Total	89	1567.266	–	–	–
Temperature	Extend of Presence of dust in the house	2	1.002675	0.501337	0.39	0.67
	Error	87	111.4434	1.280959	–	–
	Total	89	112.4461	–	–	–
Dew point	Extend of Presence of dust in the house	2	24.70821	12.35411	12.53**	0.00
	Error	87	85.73704	0.985483	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant variation in the level of PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity, and dew point was found in residential with reference to variation according to the extent of presence of dust in the house.

**Table 4.93. Mean comparison and significant probabilities between Extent of presence of dust in the house with respect to PM<sub>4</sub>**

S.no	Extend of Presence of dust	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.12	1 - 3	0.02	1.49	0.138
2.	Medium	0.10	1 - 2	0.02	2.87**	0.00
3.	Low	0.10	2 - 3	0	0.14	0.88

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference was found between houses with high and medium extent of presence of dust on PM<sub>4</sub> levels in indoor air.

**Table 4.94. Mean comparison and significant probabilities between Extent of presence of dust in the house with respect to PM<sub>2.5</sub>**

S.no	Extend of Presence of dust	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.13	1 - 3	0.03	3.02**	0.00
2.	Medium	0.26	1 - 2	0.104	1.12	0.26
3.	Low	0.10	2 - 3	0.16	4.04**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference was found between houses with high and low ; low and medium extent of presence of dust on PM<sub>2.5</sub> levels in indoor air.

**Table 4.95. Mean comparison and significant probabilities between Extent of presence of dust in the house with respect to Relative Humidity**

S.no	Extend of Presence of dust	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	41.50	1 - 3	2.17	3.62**	0.00
2.	Medium	48.24	1 - 2	6.74	2.07*	0.04
3.	Low	43.67	2 - 3	4.57	2.71**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant difference in Relative Humidity levels in indoor air was found between the houses with high and low extent of dust in houses; high and medium extent of presence of dust and medium and low extent of dust in the residential interiors

**Table 4.96. Mean comparison and significant probabilities between Extent of presence of dust in the house with respect to Dew point**

S.no	Extend of Presence of dust	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	15.00	1 - 3	0.62	5.00**	0.00
2.	Medium	17.34	1 - 2	2.34	2.34*	0.02
3.	Low	15.62	2 - 3	1.72	4.06**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly significant difference in Dew point level in indoors was found between houses with high and low; medium and low extent of presence of dust in the house. Significant difference in Dew point level in indoors was found between houses with high and medium extent of dust in the house.

The extent of presence of presence of dust was found to be a variable that contributes to the relatively higher levels of PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point in indoor in residential buildings. The houses with more dust accumulation were found to have higher level of PM<sub>4</sub> in indoors. The houses with medium level of dust were found to have more of PM<sub>2.5</sub> particles and higher level of humidity and dew point. According to the present research presence researcher presence of dust in the house contributed towards indoor air pollution.

Hence, the null hypotheses was partially rejected.

H<sub>0</sub>4.2 There exists no relation between frequency of household cleaning and indoor air quality

Significant correlation exists between frequency of household cleaning and CO<sub>2</sub> (r = 0.46) (Appendix-B, Table-1).

**Table 4.97. Analysis of variance in indoor air quality parameters with regard to Frequency of household cleaning**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Cleaning practices	2	470706.4	235353.2	3.49*	0.03
	Error	87	5850560	67247.82	–	–
	Total	89	6321266	–	–	–
VOC	Cleaning practices	2	978.6938	489.3469	1.09	0.33
	Error	87	38748.91	445.3898	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Cleaning practices	2	0.763294	0.381647	4.07*	0.02
	Error	87	8.156635	0.093754	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Cleaning practices	2	0.000717	0.000358	0.43	0.64
	Error	87	0.071843	0.000826	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Cleaning practices	2	0.104816	0.052408	6.50**	0.00
	Error	87	0.700883	0.008056	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Cleaning practices	2	71.36502	35.68251	2.07	0.13
	Error	87	1495.901	17.19427	–	–
	Total	89	1567.266	–	–	–
Temperature	Cleaning practices	2	10.48941	5.244705	4.47*	0.01
	Error	87	101.9567	1.171916	–	–
	Total	89	112.4461	–	–	–
Dew point	Cleaning practices	2	0.507026	0.253513	0.20	0.81
	Error	87	109.9382	1.263658	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant variation was found in the level of CO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, and temperature in indoors of residential buildings according to the frequency of cleaning.

**Table 4.98. Mean comparison and significant probabilities between Frequency of household cleaning with respect to CO<sub>2</sub>**

S.no	Frequency of household cleaning	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	1242.52	1 - 3	6.12	2.21*	0.02
2.	Medium	1450.67	1 - 2	208.15	0.09	0.92
3.	Low	1236.40	2 - 3	214.24	2.60*	0.01

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference was found between houses with high and low; low and medium frequency of household cleaning with regard to CO<sub>2</sub> in indoor air.

**Table 4.99. Mean comparison and significant probabilities between Frequency of household cleaning with respect to PM<sub>10</sub>**

S.no	Frequency of household cleaning	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.12	1 - 3	0	2.46*	0.01
2.	Medium	0.39	1 - 2	0.27	0.03	0.97
3.	Low	0.12	2 - 3	0.27	2.77**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significance difference in the level of PM<sub>10</sub> in indoor air was found between houses with low and medium frequency of household cleaning. Significant difference in the level of PM<sub>10</sub> in indoor air was found between the houses with high and low frequency of household cleaning.

**Table 4.100. Mean comparison and significant probabilities between Frequency of household cleaning with respect PM<sub>2.5</sub>**

S.no	Frequency of household cleaning	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.09	1 - 3	0.02	3.42**	0.00
2.	Medium	0.21	1 - 2	0.12	0.79	0.43
3.	Low	0.11	2 - 3	0.1	3.2648**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant difference was found between houses with high and low frequency of household cleaning, low and medium frequency of household cleaning with regard to PM<sub>2,5</sub> levels in indoor air.

**Table 4.101. Mean comparison and significant probabilities between Frequency of household cleaning with respect to Temperature**

S.no	Frequency of household cleaning	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	29.65	1 - 3	0.39	2.98**	0.00
2.	Medium	28.48	1 - 2	1.17	1.40	0.16
3.	Low	29.26	2 - 3	0.78	2.27*	0.02

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference was found between houses with low and medium frequency of household cleaning similarly highly significant difference was found between houses

with high and low frequency of household cleaning with regard to temperature levels in indoor air. The household cleaning practices followed by the building residents was found to be affecting the levels of CO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, and Temperature in indoor of the building. The frequency of cleaning whether regularly or frequently, or less frequently showed effect on indoor air pollutants like CO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub> and temperature. Hence, the null hypothesis was partially rejected.

H<sub>0</sub>4.3 There exists no relation between feeling of congestedness and indoor air quality

Significant correlation exists between frequency of household cleaning and CO<sub>2</sub> and dew point (r = 0.45) (r = 0.38) (Appendix-B, Table-1)

**Table 4.102. Analyses of variance in indoor air quality parameters with regard to Feeling of congestedness**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Feeling of Congestedness	2	432164.8	216082.4	3.19*	0.04
	Error	87	5889102	67690.82	–	–
	Total	89	6321266	–	–	–
VOC	Feeling of Congestedness	2	2854.44	1427.22	3.36*	0.03
	Error	87	36873.17	423.8295	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Feeling of Congestedness	2	0.02851	0.014255	0.13	0.87
	Error	87	8.891419	0.1022	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Feeling of Congestedness	2	0.017677	0.008839	14.01**	0.00
	Error	87	0.054883	0.000631	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Feeling of Congestedness	2	0.02284	0.01142	1.26	0.28
	Error	87	0.782859	0.008998	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Feeling of Congestedness	2	144.2686	72.1343	4.41*	0.01
	Error	87	1422.997	16.35629	–	–
	Total	89	1567.266	–	–	–
Temperature	Feeling of Congestedness	2	10.7754	5.387698	4.61*	0.01
	Error	87	101.6707	1.168629	–	–
	Total	89	112.4461	–	–	–
Dew point	Feeling of Congestedness	2	28.76311	14.38156	15.31**	0.00
	Error	87	81.68214	0.938875	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant and highly significant variation were found in the level of CO<sub>2</sub>, VOC, PM<sub>10</sub>, Relative Humidity, Temperature and Dew point in indoor air of residential building with regard to feeling of congestedness.

**Table 4.103. Mean comparison and significant probabilities between Feeling of congestedness with respect to CO<sub>2</sub>**

S.no	Feeling of Congestedness	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	1111.92	1 - 3	160.62	2.50*	0.01
2.	Medium	1364.18	1 - 2	252.26	1.96*	0.05
3.	Low	1272.54	2 - 3	91.64	1.22	0.22

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference was found between houses with high and low feeling of congestedness, high and medium feeling of congestedness on level of CO<sub>2</sub> in indoor air.

**Table 4.104. Mean comparison and significant probabilities between Feeling of congestedness with respect to VOC**

S.no	Feeling of Congestedness	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	3.50	1 - 3	0.24	1.92*	0.05
2.	Medium	18.81	1 - 2	15.31	0.03	0.97
3.	Low	3.74	2 - 3	15.34	2.54*	0.01

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference was found between houses with high and low feeling of congestedness, low and medium feeling of congestedness on level of VOCs in indoor air.

**Table 4.105. Mean comparison and significant probabilities between Feeling of congestedness with respect to PM<sub>4</sub>**

S.no	Feeling of Congestedness	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.14	1 - 3	0.04	4.42**	0.00
2.	Medium	0.10	1 - 2	0.04	5.14**	0.00
3.	Low	0.10	2 - 3	0	0.31	0.75

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly significant difference was found between houses with high and low feeling of congestedness, high and medium feeling of congestedness on level of PM<sub>4</sub> in indoor air.

**Table 4.106. Mean comparison and significant probabilities between Feeling of congestedness with respect to RH**

S.no	Feeling of Congestedness	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	42.31	1 - 3	0.81	2.55*	0.01
2.	Medium	46.31	1 - 2	4	0.63	0.52
3.	Low	43.12	2 - 3	3.19	2.744**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant difference was found between houses with high and low feeling of congestedness on indoor Relative Humidity. Highly significant difference was found between houses with low and medium feeling of congestedness on level of Relative Humidity.

**Table 4.107. Mean comparison and significant probabilities between Feeling of congestedness with respect to Temperature**

S.no	Feeling of Congestedness	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	28.70	1 - 3	0.5	2.94**	0.00
2.	Medium	29.93	1 - 2	1.23	1.46	0.14
3.	Low	29.20	2 - 3	0.73	2.36*	0.02

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant difference was found between houses with low and medium feeling of congestedness, on indoor temperature. Highly significant difference was found between houses high and medium feeling of congestedness on level of temperature in indoor air.

**Table 4.108. Mean comparison and significant probabilities between Feeling of congestedness with respect to Dew point**

S.no	Feeling of Congestedness	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	14.79	1 - 3	0.7	5.24**	0.00
2.	Medium	16.76	1 - 2	1.97	2.28*	0.02
3.	Low	15.49	2 - 3	1.27	4.55**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Significant difference was found between the houses with high and medium feeling of congestedness on dew point in indoor air. Similarly, highly significant difference was found between the houses with high and low, low and medium feeling of congestedness on level of dew point in indoor air.

Feeling of congestedness was found to be affecting the concentration of CO<sub>2</sub>, VOCs, PM<sub>4</sub>, Relative Humidity, Temperature and Dew point in indoor air of residential interiors. Hence, the null hypothesis was partially rejected.

H<sub>0</sub>4.4 There exists no relation between extent of use of cleaning reagent and indoor air quality

No significant correlation exists between extent of use of cleaning reagent and IAQ parameters.

**Table 4.109. Analysis of variance in indoor air quality parameters with regard to Extent of use of cleaning reagent**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Cleaning reagent for Household maintenance Practices	2	11869.4	5934.698	0.08	0.92
	Error	87	6309397	72521.8	–	–
	Total	89	6321266	–	–	–
VOC	Cleaning reagent for Household maintenance Practices	2	495.6575	247.8287	0.54	0.57
	Error	87	39231.95	450.9419	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Cleaning reagent for Household maintenance Practices	2	0.696462	0.348231	3.68*	0.029
	Error	87	8.223467	0.094523	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Cleaning reagent for Household maintenance Practices	2	0.012415	0.006208	8.97**	0.00
	Error	87	0.060145	0.000691	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Cleaning reagent for Household maintenance Practices	2	0.050496	0.025248	2.90*	0.05
	Error	87	0.755203	0.00868	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Cleaning reagent for Household maintenance Practices	2	177.3654	88.68271	5.55**	0.00
	Error	87	1389.901	15.97587	–	–
	Total	89	1567.266	–	–	–
Temperature	Cleaning reagent for Household maintenance Practices	2	3.221505	1.610752	1.28	0.28
	Error	87	109.2246	1.255455	–	–
	Total	89	112.4461	–	–	–
Dew point	Cleaning reagent for Household maintenance Practices	2	13.22026	6.610129	5.91**	0.00
	Error	87	97.22499	1.117529	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant variation was found in the level of PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub> Relative Humidity and Dew point according to the extent of use of cleaning reagents in indoors air was found.

**Table 4.110. Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to PM<sub>10</sub>**

S.no	Extent of use of cleaning reagent	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.10	1 - 3	0.03	2.23*	0.02
2.	Medium	0.38	1 - 2	0.28	0.27	0.78
3.	Low	0.13	2 - 3	0.25	2.62*	0.01

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference was found between houses with high and low ; low and medium extent of use of frequency of cleaning reagent on level of PM<sub>10</sub> in indoor air.

