Final Report

Studies on Indoor Air Quality- Formaldehyde Monitoring in Indoor Environments of Tropical Climates

Prepared for

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1. Literature Review

1.1 Background & Need of the subject

Indoor air pollution is a result of complex phenomenon due to constantly changing interaction of various indoor and outdoor factors. Among various sources of air pollution in urban indoors, sources inside the building have greater concern especially in context of sealed buildings. VOCs is one of the major pollutants in indoors which has a large subset of hazardous compounds; Formaldehyde (HCHO) is one such compound which is widely used as an adhesive in the manufacture of medium density fiberboards, furniture and other wood based products.

Average working Indians spends almost ~90% of time in indoors (8 hrs office+ 13 hrs home + 3hrs outside) (OECD, 2011); and the estimated daily average occupant exposure to formaldehyde (WHO, 2001) is as follows.

Outside	0.07-0.17	ppb
Home	0.9-1.9	ppb
Work Place	16-40	ppb

Thus it is to be noted that the work places could more polluted than home due to higher furniture density and improper ventilation. Most of the indoor air quality studies conducted in India till now are limited to individual buildings with relatively smaller sample size.

1.2 Sources of Formaldehyde

There are many sources of formaldehyde possible in the indoors like furniture, composite wood products, carpets, housekeeping chemicals, room fresheners, photo copiers, laser jet printers, cosmetics, polishes and even tobacco smoking. Figure 1.1 indicates possible sources of formaldehyde indoors. Among these possible sources, furniture accounts for 42–79% of room’s total emissions (Yamashita et al, 2011). It is however important to note that a higher exposure of HCHO in an enclosed space could due to poor ventilation and higher temperature (K W Mui et al. 2009).

Formaldehyde levels decrease with increasing ventilation rates and this relationship is not linear because, a doubling of ventilation rate could decrease HCHO levels only a 30 to 35% (Thad Godish 2000). Levels of HCHO could be higher in offices when the outside air supply rate is high, due to possible formaldehyde sources in the outside air (B Ribot et al, 2003)

Formaldehyde levels decrease significantly with time. After initial rapid decline, HCHO levels decrease at a much slower rate, with relatively elevated levels continuing for years (Thad Godish 2000). This concentration would be stable at 1/3rd of the initial concentration, three years after remodeling (Lihui Huang et al. 2013). In another study carried out by Oak Ridge Naitonal Laboratory, it was found that emissions would drop by 37% of initial rate within 2.2 years (Matthews T.G, 1985).

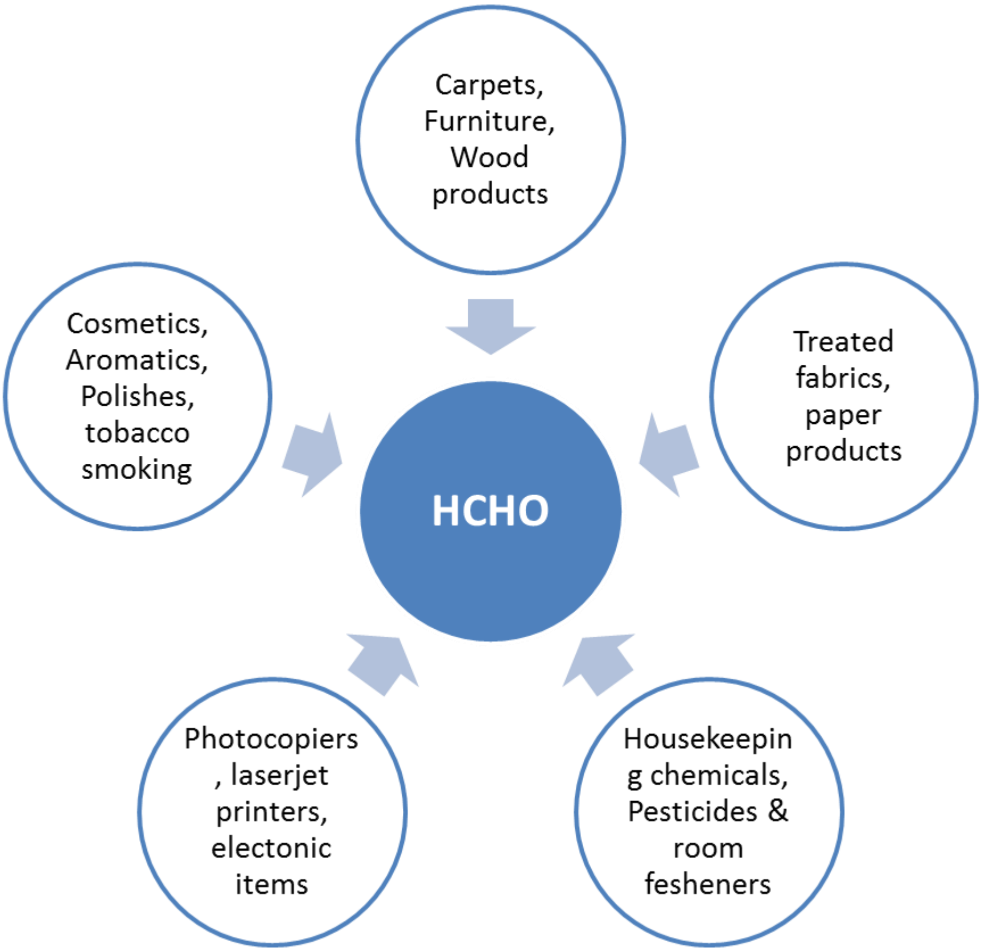


Figure 1.1 Indoor sources of Formaldehyde

It has also been identified that regardless of age, indoor formaldehyde concentration in office buildings could increase due to tobacco smoking (MI Khoder, 2006). Seasonally, highest level of formaldehyde was recorded in the summer (21.6 ppb), compared to 17.7 ppb in spring, 15.3 ppb in autumn and 16.3 ppb in winter (G Mohle D et al., 2003). A recent report published by environmental and public health of Alberta state in Canada highlights that maintaining indoor temperatures between 18°C and 21°C during the winter and between 22°C and 24°C during the summer can reduce HCHO emissions (EPH, 2012)

1.3 Impact of indoor environmental parameters (Temp, RH) on Formaldehyde levels

Temperature and relative humidity are important factors affecting the emission rate of HCHO from building materials. An increase in temperature can encourage the release of HCHO and a decrease in temperature can deter it. It was found that about 5 °C to 6°C increase in temperature can double the HCHO emission rate (EPH, 2012). It was also understood from the previous studies that the effect of temperature on indoor HCHO concentration is exponential whereas the effect of relative humidity is linear (Thad Godish 2000).

Coming to the impact of relative humidity, it was observed that the concentration of formaldehyde increased from 60 ppb to 160 ppb when the relative humidity increased