**Table 4.111. Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to PM<sub>4</sub>**

S.no	Extent of use of cleaning reagent	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.09	1 - 3	0.02	1.00	0.31
2.	Medium	0.08	1 - 2	0.01	2.46*	0.01
3.	Low	0.11	2 - 3	0.03	3.78**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference was found between houses with high and medium extent of use of frequency of cleaning reagent and between the houses with low and medium on level of extent of use of frequency of cleaning reagent on the level of PM<sub>4</sub> in indoor air.

**Table 4.112. Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to PM<sub>2.5</sub>**

S.no	Extent of use of cleaning reagent	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.08	1 - 3	0.04	2.40*	0.01
2.	Medium	0.17	1 - 2	0.09	1.49	0.13
3.	Low	0.12	2 - 3	0.05	1.64	0.10

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant difference was found between houses with high and low , extent of use of cleaning reagent on level of PM<sub>2.5</sub> in indoor air

**Table 4.113. Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to Relative Humidity**

S.no	Extent of use of cleaning reagent	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	41.68	1 - 3	1.6	3.16**	0.00
2.	Medium	46.85	1 - 2	5.17	1.27	0.20
3.	Low	43.28	2 - 3	3.57	2.84**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly Significant difference was found between houses with high and low , and low and medium extent of use of cleaning reagent on level of RH in indoor air.

**Table 4.114. Mean comparison and significant probabilities between Extent of use of cleaning reagent with respect to Dew point**

S.no	Extent of use of cleaning reagent	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	15.32	1 - 3	-0.16	-2.90**	0.00
2.	Medium	16.57	1 - 2	-1.25	-0.49	0.62
3.	Low	15.48	2 - 3	-1.09	3.28**	0.00

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

Highly Significant difference was found between houses with high and low , and low and medium extent of use of cleaning reagent on level of RH and dew point I residential interiors.

Household maintenance practices like extent of presence of dust in the house, frequency of household cleaning, feeling of congestedness, extent of use of cleaning reagents for household maintenance were found to be significantly contributing to accumulation of pollutants like CO<sub>2</sub>, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity , Temperature and Dew point.

Hence, the null hypothesis is partially rejected

#### **4.2.5 Relation between extent of use of electrical gadgets and indoor air quality parameters**

H<sub>05</sub> There exists no relation between extent of use of electrical gadgets and indoor air quality

No significant correlation exists between extent of use of electrical gadgets and IAQ parameters.

**Table 4.115. Analysis of variance in indoor air quality parameters with regard to  
Extent of use of electrical gadgets**

IAQ Parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Extent of use of electrical gadgets	2	249916.9845	124958.4923	1.79	0.17
	Error	87	6071349.386	69785.625	-	-
	Total	89	6321266.371	-	-	-
VOC	Extent of use of electrical gadgets	2	994.4241667	497.2120833	1.12	0.33
	Error	87	38733.18156	445.20898	-	-
	Total	89	39727.60573	-	-	-
PM <sub>10</sub>	Extent of use of electrical gadgets	2	0.05773437	0.02886718	0.28	0.75
	Error	87	8.86219452	0.10186430	-	-
	Total	89	8.91992889	-	-	-
PM <sub>4</sub>	Extent of use of electrical gadgets	2	0.00346825	0.00173413	2.18	0.11
	Error	87	0.06909175	0.00079416	-	-
	Total	89	0.07256000	-	-	-
PM <sub>2.5</sub>	Extent of use of electrical gadgets	2	0.03865357	0.01932679	2.19	0.11
	Error	87	0.76704532	0.00881661	-	-
	Total	89	0.80569889	-	-	-
Relative Humidity	Extent of use of electrical gadgets	2	71.36502	35.68251	2.90	0.13
	Error	87	1495.901	17.19427	-	-
	Total	89	1567.266089	-	-	-
Temperature	Extent of use of electrical gadgets	2	1.00267524	0.501337	0.39	0.67
	Error	87	111.4434	1.280959	-	-
	Total	89	112.4460889	-	-	-
Dew point	Extent of use of electrical gadgets	2	0.507026	0.253513	0.20	0.81
	Error	87	109.9382	1.263658	-	-
	Total	89	110.4452	-	-	-

$p < \infty = 0.01$  significant at 1 percent \*\*  $p < \infty = 0.05$  significant at 5 percent\*

No significant variation was found in the level of CO<sub>2</sub>, VOC, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative humidity, Temperature and Dew point in indoor air of the residential households with reference to the extent of use of electrical gadgets.

Hence, the null hypothesis was accepted.

#### **4.2.6 Relation between extent of use of personal care products and indoor air quality parameters**

H<sub>06</sub> There exist no relation between extent of use of personal care products

No significant correlation exists between extent of use of personal care products and IAQ parameters.

**Table 4.116. Analyses of variance in indoor air quality parameters with regard to Extent of use of personal care products**

IAQ parameter	Source of variation	df	Sum of square	Mean sum of squares	f-value	Level of significance
CO <sub>2</sub>	Use of Personal care product	2	229987.6	114993.8	1.64	0.19945
	Error	87	6091279	70014.7	–	–
	Total	89	6321266	–	–	–
VOC	Use of Personal care product	2	237.7767	118.8884	0.26	0.77
	Error	87	39489.83	453.9061	–	–
	Total	89	39727.61	–	–	–
PM <sub>10</sub>	Use of Personal care product	2	0.102588	0.051294	0.50	0.60
	Error	87	8.817341	0.101349	–	–
	Total	89	8.919929	–	–	–
PM <sub>4</sub>	Use of Personal care product	2	0.006299	0.003149	4.13*	0.01
	Error	87	0.066261	0.000762	–	–
	Total	89	0.07256	–	–	–
PM <sub>2.5</sub>	Use of Personal care product	2	0.091072	0.045536	5.54**	0.00
	Error	87	0.714627	0.008214	–	–
	Total	89	0.805699	–	–	–
Relative Humidity	Use of Personal care product	2	38.61228	19.30614	1.09	0.33
	Error	87	1528.654	17.57073	–	–
	Total	89	1567.266	–	–	–
Temperature	Use of Personal care product	2	2.963956	1.481978	1.17	0.31
	Error	87	109.4821	1.258415	–	–
	Total	89	112.4461	–	–	–
Dew point	Use of Personal care product	2	1.981621	0.990811	0.79	0.45
	Error	87	108.4636	1.246708	–	–
	Total	89	110.4452	–	–	–

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Significant variation was found in the level of PM<sub>4</sub> and PM<sub>2.5</sub> in indoors, with regard to the extent of use of personal care products.

**Table 4.117. Mean comparison and significant probabilities between Extent of use of personal care products with respect to PM<sub>4</sub>**

S.no	extent of use of personal care products	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.10	1 - 3	0.01	1.52	0.13
2.	Medium	0.09	1 - 2	0.01	1.08	0.28
3.	Low	0.11	2 - 3	0.02	2.83**	0.00

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly Significant difference was found between houses with low and medium extent of use personal care products on level of PM<sub>4</sub> in indoor air.

**Table 4.118. Mean comparison and significant probabilities between Extent of use of personal care products with respect to PM<sub>2.5</sub>**

S.no	extent of use of personal care products	Mean score	Mean contrast	Mean difference	t- value	Level of significance
1.	High	0.18	1 - 3	0.06	3.27**	0.00
2.	Medium	0.07	1 - 2	0.11	2.42*	0.01
3.	Low	0.12	2 - 3	0.05	1.68	0.09

p < ∞ = 0.01 significant at 1 percent \*\* p < ∞ = 0.05 significant at 5 percent\*

Highly Significant difference was found between houses with high and low extent of use personal care products on level of PM<sub>2.5</sub>, whereas significant difference was found between houses with high and medium extent of use personal care products on level of PM<sub>2.5</sub> in indoor air.

Use of personal care products by the residents was found to have an impact on the level of PM<sub>4</sub>, and PM<sub>2.5</sub> in indoor air.

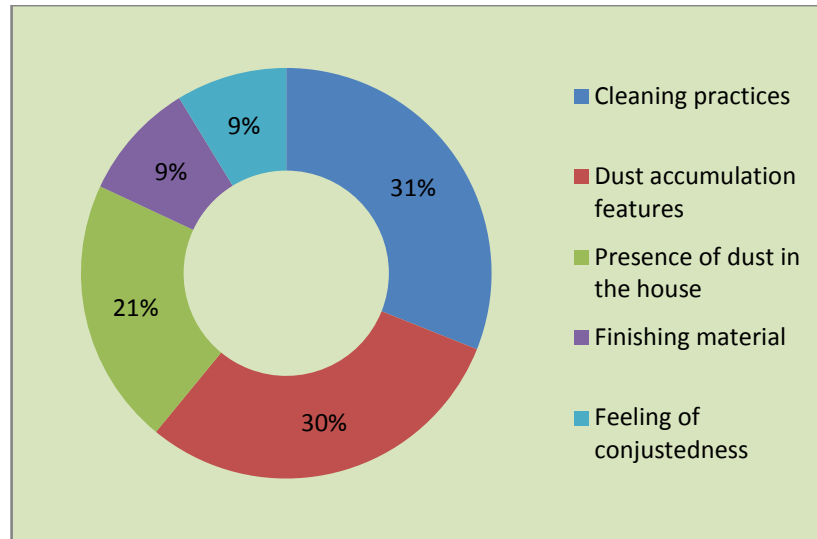
Hence, the null hypothesis was partially rejected.

#### **4.2.7 Difference in the influence exerted by variables on Indoor air quality**

Step wise regression analysis was computed to understand the influence of selected independent variables on the presence of indoor air quality parameters such as CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity, Temperature and Dew point in indoor air of residential households. From the step wise regression only the percentage contribution of variables of indoor air quality parameter was explained here. The details of the analysis are presented in Appendix C (Table 2 – 9)

#### 4.2.7.1 Influence of independent variable on level of CO<sub>2</sub> in residential households

H<sub>0</sub>7.1 There is no difference in the extent of influence exerted by selected variable on CO<sub>2</sub> level in indoor air



**Figure 4.9. Contribution of variables under study towards the level of CO<sub>2</sub> in residential households**

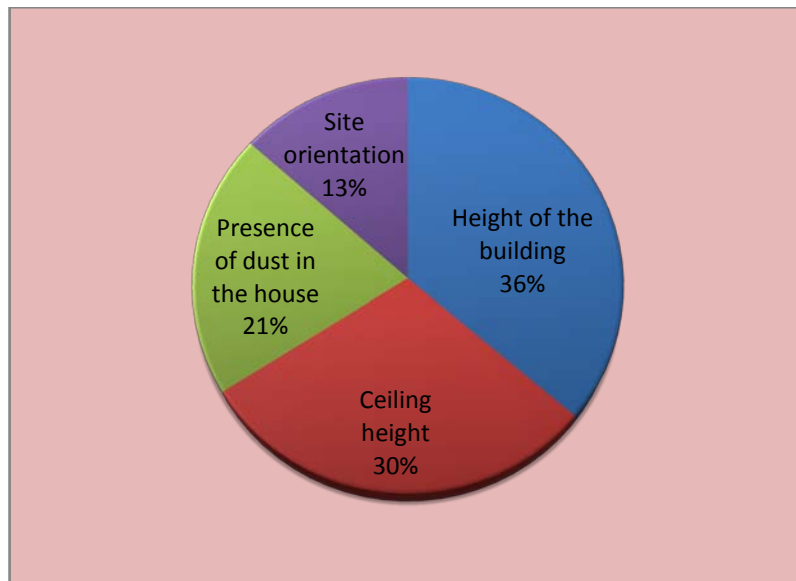
The contribution of cleaning practices for the presence of CO<sub>2</sub> in residential buildings was relatively more (31%) followed by dust accumulation features (30%) and presence of dust in the house (21%), finishing material for walls (9%) and feeling of congestedness (9%).

According to the results of the study there existed a difference in the influence exerted by study variables on the level of CO<sub>2</sub> in indoor air.

Hence, the null hypothesis was rejected.

#### 4.2.7.2 Influence of study variable on level of VOCs in residential households

H<sub>0</sub>7.2 There is no difference in the extent of influence exerted by selected variable on VOCs level in indoor air



**Figure 4.10. Contribution of variables under study towards the level of VOCs in residential households**

The contribution of height of the building towards the presence of VOCs in residential buildings was relatively high(36%) followed by ceiling height of the house (30%), presence of dust in the house(21%) and site orientation(13%).

According to the research there existed a difference in the extent of influence exerted by the study variables on the level of VOC in indoor air of residential buildings.

Hence the null hypothesis was rejected.

#### **4.2.7.3 Influence of study variable on level of PM<sub>10</sub> in residential households**

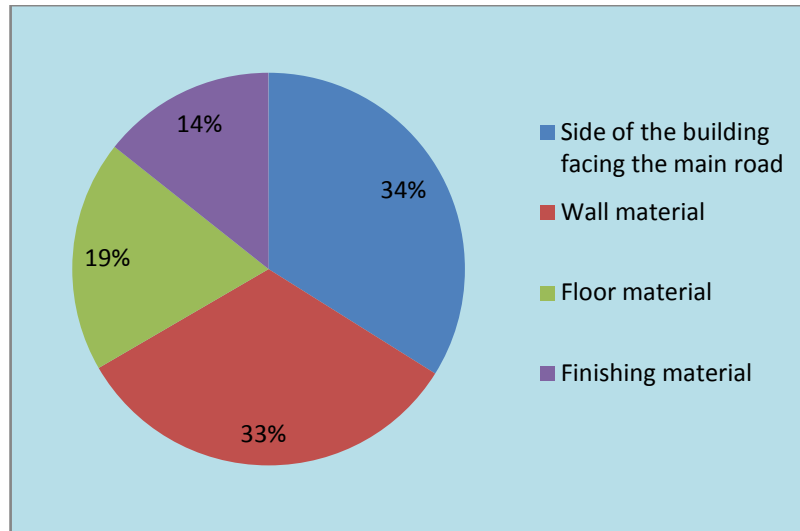
H<sub>0</sub>7.3 There is no difference in the extent of influence exerted by selected variable on PM<sub>10</sub> level in indoor air

With reference to the presence of PM<sub>10</sub> in indoor air, there was no difference in the extent of influence exerted by selected variable

Hence, the null hypothesis was accepted.

#### 4.2.7.4 Influence of study variable on level of PM<sub>4</sub> in residential households

H<sub>0</sub>7.4 There is no difference in the extent of influence exerted by selected variable on PM<sub>4</sub> level in indoor air



**Figure 4.11. Contribution of variables under study towards the level of PM<sub>4</sub> in residential households**

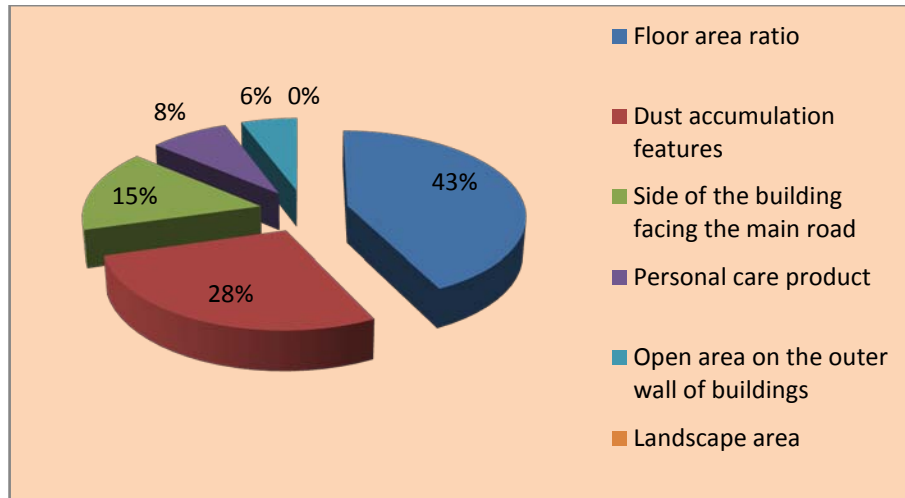
The contribution of side of the building towards the presence of PM<sub>4</sub> in indoor of residential buildings was more(34%) followed by wall material(33%) of the house. Floor materials contribution towards level of PM<sub>4</sub> in indoor air was 19 per cent and finishing material for walls contributed towards 14 per cent.

The results of the study revealed that there exist a difference in the extent of influence exerted by study variable on the level of PM<sub>4</sub> in indoor air.

Hence, the null hypothesis was rejected.

#### 4.2.7.5 Influence of study variable on level of PM<sub>2.5</sub> in residential households

H<sub>0</sub>7.5 There is no difference in the extent of influence exerted by selected variable on PM<sub>2.5</sub> level in indoor air



**Figure 4.12. Contribution of variables under study towards the level of PM<sub>2.5</sub> in residential households**

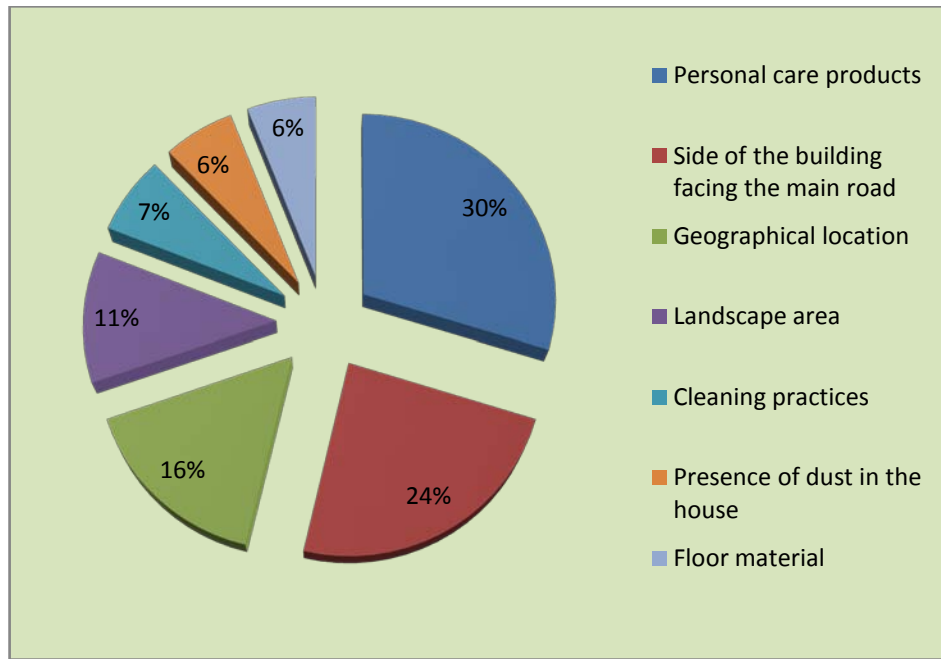
Floor area ratio(43%) followed by dust accumulation features( 28%) side of the building facing the main road (15%) , use of personal care products( 8%) , open area on the outer wall of building( 6%) contributed towards the presence of variations in the level of PM<sub>4</sub> in residential buildings. The landscape area had not shown any impact on the level of PM<sub>4</sub> in residential buildings.

According to the study there existed difference in the extent of influence exerted by selected variable on PM<sub>2.5</sub> level in indoor air

Hence, the null hypothesis was rejected

#### 4.2.7.6 Influence of study variable on level of Relative Humidity in residential households

H<sub>0</sub>7.6 There is no difference in the extent of influence exerted by selected variable on Relative Humidity level in indoor air



**Figure4.13 . Contribution of variables under study towards the level of Relative Humidity in residential households**

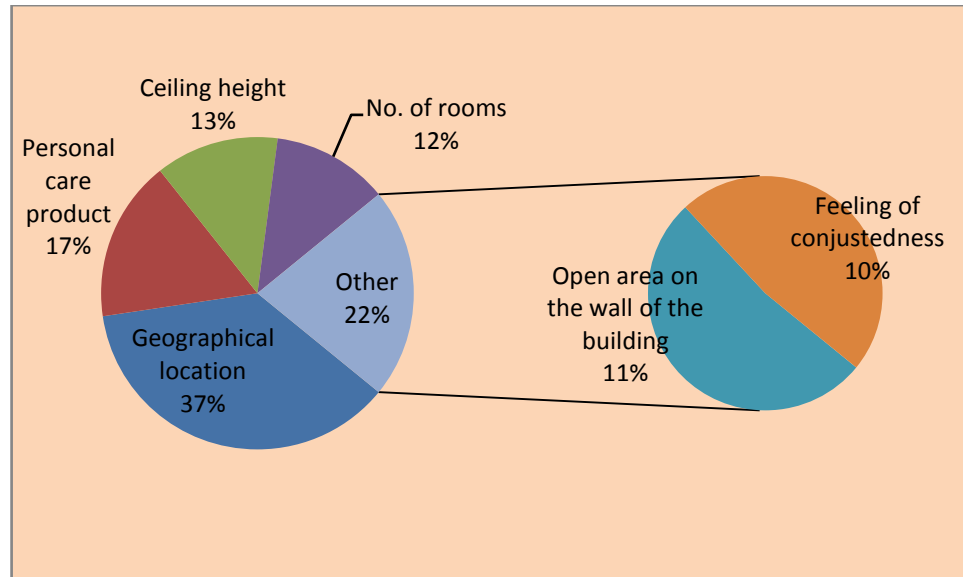
Highest contribution (30%) towards the presence of Relative Humidity in indoor air was from personal care products. The other variables contributed were side of the building facing the main road (24%), geographical location (16%), landscape area (11%), cleaning practices (7%), and floor material (6%).

According to the present investigation there existed difference in the extent of influence exerted by study variable on the level of Relative Humidity in indoor air.

Hence, the null hypothesis was rejected.

#### 4.2.7.7 Influence of study variable on level of Temperature in residential households

H<sub>0</sub>7.7 There is no difference in the extent of influence exerted by selected variable on temperature level in indoor air



**Figure 4.15. Contribution of variables under study towards the level of Temperature in residential households**

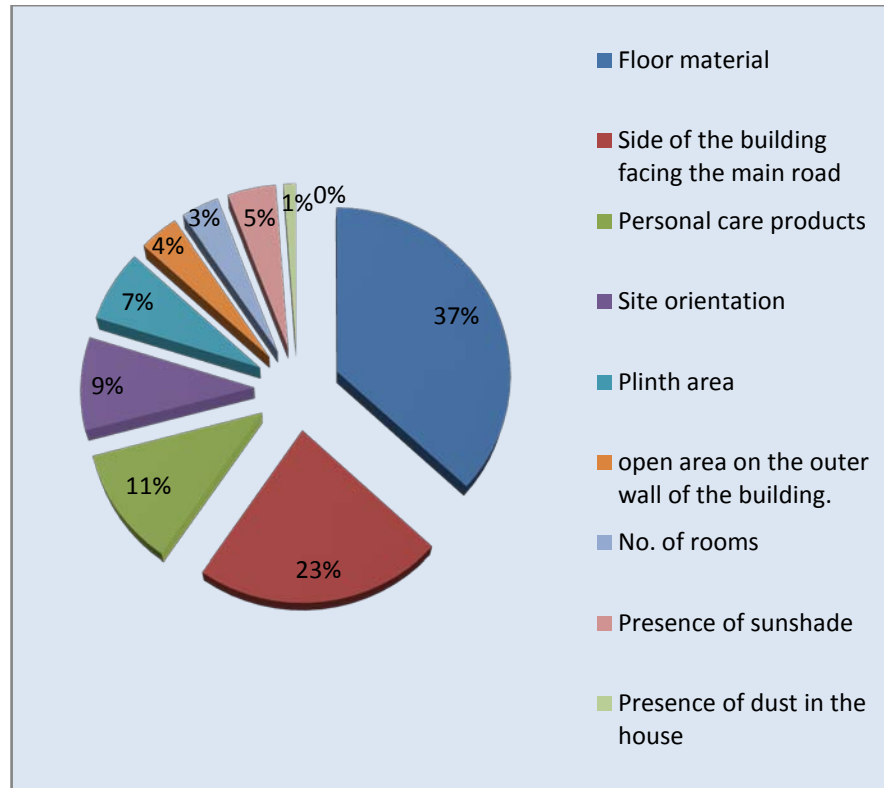
Highest contribution 37 per cent towards the presence of Temperature in indoor air was from geographical location. The other variables contributed were personal care products (17%), ceiling height (13%), number of rooms (12%), open area on the wall of the building facing the main road (11%), and feeling of congestedness(10%).

According to the study there existed difference in the extent of influence exerted by selected variable on indoor air temperature.

Hence, the null hypothesis was rejected

#### 4.2.7.8 Influence of study variable on level of Dew point in residential households

H<sub>0</sub>8. There is no difference in the extent of influence exerted by selected variable on dew point level in indoor air



**Figure 4.16. Contribution of variables under study towards the level of Dew point in residential households**

Highest contribution (37 %) towards the presence of Dew point in indoor air was from floor material. The other variables contributed were side of the building facing the main road (23%), personal care products (11%), site orientation (9%), plinth area (7%) open area on the outer wall of the building (4%), number of rooms (3%) presence of sunshade (5%) and presence of dust in the house (1%).

According to the study there existed difference in the extent of influence exerted by selected variable on Dew point level in indoor air

Hence, the null hypothesis was rejected

## Chapter V

# SUMMARY AND CONCLUSION

Indoor air quality can be defined as the absence of air contaminants which may impair the comfort or health of building occupants (Rousseau, 2003). In the present day the effects of indoor air quality as relate to human health has become much more of an important issue, hence, the study was planned with an aim to explore building location characteristics, design aspects, material and maintenance practices that affect the Indoor air quality of the residential buildings and contribute to the knowledge bank, so that it can be of assistance to architects and interior designers while designing residential interiors for promoting comfort and health.

Sample for research was drawn from five highly polluted zones of Hyderabad and Secunderabad. Indoor Air Quality (IAQ) was the Dependent variable and measured in terms of presence of (i) Carbon dioxide (ii) Volatile organic compounds (iii) PM<sub>10</sub> (iv) PM<sub>4</sub> (iv) PM<sub>2.5</sub> (v) Relative humidity (vi) Temperature and (vii) Dew point. Each of these parameters was considered as separate variable in the data analyses. The independent variables of the study were categorized under the six major heads viz., (i) Building location characteristics (ii) Building design features (iii) Construction material (iv) Household maintenance practices (v) Extent of use of electrical gadgets and (vi) Extent of use of personal care products..

### **Salient findings**

The mean number of family members was 5.9 with a standard deviation of 2.5. Slightly more than half of the houses included in the study were built ten years ago. Comparatively more number of houses was facing towards north, and least number of houses had east facing. Fairly more number of houses were on the same level with reference to the height of the main traffic road. For relatively more number of houses the front side of the building was facing the main road. The mean plot area, plinth area and floor area ratio were 1683.3 sq.ft., 1350.83 sq.ft and 0.80 sq.ft respectively. Nearly three fourth of the households had open area in the form of doors, windows, ventilators on the outer walls of the house between 42 and 110 sq.ft. The mean ceiling height was 10.02 ft. The extent of presence of dust accumulation features were relatively more in only 10 percent of

the households and moderate in 63.3 percent of the households. More number of the houses used the traditional brick, cement mortar, and cement plaster for wall construction and cement plastering with luppum and cement plastering with paint as wall finish. Marble and Shaabad stones were common flooring material. The type of the ceiling found was either RCC or false ceiling with RCC. About 70 per cent of the samples were found to have moderate dust. Relatively more number of the houses was found to have moderate feeling of congestedness in the houses. About 76.6 percent of the houses were found using of cleaning reagent regularly. Comparatively more households were found to have moderate use of electrical gadgets and use of personal care products.

### **Indoor Air Pollution**

The houses near to heavy traffic roads were found with inadequate ventilation due to closing of windows to prevent the entry of outdoor polluted air. This resulted in high concentration of CO<sub>2</sub> in indoors. The release of VOCs in indoor was mainly when the residents were using cleaning reagents and personal care products. Relatively more amount of VOCs were released in indoors where residents were using cosmetics, like body lotion, nail polish, perfumes, deodorants, lipsticks and so on.

According to the ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) the acceptable level of particulate matter in indoors is 3mg/m<sup>3</sup>. Majority of the households had PM<sub>10</sub> above 2.1 mg/m<sup>3</sup>, PM<sub>4</sub> levels between 1.3 – .3.1 mg/m<sup>3</sup> and PM<sub>2.5</sub> levels between 1.3 – .3.1 mg/m<sup>3</sup>. About 73.3 percent of the houses were found to have Relative Humidity levels more than the acceptable levels.

According to the ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) the acceptable level of indoor temperature for indoor environment is 20-27 °C. The mean indoor temperature in the households under study was found to be higher than the standard acceptable indoor temperature. Majority of the households (83.3%) had dew point levels between 14.5 – 16.72 % in indoor air.

### **Relation between building location characteristics and indoor air quality**

The building location characteristics selected for the study were found to be affecting the IAQ of residential buildings. CO<sub>2</sub> was found to be influenced by geographical

location of building site and site orientation. VOC was found to be influenced by only side of the building facing the main road. None of the building location characteristics were found influencing the level of PM<sub>10</sub> in indoor air of residential buildings. PM<sub>4</sub> was found to be influenced by geographical location of building site and side of the building facing the main road. PM<sub>2.5</sub> was found to be influenced by site orientation, height of the base of the building with reference to main traffic road, side of the building facing the main road. Relative Humidity was found to be influenced by geographical location of building site, site orientation, and side of the building facing the main road. Temperature was found to be influenced by geographical location of building site, and side of the building facing the main road. Dew point was found to be influenced by site orientation and side of the building facing the main road. Side of the building facing the main road was found to be a major factor that influence the IAQ. Height of the base of the building with reference to road in front of the house had not shown any impact on IAQ.

### **Relation between Building Design Parameters and indoor air quality**

An attempt was made in the present research to explore the relation between the selected building design parameters such as (i) plot area (ii) plinth area (iii) landscape area (iv) floor area ratio (v) open area on the wall of the building facing the main road (vi) open area on the outer wall of the building (vii) height of the building (viii) ceiling height (ix) number of rooms (x) extent of dust accumulation features and indoor air quality

**Plot area:** The size of the plot area was found influencing the level of CO<sub>2</sub>, PM<sub>4</sub>, PM<sub>2.5</sub> and Relative Humidity in the indoor air of residential building. Highly significant difference in the level of CO<sub>2</sub> in indoor air was found between the houses with large and small size plot area. As the area of the plot increased, the concentration of CO<sub>2</sub> in indoor air decreased.

Highly significant difference in the level of PM<sub>4</sub> in indoor air was found between the houses with large plot area and small plot area. Highly significant difference in the levels of PM<sub>2.5</sub> in indoors was found between the houses with large and small plot area; small and medium plot area. No difference in the level of PM<sub>2.5</sub> in indoor air was found between the houses with large and medium plot area. Highly significant difference in the

levels of Relative Humidity in indoors was found between the houses with large and small plot area , and between the houses with large and medium plot area.

**Plinth area:** Among the eight IAQ parameters selected for the study, significant variation according to the plinth area with regard to indoor air quality was found in the level of CO<sub>2</sub>, PM<sub>2.5</sub>, Relative Humidity and dew point. The level of CO<sub>2</sub> in indoors was found to be influenced by the size of the plinth area. As the size of the plinth area increased mean score of CO<sub>2</sub> decreased. The concentration of CO<sub>2</sub> decreased with an increase in plinth area of the house. The size of the plinth area showed impact on the level of PM<sub>2.5</sub>, Relative Humidity, and Dew point in indoor air of residential buildings. Level of Relative Humidity and Dew point decreased with increased plinth area.

**Landscape area:** No significant variation existed in the levels of indoor air quality parameters with reference to landscape area. The size of landscape area around the residential building had no impact on indoor air quality

**Floor area ratio:** Variations in the levels of PM<sub>4</sub> in indoor air with reference to floor area ratio was significant between the residential buildings with small and medium floor are ratio. Out of all IAQ parameters significant mean difference in the level of only PM<sub>4</sub> in indoor environment was found between the houses with relatively small and medium floor area ratio.

**Open area on the wall of the building facing the main traffic road:** Variations in the level of temperature in indoor air with reference to open area on the wall of the building facing the main traffic road was found highly significant. Open area in the form of windows, doors and ventilators had impact only on the level of indoor air temperature in residential buildings and it had not shown any impact on the level of CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub> Relative Humidity and Dew point in indoor environment of households.

**Open area on the outer wall of the building:** According to the study open area on the outer wall of the building affected the concentration of CO<sub>2</sub> in indoors environments of residential households. The concentration of CO<sub>2</sub> in indoors increased with an increase in the open area on the outer wall of the building.

**Height of the building:** No significant variation existed in the level of selected indoor air quality parameters such as CO<sub>2</sub>, VOCs, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub> Relative Humidity and Dew point with reference to the height of the building. According to the present study height of the building had no impact on indoor air quality.

**Ceiling height:** Ceiling height of the building had an impact on the level of PM<sub>4</sub>, PM<sub>2.5</sub>, Temperature and Dew point in residential interiors. Significant difference between the homes with high and low ceiling height with respect to PM<sub>4</sub> and PM<sub>2.5</sub> was found. Residential buildings with medium ceiling height were found to have high indoor temperature. Buildings with low ceiling height differed significantly with buildings with high and medium ceiling height on the level of Dew Point in interiors.

**Number of rooms:** Variation in the level of CO<sub>2</sub>, Relative Humidity, and Dew point according to the number of rooms in the house was found out. The concentration of CO<sub>2</sub> levels in houses with 5 rooms was found to be less. The difference in the level of CO<sub>2</sub> in indoor air was significantly different from houses with 4 and 5 rooms and 5 and 6 rooms. Relative Humidity and Dew point in the indoor air decreased with an increase in the number of rooms probably the air circulation was better and helped in reduction of Humidity and Dew point.

**Extent of dust accumulation features:** Variations in the level of CO<sub>2</sub>, Relative Humidity, Temperature and Dew point according to the presence of dust accumulation features were found. Significance mean differences were found in the level of CO<sub>2</sub>, Relative Humidity and Temperature based on the extent of dust accumulation features.

### **Relation between building construction material and indoor air quality**

In the present research the impact of building construction material on indoor air quality was explored. The building construction materials included in the study were (i) wall material (ii) finishing material for wall (iii) flooring material (iv) ceiling type.

**Wall material:** Level of CO<sub>2</sub> was found to be more in the houses with walls constructed with traditional brick, lime mortar and lime plaster. Concentration of VOC, PM<sub>2.5</sub>, Relative Humidity, and Dew point were high in the houses used cement brick, cement mortar and cement plaster for wall construction. Indoor temperature was relatively

high in the houses that used traditional brick, lime mortar and cement plaster for wall construction. Wall material was found to be influencing the quality of indoor air. The major difference found could be due to the use of either cement or lime as a mortar or plastering material and use of either traditional brick or cement brick for wall construction.

**Finishing material for walls:** The four types of wall finishes found in residential interiors were type-1 Cement plastering, Luppum, Whitewash, type-2 Cement plastering, Luppum, paint, type- 3. Cement plastering, whitewash and distemper type- 4. Cement plastering, whitewash, and paint. Cement plastering was the common factor for all four types; therefore type-1 is luppum with white wash, type-2 luppum with paint, type-3 whitewash with distemper and type-4 whitewash with paint.

The finishing material used on the walls of the residential buildings was found to be affecting the concentration levels of air pollutants such as CO<sub>2</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity, Temperature and Dew point in indoor air. Wall finished with luppum finish and paint were found to be contributing for relatively high level of CO<sub>2</sub>, and VOC in indoor air. Walls finished with white wash and distemper contributed for relatively high level of PM<sub>4</sub> and walls finished with luppum and paint contributed for high indoor temperature.

**Flooring material:** According to the results of the present research variation in the levels of indoors PM<sub>2.5</sub>, Temperature and Dew point was found according to the flooring material. The houses used granite as flooring material were found to be with relatively high level of PM<sub>2.5</sub> in indoor air. The houses with granite flooring were found significantly different from the houses used shahbad stone, mosaic, marble, and tiles as floor material in the level of PM<sub>2.5</sub> in indoor air.

The houses used granite as flooring material were found to be with relatively low indoor air temperature and differed significantly with the houses used flooring material such as shahbad stone, mosaic, marble, and tiles in the level of indoor temperature. The concentration of PM<sub>2.5</sub> was found to be relatively more in the houses used granite for flooring. The flooring material contributed for accumulation of pollutants in indoor air.

**Ceiling type:** No significant variation in the level of indoor air temperature was found between the houses with RCC ceiling and RCC ceiling treated with false ceiling. The type of ceiling had not shown any impact on indoor air pollution

## **Relation between household maintenance practices and indoor air quality**

Household maintenance practices were studied in terms of (i) extent of presence of dust in the house (ii) frequency of household cleaning (iii) feeling of congestedness (iv) extent of use of cleaning reagents

**Extent of presence of dust in the house:** The extent of presence of dust was found to be a variable that contributes to the relatively higher levels of PM<sub>4</sub>, PM<sub>2.5</sub>, Relative Humidity and Dew point in indoor in residential buildings. The houses with more dust accumulation were found to have higher level of PM<sub>4</sub> in indoors. The houses with medium level of dust were found to have more of PM<sub>2.5</sub> particles and higher level of humidity and dew point. According to the present research presence of dust in the house contributed towards indoor air pollution.

**Frequency of household cleaning:** The household cleaning practices followed by the building residents was found to be affecting the levels of CO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, and Temperature in indoor of the building. The frequency of cleaning whether regularly or frequently, or less frequently showed effect on indoor air pollutants like CO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub> and temperature.

Significant difference was found between houses with high and medium extent of use of cleaning reagent and between the houses with low and medium on level of extent of use of cleaning reagent on the level of PM<sub>4</sub> in indoor air. Significant difference was found between houses with high and low, extent of use of cleaning reagent on level of PM<sub>2.5</sub> in indoor air

Highly Significant difference was found between houses with high and low, and low and medium extent of use of cleaning reagent on level of RH and dew point in residential interiors.

**Feeling of congestedness:** Feeling of congestedness was found to be affecting the concentration of CO<sub>2</sub>, VOCs, PM<sub>4</sub>, RH, Temperature and Dew in indoor air of residential interiors

**Extent of use of cleaning reagent:** Significant variation was found in the level of PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub> Relative Humidity and Dew point according to the extent of use of

cleaning reagents in indoors air was found. Significant difference was found between houses with high and low; low and medium extent of use of frequency of cleaning reagent on level of PM<sub>10</sub> in indoor air.

Household maintenance practices like extent of presence of dust in the house, frequency of household cleaning, feeling of congestedness, extent of use of cleaning reagents for household maintenance were found to be significantly contributing to accumulation of pollutants like CO<sub>2</sub>, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, RH, Temperature and Dew point

### **Extent of use of electrical gadgets**

No significant variation was found in the level of CO<sub>2</sub>, VOC, PM<sub>10</sub>, PM<sub>4</sub>, PM<sub>2.5</sub>, Relative humidity, temperature and dew point in indoor air of the residential households with reference to the extent of use of electrical gadgets.

### **Extent of use of personal care products**

Significant variation was found in the level of PM<sub>4</sub> and PM<sub>2.5</sub> in indoors, with regard to the extent of use of personal care products. Highly Significant difference was found between houses with low and medium extent of use personal care products on level of PM<sub>4</sub> in indoor air.

Highly Significant difference was found between houses with high and low extent of use personal care products on level of PM<sub>2.5</sub>, whereas significant difference was found between houses with high and medium extent of use personal care products on level of PM<sub>2.5</sub> in indoor air. Use of personal care products by the residents was found to have an impact on the level of PM<sub>4</sub>, and PM<sub>2.5</sub> in indoor air.

### **Difference in the influence exerted by variables on Indoor air quality**

**Influence of independent variable on level of CO<sub>2</sub> in residential houses:** The contribution of cleaning practices for the presence of CO<sub>2</sub> in residential buildings was relatively more (31%) followed by dust accumulation features (30%) and presence of dust in the house (21%), finishing material for walls (9%) and feeling of congestedness (9%).

**Influence of study variable on level of VOCs in residential houses:** The contribution of height of the building towards the presence of VOCs in residential buildings

was relatively high(36%) followed by ceiling height of the house(30%), presence of dust in the house(21%) and site orientation(13%).

**Influence of study variable on level of PM<sub>10</sub> in residential houses:**With reference to the presence of PM<sub>10</sub> in indoor air, there was no difference in the extent of influence exerted by selected variable

**Influence of study variable on level of PM<sub>4</sub> in residential houses:**The contribution of side of the building towards the presence of PM<sub>4</sub> in indoor of residential buildings was more(34%) followed by wall material(33%) of the house. Floor materials contribution towards level of PM<sub>4</sub> in indoor air was 19 per cent and finishing material for walls contributed towards 14 per cent.

**Influence of study variable on level of PM<sub>2.5</sub> in residential houses:**Floor area ratio(43%) followed by dust accumulation features( 28%) side of the building facing the main road (15%) , use of personal care products( 8%) , open area on the outer wall of building( 6%) contributed towards the presence of variations in the level of PM<sub>4</sub> in residential buildings. The landscape area had not shown any impact on the level of PM<sub>4</sub> in residential buildings.

**Influence of study variable on level of RH in residential houses:** Highest contribution (30%) towards the presence of Relative Humidity in indoor air was from personal care products. The other variables contributed were side of the building facing the main road (24%), geographical location (16%), landscape area (11%), cleaning practices (7%), and floor material (6%).

**Influence of study variable on level of temperature in residential houses:** Highest contribution 37 per cent towards the presence of Temperature in indoor air was from geographical location. The other variables contributed were personal care products (17%), ceiling height (13%), number of rooms (12%), open area on the wall of the building facing the main road (11%), and feeling of congestedness(10%).

**Influence of study variable on level of dew point in residential houses:** Highest contribution( 37 %)towards the presence of Dew point in indoor air was from floor material. The other variables contributed were side of the building facing the main road

(23%), personal care products (11%), site orientation (9%), plinth area (7%) open area on the outer wall of the building (4%), number of rooms (3%) presence of sunshade (5%) and presence of dust in the house(1%).

## **Conclusion**

CO<sub>2</sub> can be present in buildings as a result of respiration of people and animals, as a product of combustion and as a component of soil gas. Therefore, CO<sub>2</sub> levels in indoors is closely related to the ventilation rate relative to the number of occupants and building volume. According to White (1994) if indoor carbon dioxide levels are more than 1000 ppm there is probably inadequate ventilation. According to the present investigation CO<sub>2</sub> levels in 80 per cent of the households was found to be above 1,000 ppm. The probability of these occupants experiencing complaints such as headaches, fatigue, and eye and throat irritation is high. While designing building in cities especially in areas of high traffic the rate of ventilation should be increased for increasing comfort and for avoiding health complaints like headache, and eye, nose and throat irritation.

The majority of VOCs found in the indoor environment originate from buildings materials, indoor furnishings cleaning reagents, consumer products and process (Brown, 1994). According to a study conducted by Yoshino *et al.* (2000) concentration of VOCs was higher in new homes or in those with air tightness and low air change rate, and where there were new furniture or moth crystals were used. The results of the study revealed that the highest concentration of VOCs in indoors was below 14.91ppm and this was found in 90 per cent of the households. To control the concentration of VOCs in indoors, the interior designers, should select building material that are non synthetic and eco friendly. By increasing the air exchange rate the concentration of VOCs in indoors can be diluted.

Particulate matter less than 10 micrometers in diameter are called as PM<sub>10</sub>. Those less than 10 micrometers in diameter (PM<sub>10</sub>) are so small that they can get into the lungs, potentially causing serious health problems (Abbey, 1991). Ten micrometers is smaller than the width of a single human hair. The present investigation revealed that 90 per cent of the households were found to have PM<sub>10</sub> levels between 2.1 – 3.1 mg/m<sup>3</sup>.

Particulate matter Very small particles that are less than 2.5 micrometers in width are known as fine particulate matter or PM<sub>2.5</sub> Fine particulates can play a role in causing

serious illnesses and death because they are small enough to be inhaled deep into the lungs. Once fine particles are in the lungs, they can affect the heart, blood vessels, and lungs (Dockery, 1992). The result of the study showed that PM<sub>2.5</sub> levels were found between 1.3- 3.1 mg/m<sup>3</sup> in 90 per cent of the households. The study showed that PM<sub>4</sub> levels were found between 1.3- 3.1 mg/m<sup>3</sup> in 90 per cent of the households.

According to the research study, PM<sub>4</sub> was found to be influenced by geographical location of building site and side of the building facing the main road. PM<sub>2.5</sub> was found to be influenced by site orientation, height of the base of the building with reference to main traffic road, side of the building facing the main road. Hence to control the level of particulate matter in indoors, the Architects and Interior designers should take into consideration site orientation, height of the base of the building with reference to main traffic road, side of the building facing the main road.

According to Sundell, 2004 elevated humidity in indoors can promote the growth of mold, bacteria, and dust mites, which can aggravate allergies and asthma. The recent research showed that about 73.3 % households had humidity levels between 39.34 -47.74% which is below the acceptable limits suggested by ASHRAE which is 30 – 60 % in indoors. Relative Humidity was found to be influenced by geographical location of building site, site orientation, and side of the building facing the main road. By taking due considerations while selecting site for building construction, the problem of indoor Humidity can be solved.

There is no ideal temperature suitable for all building occupants. The location of building site, its orientation and the design aspects of the building structure can affect the concentration of temperature in indoors (Sundell, 2004). The present study revealed that the indoor temperature in majority of the households was between 28.31 – 30.37 °C above the acceptable limits of 20-27 °C. Temperature was found to be influenced by geographical location of building site, and side of the building facing the main road. The design of the building should be such that the area of the side of the building facing the main road should be as less as possible.

The dew point is the temperature at which the water vapor in a sample of air at constant barometric pressure condenses into liquid water at the same rate at which it

evaporates( Peat, 1998). About 83.3 % of the households had Dew points levels between 14.5 -16.72 % in indoors. Dew point was found to be influenced by site orientation and side of the building facing the main road.

## **IMPLICATIONS OF THE STUDY**

The Architects and Interior Designers can take the factors such as geographical location of the building site, site orientation, height of the building site with reference to main traffic road, height of the base of the building site with reference to road in front of the house into consideration while selection of site for building construction.

The results of the study can serve as be an input to Architects and Interior designers while working on building design parameters such as the plot area, plinth area, landscape area, floor area ratio, open area on the wall of the building facing the main traffic road, open area on the outer wall of the building, height of the building, ceiling height, no. of rooms and extent of dust accumulation features.

The results of the study can guide on selection of building material for construction and finishing for promoting indoor air quality

Study material on the results relating to household maintenance practices and use of cleaning reagents can help consumers adopt practices favorable to protect Indoor Air Quality

## **FUTURE RESEARCH**

1. Using the same methodology similar studies can be conducted in Educational Institutes
2. Similar study can be taken up for Rural households
3. Exploratory study on role of ventilation in controlling pollutants like CO<sub>2</sub> and VOCs can be taken up
4. Contribution of specific cleaning reagents to Indoor Air Pollution can be taken up
5. Impact of use of cosmetics on Indoor Air Quality can be studied

## LITERATURE CITED

- Abbey, D.E. 1991. Estimating cumulative ambient concentration of air pollutants description and precision of method used for an epidemiological study. *Arch.Environ.Health*.46 (5):281-287.
- Ashraf, S. A. W., Khanam, S and Ahmad, A .2013. Effects of indoor air pollution on human health: A micro-level study of Aligarh City India. *Merit Research Journal of Education and Review*.1(6):139-146.
- Ackoff and Russell.L.1962.Scientific method New York: John Wiley and Sons.32.
- Brunekreef, B., Janssen,N.A.H., Hartog,J.D., Harssema. H., Knape, M and Vliet, P.V. 1997. Air Pollution from Truck Traffic and Lung Function in Children Living near Motorways. *Epidemiology*. 8(3):298-303.
- Behera,D and Balamugesh,T. 2005. Indoor Air Pollution as a Risk Factor for Lung Cancer in Women. *JAPI*.53. <http://www.ncbi.nlm.nih.gov/pubmed/15926600>
- Brown, S.K.1994. Source emission control of indoor air pollution. In *Indoor Air: AnIntegrated Approach*. 355–358.
- Brown and Dekay.2000. 'Sun Wind and Light' John Wiley. An excellent primer looking at buildings' relationship with the sun. <http://www.architecture.com/RIBA/Aboutus/SustainabilityHub/Designstrategies/Earth/1-1-3-2-Buildingorientation.aspx>
- Burge, S., Hedge, A., Wilson, S., Bass, J.H and Robertson, A. 1987. Sick building syndrome: a study of 4373 office workers. *Ann Occupation Hygiene*, 31: 498- 504.
- Brown, S.K., Cole, I and Martin, A.K. 1994. The effect of building factors and indoor climate on house dust mite numbers in three houses. In *Mites, asthma and domestic design*, University of Sydney. <http://laptop.deh.gov.au/soe/1996/publications/technical/pubs/12indora.pdf>
- Brown, S.K.1981. *A review of occupational and environmental exposure to asbestos dust*.Division of Building Research Report, CSIRO, Melbourne.

- Banham and Rayner. 1984. *The architecture of the well-tempered environment*, second edition, university of Chicago press.  
[http://pdf92.mangybooks.org/fr34u\\_architecture-of-the-well-tempered-environment.pdf](http://pdf92.mangybooks.org/fr34u_architecture-of-the-well-tempered-environment.pdf)
- Bttermann, S., Hatzivasikis, G and Chunrong, J. 2005. Concentration and emission of gasoline and other vapor from residential vehicle garages. *Atmospheric environment*.11:1828-1844.
- Bruce, N., Perez, P.R. and Albalak, R. 2000. Indoor air pollution in developing countries: A major environmental and public health challenge, *Bulletin of the world health organization*. 78: 1078-1092.
- Brown, S.K. 1991. Field performance, hydrolysis and durability of urea formaldehyde foam insulation in Australian dwellings. In *Insulation materials: Testing and applications*.2:1116.
- Bruinen de Briun Y., Kotzaic, D and Kephalaopoulos. 2005. Characteristics of indoor sources. Emission of chemical substances from material and products.
- Baggs, S.J. 1996. The healthy house. The gaian approach to creating a safe healthy and environmental friendly home. [www.oldbuilders.com](http://www.oldbuilders.com).
- Balaras, C.A., Droutsas, K., Argiriou, A.A and Asimakopoulous, D. N. 2000. Air conditioning Energy consumption and Environmental quality. *Indoor air quality*.  
[www.eolss.net/sample-chapters/c08/E3-17-02-04.pdf](http://www.eolss.net/sample-chapters/c08/E3-17-02-04.pdf)
- Brawer and Spengler JD. 1994 Evidence for improved ambient air quality and the need for personal exposure research. *Environmental Science Technology*.18:268-80.
- Cutter Information Corporation. 1992. How office furnishings and equipment affect indoor air quality. *Indoor Air Quality Update*. 5(6): 1-6.
- Coultas, D.B and Lambert, W.E. 1991. Carbon monoxide. In *Indoor air pollution: A health perspective*, J.M. Samet and J.D. Spengler (Eds), Johns Hopkins University Press, Baltimore, 187-208.

- Carrer, A., Fanetti, F., Forastiere, I., Holcatova, L., Molhave, J., Sundell, G., Viegi, M and Simoi. 2009. *ENVIE co-ordination action on indoor air quality and Health effect*. WPI final report health effects. [www.envie-iaq.eu](http://www.envie-iaq.eu).
- CLG(Communities and Local Government). 2008. *Review of health and safety risk drivers*. Reported BD2518 London. <http://webarchive.nationalarchives.gov.uk/20120919132719/http://www.communities.gov.uk/documents/planningandbuilding/pdf/reviewhealthsafety.pdf>
- Chengappa, C., Edwards, E., Bajpai, R., Shields, K., N and Smith, K. R. 2007. Impact of improved cook stoves on indoor air quality in the Bundelkhand region in India. *Energy for Sustainable Development*. 11(2):33-44.
- Crump, D. 2004. Minimizing risk due to the organic vapors into buildings from contaminated land. BRE digest. 482. BRE bookshop. Watford. 35(38): 50-56.
- Darus, M.F., Ahmed, A and Talib, M. 2011. Preliminary Assessment of Indoor Air Quality in Terrace Houses. *Health and the Environmental Journal*, 2(2):8-14.
- Dingle, P and Olden, P. 1992. A temporary sick building? *Australian Institute of Refrigeration, Air Conditioning and Heating*, 46(11):43-47.
- Dockery, D.W and Pope, C.A. 1994. Acute respiratory effects of particulate air pollution. *Ann. Rev. Pub. Health* 15:107-132.
- Dockery, D.W. 1992. Air pollution and daily mortality. Association with particulates and acid aerosols. *Environ. Res.* 59:362-373.
- Duhme, H., Weiland, S.K and Keil, U. 1998. Epidemiological analyses of the relationship between environmental pollution and asthma. *Toxicology Letters*. 10(3):307-316.
- Dennekamp, M., Howarth, S., Dick, C.A.J., Cherrie, J. W., Donaldson, K and Seaton, A. 2001. Ultrafine particles and nitrogen oxides generated by gas and electric cooking. *Occup Environ Med.* 58:511-516.

- Environmental Protection Agency (EPA). 2001. Introduction to indoor air quality, A reference manual: Washington. D.C.  
<https://books.google.co.in/books?isbn=1133711359>
- EPA (U.S Environmental Protection Agency). 2004. Partnership for clean Indoor air, Washington,DC. <http://www.epa.gov/iaq/pcia.html>
- ECA, European Collaborative Action. 2000. Risk assessment in relation to indoor air quality. Report No 22. European commission, Office for Publications of the European Communities, Luxembourg.  
<https://books.google.co.in/books?id=v0AoAQAAAMAAJ>
- Engvall, K., Corner, R., Emenius, G and Hult, M. 2006. Healthy houses presentation of an interdisciplinary investigation on indoor air quality and building related health effects in residences. *Proceedings of healthy buildings*. 3:153-156.
- Ezzati.M., Saleh,H and Kammen,D.M. 2000.The Contributions of Emissions and Spatial Microenvironments to Exposure to Indoor Air Pollution from Biomass Combustion in Kenya.*Environ Health Perspect*108:833–839.
- Engen, T. 1982.The Perception of Odors. Academic Press, New York.
- Ferrari, L., McPhail, S and Johnson, D. 1988. Indoor air pollution in Australian Homes results of two winter campaigns. *Clean Air* 22(2): 68–74.
- Frey, L.R., Carl, H. B and Gary,L. K. 2000.*Investigating Communication: An Introduction to Research Methods*.Boston: Allyn and Bacon(2<sup>nd</sup> edition).19:3-10.
- Fisk, W., LeiGomez and Mendell. 2007. Met analyses of the association of respiratory health effects with dampness and mold In homes. *Indoor air*. 17(4).284-296.
- Guerin, M.R., Jenkins, A.R and Tomkins, B. A. 1992. *The chemistry of environmental tobacco smoke: Composition and measurement*. Lewis Publishers, Michigan. 16: 223-244.

- Gertler, A.W., Gillies, J.A and Pierson, W.R. 2000. An assessment of the mobile source contribution of PM<sub>10</sub> and PM<sub>2.5</sub> in the United States. *Water Air and Soil Pollution*. 123:203–214.
- Garette, M, H., Rayment, P. R., Hooper, M. A., Abramson, M.J and Hooper, B.M. 1998. Indoor air borne fungal spores, house dampness and association with environmental factors and respiratory health in children. *Clinical and experimental allergy*. 28:459-467.
- Gauderman, W. J., Avol, E., Lurmann, F., Kuenzli, N., Gilliland, F., Peters, J and McConnell, R. 2005. Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide. *Epidemiology*. 16(6): 1-7.
- Gallego, E., Roca, X., Perales, J. F and Guardino, X. 2008. Determining indoor air quality and identifying the origin of odor episodes in indoor environments. *Journal of Environmental Sciences*. 21: 333–339.
- Gertler, A.W., Gillies, J.A and Pierson, W.R. 2000. An assessment of the mobile source contribution of PM<sub>10</sub> and PM<sub>2.5</sub> in the United States. *Water Air and Soil Pollution*. 123:203–214.
- Hodgson, A.T., Beal, D and McIlvaine, J.E.R. 2002. Sources of formaldehyde, other aldehydes and terpenes in a new manufactured houses. *Indoor air*. 12: 235-247.
- Hodgson, A.T., Rudd, A.F., Beal, D and Chandra, S. 2000. VOCs concentration emission rates in new manufactured and site built houses. *Indoor air*. 3: 178-192.
- Hanninen, O.O., Lebrecht, E., Acquas, V., Katsouyannis, K., Kunzli, N. Srame, R.J and Jantunena, M. 2004. Infiltration of ambient PM<sub>2.5</sub> and levels of indoor generated non-ETS PM<sub>2.5</sub> in residences of four European cities. *Atmospheric Environment*. 38: 6411–6423.
- Health Effects Institute—Asbestos Research. 1991. *Asbestos in public and commercial buildings: A literature review and synthesis of current knowledge*. HEI-AR, Cambridge, MA.

- HPA( Health Protection Agency).2008. Health protection agency board gives advice on radon measures for new homes. <http://www.bre.co.uk/radon/protect.html>.
- Humford, J.L.1987. Lung cancer and indoor air pollution in Xuan wei. *China science*. 235(4785): 217 – 220.
- Hoek, G., Kos, G., Harrison, R., Hartog, D. J., Meliefste, K and Brinkten, H. 2008. Indoor outdoor relationship of particle number and mass in four European cities. *Atmospheric Environment* .42:156–6.
- Huang and Haghitat. 2002.Spatial Spatial variation and relationship of indoor/outdoor VOCs at residential homes in Guangzhou city.*Aerosol and Air Quality Research*. China. 7:518–530.
- Jarnstrom, H. 2008.Reference values for building material emissions and indoor air quality in residential buildings. VTT publications 672.
- Janssen, N.A.H., Hoek,H., Brunekreef,B., Harssema,H., Mensink,I and Zuidh 1997.A. Personal Sampling of Particles in Adults: Relation among Personal, Indoor, and Outdoor Air Concentrations.*American Journal of Eptdemiology*. 147 (6).537-547.
- Joshi, H.D.,Pandeya, R and Dhakal, B. 2009.*Health Impact of Indoor Air Pollution*. 7(15):69-75.
- Jacobs, D., Kelly, T and Sobolewski . 2007. Linking public health, housing, and Indoor Environment policy successes and challenge at local and federal in the United States. *Environment Health perspectives*. 115:976-982.
- Joseph,A and Demkin, A.I.A. 2007.*The Architect's Handbook of Professional Practice*, 13(18): 563.
- Kelly, J.T., Smith.L.D and Jansatola. 1999. Emission Rates of Formaldehyde from Materials and Consumer Products Found in California Homes. *Environmental Science and Technology*. 33:81-88.

- Kemp, P and Dingle, P. 1994. The indoor environment, occupant symptoms and perceptions in a sick new office building. *Proceedings of the 12th International Conference of Clean Air Society of ANZ*. 1:569–574.
- Koveri,T., Nicolas, L., Gilbert., Stocco, C., Fugler, D. E., Robert., Dales., Guay and Miller, J. D. 2007. Indoor air quality and the risk of lower respiratory tract infections in young Canadian Inuit children.177(2):155-60.
- Khoder, M. I., Shakour, A. A., Farag, S. A and Hameed, A.A.2000. Indoor and outdoor formaldehyde concentrations in homes in residential areas in Greater Cairo. *J. Environ. Monit.* 2:123-126.
- Kerlinger, F.1995. Foundations of Behavioral research (3<sup>rd</sup> edition) Prism Books Pvt.Ltd. New Delhi.280-285.
- Levin. 2006.Characteristics of indoor sources. *Emission of chemical substances from material and products*. 2:560–567.
- Levin, H.1995. Physical factors in indoor environment. *Effects of indoor environment on health*, Occupational medicine: state of the art reviews. 10(1).
- Leech, J., Raizenne,M and Gusdorf, J.2004. Health in occupants of energy efficient homes.*Indoor air*. 14:169-173.
- Levin, H. 2006. Environmental impacts of technologies for sustainable buildings. *Proceedings of healthy buildings*. 45-50.
- Lewis. S.A., Weiss, S.T., Platts, M.T.A., Burge, H and Gold, D.R. 2002. The role of indoor allergen sensitization and exposure in causing morbidity in women with asthma. *Respiratory Critical Care Medical*. 165:961–966.
- Liao, C.M., Suh, H.H and Koutrakis, P. 1999. Characterization of indoor particle sources using continuous mass and size monitors. *Journal of the Air & Waste Management Association*.50:1236–1250.

- Massey,D., Masih, J ., Kulshrestha, A .,Habil, M and Taneja, A. 2009. Indoor/outdoor relationship of fine particles less than 2.5 mm (PM<sub>2.5</sub>) in residential homes locations in central Indian region.*Building and Environment*. 44 : 2037–2045
- Mcdonnell,W.F., Ihikawa,N.N., Petersen, F.F., Chen, H.L and Abbey, D.E. 2000. Relationship of mortality with the fine and course fraction of long term ambient PM<sub>10</sub> in non smokers. *Journal of exposure analyses and environmental epidemiology* 10, 427-436.
- Metzger, A.S. 1998.Assurance of indoor environmental quality through building diagnostics at schematic design. <http://scholar.lib.vt.edu/theses/available/etd-012899-103422/unrestricted/ETD.PDF>.
- Maier, T., Krzaczek, M and Tejchman, J. 2009. Comparision of physical performance of the ventilation system in low energy residential houses. *Energy and buildings*. 41:377-353.
- Martuzevicius, D., Grinshpun, S. A., Lee, T., Hub, S., Biswas, P., Reponen, T and LeMasters,G. 2008. Traffic-related PM<sub>2.5</sub> aerosol in residential houses located near major highways: Indoor versus outdoor concentrations. *Atmospheric Environment*.42:6575–6585.
- Meng,Y.Y., Wilhelm,M .,Rull, R. P., English, P., Nathan, S and Ritz, B. 2008. Are Frequent Asthma Symptoms among Low-Income Individuals Related to Heavy Traffic Near Homes, Vulnerabilities, or Both? *Ann Epidemiol*. 18: 343–350.
- Mendell, M.2007.Indoor residential chemical emission as risk factor for respiratory and allergic affects in children. *Indoor air*. 17:259-277.
- Mehta.S and Shahpar, C.2004. The health benefits of interventions to reduce indoor air pollution from solid fuel use: a cost-effectiveness analysis. *Energy for Sustainable Development*.8 (3): 45-65.
- Mishra,V. 2003.Effect of Indoor Air Pollution from Biomass Combustion on Prevalence ofAsthma in the Elderly. *Environmental Health Perspectives*.111(1):70-77.

- Meaklin, J. 1992. Pesticides in indoor air. In *Future Directions for Indoor Air Quality*, EPA/CAS Conference, Melbourne.
- McPhail, S and Betts, A. 1992. Flueless gas heaters in NSW government schools. *11<sup>th</sup> International Conference of the Clean Air Society of Australia and New Zealand*, Brisbane.227–231.
- Meng, Q.Y., Turpin, B.J., Korn, L., Weisel, C.P., Morandi, M., Colome, S., Zhang, J., Stock, T., Spektor, D., Winer, A., Zhang, L., Lee, J.H., Giovanetti, R., Cui, W., Kwon, J., Alimokhtari, S., Shendell, D., Jones, J., Farrar, C and Marberti, S. 2005. Influence of ambient (outdoor) sources on residential indoor and personal PM<sub>2.5</sub> concentrations: analysis of RIOPA data. *Journal of Exposure Analysis and Environmental Epidemiology*. 15:17–28.
- Maston, U. 2005. Indoor & outdoor concentrations of ultrafine particles in some Scandinavian rural and urban areas. *Science of the Total Environment*. 169: 3431–3433.
- Morrison, G.C ., Nazaroff, W.W., Ruiz, J.A., Alfred, C ., Hodgson, T and Modera, M.P. 1998. Indoor Air Quality Impacts of Ventilation Ducts: Ozone Removal and Emissions of Volatile Organic Compounds. *Journal of the Air & Waste Management Association* 48:941-952.
- NOHSC (National Occupational Health and Safety Commission).1989.*Office copying machines*. AGPS, Canberra.  
[http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/267/CodeofPractice Labelling WorkplaceSubstances NOHSC2012-1994 PDF.pdf](http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/267/CodeofPractice%20Labelling%20WorkplaceSubstances%20NOHSC2012-1994%20PDF.pdf)
- Nazaroff, W. W and Weschler, C.J. 2004. Cleaning products and air fresheners: exposure to primary and secondary air pollutants. *Atmospheric Environment*. 38 :2841–2865.
- Naeher, L. P., Leaderer, B. P and Smith, K. R.2000. Particulate Matter and Carbon Monoxide in Highland Guatemala: Indoor and Outdoor Levels from Traditional and Improved Wood Stoves and Gas Stoves. *Indoor Air*; 10: 200–205

- Norback, D., Michel, I and Widstrom, J. 1990. Indoor air quality and personal factors related to the sick building syndrome. *Journal of Work, Environment and Health*. 16(2):121-128.
- ORG (office of the registrar general). 2011. Tables on houses, household maintenance amenities and assets. Census of India. Vital statistics division, office of the registrar general. New Delhi. Ministry of home affairs. <http://censusindia.gov.in/>
- Palonen, J., Kurnitski, J and Eskola, L. 2008. Thermal comfort and perceived air quality in 102 finish single family houses. *Proceedings of indoor air*. 944: 17-22.
- Pekkanen, J., Peters, A., Hoek, G., Tiittanen, P., Brunekreef, B., Heinrich, J., Ibaldo-Mulli, A., Kreyling, W.G., Lanki, T., Timonen, K.L and Vanninen, E. 2002 Particulate air pollution and risk of ST-segment depression during repeated sub maximal exercise tests among subjects with coronary heart disease, *Circulation*, 106: 933–944.
- Peat, J.K., Dickerson, J and Li, J. 1998. Effects of damp and mould in the home on respiratory health *Allergy*. 53: 120-128.
- Pearson. 1994. The healthy house. The green approach to creating a safe healthy and environmental friendly home. [www.oldbuilders.com/.../indoor%20air%20quality%20-%20index.html](http://www.oldbuilders.com/.../indoor%20air%20quality%20-%20index.html)
- Rowe, D.M and Wilke., S.E. 1994. Thermal comfort and air quality in eight office buildings: An interim report. *Proceedings of the National Conference of the Australian Institute of Refrigeration, Air Conditioning and Heating*, Surfers Paradise. <http://soer.justice.tas.gov.au/2003/source/154/index.php>.
- Roodman, D.M and Lense, N.A. 1995. *Building resolution: How ecology and health concern are transforming construction*. World watching institute. Washington, D.C. <http://www.worldwatch.org/node/866>.
- Romieu, I., Menses, F. Ruiz, F. Sierra, J.J. Huerta, J. White, M.C. and Etzel, R.A. 1996. Effects of air pollution on the respiratory health of asthmatic children living in Mexico city. *American journal of respiratory and critical care medicine*. 154:300-307.

- Raw, G.J. 1992. *Sick building syndrome: A review of the evidence on causes and solutions*. HSE Contract Research Report No. 42. Health and Safety Executive. UK.
- Reardon, J.T and Shaw, C.Y. 1993. Carbon dioxide concentrations and minimum air change rates in a high-rise office building. *Indoor Environment*. 2:337–343.
- Roulet, C. 2006. Indoor air quality and energy performance of buildings. *Proceedings of healthy buildings*. 1:37-47.
- Rabone, S., Phoon, W.O., Seneviratne, M., Gutierrez, L., Lynch, B and Reddy, B. 1994. Associations between work-related symptoms and recent mental distress, allowing for work variables and physical environment perceptions in a 'sick' office building. In *Indoor Air: An Integrated Approach*, Gold Coast. 243–246.
- Rousseau, D. 2003. A guide to mechanical equipment for healthy indoor environments. Research report, Canada and mortgage housing co-operation, Canada.
- Shaughnessy, J. J., Zechmeister, E.B and Zechmeister, J.S. 2000. *Research methods in physiology*. 5<sup>th</sup> edition. McGraw-hill.
- Samet, J.M and Spengler, J.D. (Eds). 1991. *Indoor air pollution: A health perspective*. Johns Hopkins University Press, Baltimore. 20(25):31-36
- Smith-Sivertsen., 2004. Reducing indoor air pollution with a randomized intervention design- A presentation of the Stove Intervention Study in the Guatemalan Highlands. *Norsk Epidemiologi*. 14(2): 137-143.
- Sundell, J. 2004. On the history of indoor air quality and health. *Indoor air*, 14(7):51-58.
- Schwartz, J., Dockery, D.W and Neas, L.M. 1996. Is daily mortality associated specifically with the particles? *Journal of the Air & Waste Management Association* 46:927–939.
- SCHER (scientific committee on health and environment risks). 2007. Opinion on risk assessment on indoor air quality. European commission. [http://ec.europa.eu/health/ph\\_risk/committees/04\\_scher/docs/scher\\_o\\_055.pdf](http://ec.europa.eu/health/ph_risk/committees/04_scher/docs/scher_o_055.pdf)

- Smith, K.R and Sumi, M .2003. The burden of disease from indoor air pollution in developing countries: comparison of estimates. *International Journal of Hygiene and Environmental Health*.206:279-289.
- Smith, K.R.2002.Indoor air pollution in developing countries: recommendations for research. *Indoor Air*. 12:198-207.
- Seppanen,O. 1999.Estimated cost of Indoor Climate in Finland. *In The Proceedings of the 8th International Conference on Indoor Air and Climate*. 4:13-18.
- Smith, K.R., Samet, J.M. Romlew,I and Bruce, N. 2000. Indoor air pollution in devolpoing countries and acute lower respiratory infection in children.*Thorax*. 55. 518-532.
- Solomon, W.R and Burge, H.A.1984. Allergens and pathogens. In *Indoor air quality*, (Eds), CRC Press, Boca Raton, Florida.
- Saijo, Y., Kiski, R., Sata, F., Katakura, Y., Urashami, Y., Hatakeyama, A., Kobayashi, S., Jin, K., Kurahashi, N., Kondo, T., Gong and Y. Umemura. 2004. Symptoms in relation to chemicals and dampness in newly built dwellings. *Arch Occupation Environment Health*.77: 461-470.
- Spengler, J.D., Duffy, C.P. Letz, R. Tibbetts, T.W and Ferris, B.G. 1983. Nitrogen dioxide inside and outside 137 homes and implications for ambient air quality standards and health effects research. *Envir. Sci. Technol*. 17:164–168.
- Sundell, J., Lindvall, T and Stenberg, B. 1994. Association between type of ventilation and air flow rates in office building and risks of SBS symptoms among occupants. *Environmental International*. 20(2):239–51.
- Smith, K.R. 1999. The national burden of disease from indoor air pollution in India. Presented at Indoor Air 99: The 8<sup>th</sup> International Conference on Indoor Air Quality and Climate.10:13–18.
- Thatcher, T. L and Layton, D.W.1995. Deposition, re-suspension and penetration of particles within a residence. *Atmospheric Environment*.29:1487–97.

- Tuomainen, M., Pasanen, A., Tuomainen, A., Liesivuori, J and Juvonen. 2001. Usefulness of the finish classification of indoor climate, construction and finishing material: Comparison of indoor climate between two new blocks of flats in Finland. *Atmospheric Environment*, 35:305-313.
- Lee.T.G.1998. Health and the built environment. Indoor Air Quality. The faculty of environment design, the University of Calgary. Canada. <http://evds.ucalgary.ca/profiles/tang-gim-lee>
- US EPA.2009. Buildings and their Impact on the environment: A statistical summary, <http://www.epa.gov/greenbuilding/pubs/gbstats.pdf>.
- Venn, A., Cooper, M., Antoniah, M., Laughlin, C., Brillion, J and Lewis, S. 2003. Effects of VOCs, damp and other environmental exposures on wheezing illness in children. *Thorax*. 58:955-960.
- Yoshimo, H., Netsu, K., Yashida, M., Ikeda, K., Nazaki, A., Kakuka , K., Hojo, S., Yashino, H., Amano, K and Ishikawa, S. 2006. Long term field survey in Indoor air quality and occupants health in 57 sick houses in Japan. *Proceedings of healthy buildings*.315-320.
- Waring, M.S and Siegel, J. A. 2011. The effect of an ion generator on indoor air quality in a residential room. *Indoor Air*. 21: 267–276
- Woolcock, A. 1991. Current issues of indoor air quality: Health effects. *J. Occupational Health Safety*.7 (2): 117–119.
- World Health Organisation (WHO).2007. Air quality guidelines. <http://www.int/phe/health/topics/outdoor-apg/e/index.html>: Global update.
- World Health Organisation (WHO).2003. Making choices in health: WHO guide to cost effective analyses. Geneva. [www.who.int/violence\\_injury/world\\_report/ft\\_violencealcohol.pdf](http://www.who.int/violence_injury/world_report/ft_violencealcohol.pdf)
- Wadden, R.A and Scheff, P.A. (1983). *Indoor air pollution, characterisation, prediction and control*. Wiley Interscience, New York. <http://nepis.epa.gov/Exe/ZyPDF.cgi/000000S0.PDF?Dockey=000000S0.PDF>

- World Health Organisation(WHO).1982.*Indoor air pollutants: Exposure and health effects*. Report on a WHO meeting, Regional Office for Europe, Copenhagen. volume 74 of American journal of public health:JPH, american public health association
- World Health Organisation(WHO).2002. The world health report: Reducing risks promoting health life. Geneva. <https://books.google.co.in/books?isbn=9241562439>
- World Health Organisation(WHO).1989. Indoor air quality: organic pollutants. EURO reports and studies No.111.Copenhagen.
- World Health Organization(WHO).1982. World Health Report. Geneva.
- Willard,A., Wade, III. William, A. Cote. and John E. Yocom.1997. *A Study of Indoor Air Quality*. 25(9):933-939.
- White, J.H. 1994. White on CO<sub>2</sub> testing.*Indoor Air Bull.* 3(1):14–15.
- Wargocki, P., Sundell,J., Biscchof, W., Brundrett, G., Fanger, P., Gyntelberg, F., Hassen,S., Harrison, P., Pickering, A., Seppanen, U and Wouters, P. 2002. Ventilation and health in non industrial indoors environmental report from a European multidisciplinary scientific consensus meeting(EUROVEN). *Indoor air*. 12:113- 128.
- Walsh, P. J., Dudney, C. S and Copenhaver, E. D. 1983. *Indoor air quality*. CRC. 62 : 226.

# APPENDICES

## Appendix-A

### Interview schedule to elicit information on building design, personal and household maintenance practices

#### 1. Personal information

- 1.1 Name of the respondent
- 1.2 Age of the building
- 1.3 Number of family members

S.no	Name	Gender	Age	Relationship with respondent	occupation
1.3.1					
1.3.2					
1.3.3					
1.3.4					

1.4	No. of females	
1.5	No. of males	
1.6	No. of adults ( Age: Above 21 years )	
1.7	No. of children (Age: Below 20 years )	

#### 2. Basic information about building site and location

2.1	Geographical location of the building site	Abids / Kukatpally / MG road / Panjagutta / Zoo park
2.2	Site orientation	East/West/North/South.
2.3	Height of the base of the building site with reference to main traffic road	Above/ Below /Same level
2.4	Height of the base of the building site with reference to road in front of the house	Above/ below/same level
2.5	Side of the building facing the main road	Front/Side/Left/Right
2.6	Site drainage	Open /Closed

### 3. Information about building design

3.1	Plot area ( Sft )	
3.2	Plinth area/Floor area ( Sft )	
3.3	Landscape area ( Sft )	
3.4	FAR: Total building square footage ( floor area) / Site square footage ( plot area)	
3.5	Open area in the form of windows on the wall of the building facing the main traffic road.	
3.6	Open area in the form of doors on the wall of the building facing the main traffic road.	
3.7	Total open area on the wall of the building facing the main traffic road.	
3.8	Open area in the form of window area on the outer wall of the building.	
3.9	Open area in the form of door area on the outer wall of the building.	
3.10	Total open area on the outer wall of the building.	

#### Door details

1.	Doors	Area	Treatment	Duration of doors kept open
	D1			
	D2			
	D3			

#### Window details

2.	Windows	Area	Treatment	Duration of windows kept open
	W1			
	W2			
	W3			

#### Ventilator details

3.	Ventilators		Area
	V1		
	V2		

#### Exhaust fan details

4.	Exhaust fan		Area
	E1		
	E2		

\* **Door/ window treatment:** 1.ply+ veneer 2.wood+veneer 3.ply+laminated 4. Wood+ laminate 5.wood 6. Steel+glass 7.glass 8. Glass+wood

3.11	Height of the building	
3.12	Ceiling height	
3.13	No. of rooms	
3.14	Presence of sunshade	

### 3.15 Extend of dust accumulation features

S.no	Features	The extend of its presence		
		High	Moderate	Low
1.	Nooks and corners			
2.	Lighting fixtures			
3.	Top of storage /almarahs			
4.	T.v/computer			
5.	Carpets/mats			
6.	Curtains/draperies			
7.	Window sills			
8.	Furniture			
9.	Cabinets in kitchen			
10.	Electrical gadgets			

### 4. Construction and finishing material in the house

S.no	Room	walls	Floors	Ceiling	Finishing material
1.	Bedroom 1				
2.	Bedroom 2				
3.	Living/Dining room				
4.	Kitchen				
5.	Any other				

\* **Wall:** 1. Traditional brick, lime mortar, cement plaster.2. Traditional brick, lime mortar, lime plaster.3. Traditional brick, cement mortar, cement plaster.4. . Traditional brick, cement mortar, lime plaster.5. Hollow brick, cement mortar, cement plaster.

\***Floor:** 1.Shabaad stone, 2.Mosiac.3.Marble, 4.Granite, 5.Tiles.

\***Ceiling:** 1. RCC 2. False ceiling

\***Finishing material:** 1.Cement plastering, Luppum, Whitewash. 2. Cement plastering, Luppum, paint 3. Cement plastering, whitewash, distemper. 4. Cement plastering, whitewash, paint.

## 5. Household maintenance practice

### 5.1. Extend of presence of dust in the house

S.no	Features	The extend of its presence		
		High	Moderate	Low
1.	On the floors			
2.	On the walls			
3.	On the carpets/mats/ Rugs			
4.	Curtains / Draperies			
5.	Lighting fixtures			
6.	On Furniture			
7.	Home accessories			
8.	Storage/ almarahs			
9.	Window sills			
10.	Fans			
11.	Coolers			
12.	Air condition			

### 5.2. Frequency of household Cleaning

S.no	Cleaning practices	Frequency of use						
		Daily	Alternate days	Weakly once	Once in fortnight	In a month	Twice in month	Yearly
1.	Sweeping the floor							
2.	Mopping the floor							
3.	Washing floors							
4.	Changing & washing bed Lenin							
5.	Washing curtains							
6.	Cleaning carpets							
7.	Dusting doors & windows							
8.	Dusting furniture							
9.	Dusting lighting fixtures							
10.	Any other							

### 5.3. Feeling of congestedness

S.no	Features	The extend of its presence		
		High	Moderate	Low
1.	Congestedness due to poor ventilation in the house.			
2.	Congestedness due to Improper placement of furniture in the house.			
3.	Congestedness due to excess of furniture.			
4.	Congestedness due to heavy storage units.			
5.	Congestedness due to excess of furnishings.			
6.	Congestedness due to overloaded loft.			
7.	Congestedness due to heavy artificial lighting fixtures.			
8.	Congestedness due to circulation in the room.			

### 5.4. Extent of use of cleaning reagent for household maintenance Practices

R: Everyday in a month, S: Four times in a month (week wise), O: Twice in a month, R: Once in a month, N: Never in a month.

S.no	Activity	Frequency				
		Regular	Sometime	Occasionally	Rarely	Never
1	Use of detergent for washing clothes					
2	Dry cleaning of curtains/draperies					
3	Use of reagent for fabric conditioner					
4	Use of Reagent for washing furnishings					
5	Use of detergent for dishwashing					
6	Use of chemical reagent for mopping floors					
7	Use of chemical reagent for washing the floors					
8	Use of reagent for Cleaning washbasin.					
9	Use of reagent for Cleaning Sink					
10	Use of reagent for Cleaning toilets					
11	Use of reagent for Cleaning bathrooms					

12	Use of reagent for cleaning glass cabinets					
13	Use of reagent for cleaning T.V					
14	Use of reagent for Cleaning storage units					
15	Use of room fresheners					
16	Use of mosquito repellent					
17	Use of cockroach spray					
18	Use of reagent for cleaning Household gadgets					
19	Use of reagent for cleaning air condition					
20	Use of reagent for cleaning refrigerator					
21	Use of reagent for cleaning geyser/water heater					
22	Use of reagent for cleaning Grinder mixer					
23	Cleaning kitchen accessory storage					
24	Use of cleaner for cleaning furniture					
25	Use of cleaner for cleaning lighting fixtures					
26	Use of liquid cleaner for wiping switch board					
27	Cleaning of Fans/coolers					
28	Cleaning of accessories					
29	Use of naphthaline balls					
30	Use of scented agarbatti/					
31	Use of laxman rekha					
32	Rearing of pet animals					
33	Smoking of cigarette by inmates					
34	Cleaning whole house					
35	Any other					

### 5.5. Amount of cleaning reagent used in a month

S.no	Cleaning reagent	Amount
1.	Harpic (Toilet cleaner)	
2.	Phenol /Dettol	
3.	Detergent	
4.	Scented liquid Cleaner	
5.	Mosquito repellent	
6.	Cockroach spray (Hit)	
7.	Insects spray	
8.	Room fresheners	
9.	Soaps	
10.	Any specific	

### 5.6. Extend of use of electronic gadgets:

R: Everyday in a month, S: Four times in a month (week wise), O: Twice in a month, R: Once in a month, N: Never in a month.

S.no	Electronic product	Frequency of use				
		Regular	Sometime	Occasionally	Rarely	Never
1.	Microwave					
2.	Refrigerator					
3.	Air condition					
4.	Water heater					
5.	Geysor					
6.	Mixer grinder					

### 6. Extend of use of use of personal care product

R: Everyday in a month, S: Four times in a month (week wise), O: Twice in a month, R: Once in a month, N: Never in a month.

S.no	Activity	Frequency				
		Regular	Sometime	Occasionall y	Rarely	Never
1.	Body lotion					
2.	Deodorant					
3.	Body spray					
4.	Perfumes					
5.	Powders					
6.	Nail polish					
7.	Acetone (nail remover)					
8.	Hair removal cream					
9.	Use of Hair dye					
10.	Use of shampoo for hairs					
11.	Use of conditioners					
12.	Pharmaceutical (Medicines)					

### 6.1 Amount of personal product usage per month

S.no	Product	Amount
1.	Body lotion	
2.	Deodorant	
3.	Body spray	
4.	Perfumes	
5.	Powders	
6.	Nail polish	
7.	Hair removal cream	
8.	Hair dye	
9	Shampoo for hairs	
10	Conditioners	

## Appendix-B

**Table 1. Correlation between building independent variables of the study and indoor air quality parameters**

Variables	CO2	VOC	PM 10	PM 4	PM 2.5	RH	TEMP	DEW POINT
Geographical location of the building site	0.19NS	0.16NS	0.05NS	-0.22NS	-0.01NS	0.25NS	-0.38*	0.06NS
Site orientation	0.31NS	0.12NS	0.25NS	-0.01NS	-0.05NS	0.22NS	0NS	0.16NS
Height of the building site with reference to main traffic road	0.22NS	0.1NS	0.26NS	0.18NS	-0.24NS	0.11NS	0.03NS	0.09NS
Height of the building site with reference to road in front of the house	0.31NS	0.21NS	0.22NS	0.08NS	0.18NS	0.13NS	0.01NS	0.06NS
Side of the building facing the main road	0.16NS	0.37*	0.28NS	0.28NS	0.25NS	0.33NS	0.39*	0.22NS
Plot area	0.46**	0.02NS	0.24NS	0.11NS	0.01NS	0.36NS	0.08NS	0.26NS
Plinth area	0.44*	0.06NS	0.26NS	0.05NS	0.07NS	0.34NS	0.18NS	0.18NS
Landscape area	0.22NS	0.19NS	0.09NS	0.04NS	0.12NS	0.26NS	0.01NS	0.21NS
FAR	0.07NS	0.28NS	0NS	0.01NS	0.01NS	0.03NS	0.13NS	0.01NS
Open area on the wall of the building facing the main traffic road.	0.22NS	0NS	0.23NS	-0.16NS	0.07NS	0.05NS	0.04NS	0.05NS
Open area on the outer wall of the building	0.23NS	0.12NS	0.17NS	0.25NS	0.16NS	0.06NS	0.27NS	0.04NS
Height of the building	0.36NS	0.46*	0.08NS	0.16NS	0.21NS	0.36NS	0.07NS	0.34NS
Ceiling height	0.2NS	0.08NS	0.02NS	0.12NS	0.09NS	0.31NS	0.37*	0.12NS
No. of rooms	0.12NS	0.19NS	0.06NS	0.14NS	0.1NS	0.2NS	0.07NS	0.23NS
Presence of sunshade	0.15NS	0.1NS	0.15NS	0.39*	0.22NS	0.07NS	0.16NS	0.12NS
Extent of Dust accumulation features	0.45*	0.19NS	0.05NS	0.33NS	0.33NS	0.33NS	0.14NS	0.4*
Wall material	-0.05NS	-0.06NS	0.17NS	0.3NS	0.09NS	0.01NS	-0.01NS	0.02NS
Finishing material for walls	-0.22NS	0.12NS	-0.02NS	0.32NS	0.01NS	0.14NS	-0.02NS	-0.19NS
Flooring material	0.11NS	0.04NS	0.09NS	0.09NS	0NS	0.19NS	0NS	-0.37*
Ceiling type	0.15NS	0.08NS	-0.1NS	0.07NS	0.21NS	0.28NS	-0.28NS	-0.22NS
Extent of	0.19NS	-0.05NS	-0.25NS	0.39*	0.12NS	0.24NS	0.13NS	-0.2NS

Presence of dust								
Frequency of household Cleaning	0.46*	0.04NS	0.03NS	-0.05NS	0.15NS	0.24NS	0.13NS	0.13NS
Feeling of Congestedness	0.45*	0.12NS	0.21NS	0.26NS	0.28NS	0.3NS	0.24NS	0.38*
Frequency of use of Use of cleaning reagent	0.03NS	0.04NS	0.09NS	0.17NS	0.02NS	0.18NS	0.02NS	0.23NS
Extent of use of electrical gadgets	0.2NS	0.17NS	0.34NS	0.12NS	0.07NS	0.14NS	0.19NS	0.16NS
Extent of use of Personal care product	0.18NS	0.06NS	0.22NS	0.3NS	0.3NS	0.11NS	0.04NS	0.06NS

## Appendix-C

**Table 2. Contribution of study variable to the levels of CO<sub>2</sub> present in residential households**

Variable	DF	Estimate (b)	StdErr	t-Value	Pr >  t	SS	Contribution (%)
Cleaning practices	1	-19.35	5.36	-3.61	0.0016	295539	31.04
Dust accumulation features	1	-37.00	11.03	-3.35	0.003	284713	29.90
Presence of dust in the house	1	20.16	7.58	2.66	0.0146	200071	21.01
Finishing material	1	-49.61	23.79	-2.09	0.0494	88701	9.32
Feeling of conjustedness	1	-15.23	7.21	-2.11	0.0467	83083	8.73
<b>Intercept</b>	2733.34						
<b>Adj - Rsquare</b>	0.64						

**Table 3. Contribution of study variable to the levels of VOCs present in residential households**

Variable	DF	Estimate (b)	StdErr	t-Value	Pr >  t	SS	Contribution (%)
Height of the building	1	-0.94	0.33	-2.89	0.0084	666.092	36.230
Ceiling height	1	3.98	2.47	1.61	0.1209	547.441	29.776
Presence of dust in the house	1	-1.08	0.60	-1.79	0.0876	377.753	20.547
Site orientation	1	6.09	2.65	2.3	0.0316	247.235	13.447
<b>Intercept</b>	<b>0.880</b>						
<b>Adj - Rsquare</b>	<b>0.31</b>						

**Table 4. Contribution of study variable to the levels of PM<sub>10</sub> present in residential households**

Variable	DF	Estimate (b)	StdErr	t-Value	Pr >  t
Height of the building	1	0.01141	0.00497	2.3	0.0303
<b>Intercept</b>		-0.101			
<b>Adj Rsquare</b>	-	0.14			

**Table 5. Contribution of study variable to the levels of PM<sub>4</sub> present in residential households**

Variable	DF	Estimate (b)	StdErr	t-Value	Pr >  t	SS	Contribution (%)
Side of the building facing the main road	1	-0.01158	0.00274	-4.22	0.0004	0.00329	33.92
Wall material	1	0.01142	0.00339	3.37	0.0028	0.00317	32.68
Floor material	1	-0.00713	0.00241	-2.96	0.0073	0.00185	19.07
Finishing material	1	0.00697	0.00311	2.24	0.0354	0.00139	14.33
<b>Intercept</b>	<b>0.095</b>						
<b>Adj - Rsquare</b>	<b>0.54</b>						

**Table 6. Contribution of study variable to the levels of PM<sub>2.5</sub> present in residential households**

Variable	DF	Estimate (b)	StdErr	t-Value	Pr >  t	SS	Contribution (%)
Floor area ratio	1	-0.8481	0.1647	-5.15	<.0001	0.07366	42.65
Dust accumulation features	1	0.0158	0.0052	3.06	0.0062	0.04816	27.89
Side of the building facing the main road	1	0.0404	0.0107	3.76	0.0012	0.02695	15.60
Personal care product	1	0.0077	0.0038	2	0.0595	0.01401	8.11
Open area on the outer wall of buildings	1	0.0008	0.0003	2.25	0.0359	0.00993	5.75
Landscape area	1	-0.0003	0.0001	-3.31	0.0035	2.21E-06	0.001
<b>Intercept</b>	<b>0.047</b>						
<b>Adj - Rsquare</b>	<b>0.62</b>						

**Table 7. Contribution of study variable to the levels of RH present in residential households**

<b>Variable</b>	<b>DF</b>	<b>Estimate (b)</b>	<b>StdErr</b>	<b>t-Value</b>	<b>Pr &gt;  t </b>	<b>SS</b>	<b>Contribution (%)</b>
Personal care products	1	0.665	0.154	4.32	0.0004	89.58	29.79
Side of the building facing the main road	1	1.034	0.400	2.58	0.0182	71.89	23.91
Geographical location	1	1.477	0.337	4.39	0.0003	48.07	15.99
Landscape area	1	-0.005	0.003	-1.73	0.0993	34.14	11.36
Cleaning practices	1	-0.192	0.098	-1.97	0.0638	20.49	6.82
Presence of dust in the house	1	-0.533	0.140	-3.82	0.0012	18.64	6.20
Floor material	1	-1.200	0.337	-3.56	0.0021	17.86	5.94
<b>Intercept</b>	<b>33.190</b>						
<b>Adj - Rsquare</b>	<b>0.68</b>						

**Table 8. Contribution of study variable to the levels of temperature present in residential households**

<b>Variable</b>	<b>DF</b>	<b>Estimate (b)</b>	<b>StdErr</b>	<b>t-Value</b>	<b>Pr &gt;  t </b>	<b>SS</b>	<b>Contribution (%)</b>
Geographical location	1	-0.392	0.088	-4.46	0.0002	6.32	36.75
Personal care product	1	-0.081	0.028	-2.88	0.0094	2.86	16.65
Ceiling height	1	-0.462	0.142	-3.25	0.004	2.20	12.77
No. of rooms	1	0.409	0.151	2.7	0.0136	2.07	12.03
Open area on the wall of the building	1	-0.008	0.004	-2.2	0.0401	1.95	11.37
Feeling of conjustedness	1	-0.082	0.036	-2.26	0.0348	1.79	10.42
<b>Intercept</b>	<b>38.850</b>						
<b>Adj - Rsquare</b>	<b>0.62</b>						

**Table 8. Contribution of study variable to the levels of dew point present  
in residential households**

<b>Variable</b>	<b>DF</b>	<b>Estimate (b)</b>	<b>StdErr</b>	<b>t-Value</b>	<b>Pr &gt;  t </b>	<b>SS</b>	<b>Contribution (%)</b>
Floor material	1	-0.507	0.079	-6.39	<.0001	8.77	36.884
Side of the building facing the main road	1	0.167	0.100	1.68	0.1133	5.39	22.677
Personal care products	1	0.124	0.038	3.24	0.0051	2.69	11.318
Site orientation	1	0.205	0.133	1.55	0.1415	2.14	9.004
Plinth area	1	-0.001	0.000	-3.46	0.0032	1.65	6.941
open area on the outer wall of the building.	1	-0.007	0.003	-2.15	0.0468	0.90	3.772
No. of rooms	1	-0.413	0.170	-2.43	0.0274	0.86	3.614
Presence of sunshade	1	-1.161	0.290	-4.01	0.001	1.10	4.617
Presence of dust in the house	1	-0.077	0.036	-2.14	0.0485	0.28	1.172
Ceiling height	1	0.276	0.153	1.8	0.0905	0.0002	0.001
<b>Intercept</b>	<b>15.56</b>						
<b>Adj - Rsquare</b>	<b>0.76</b>						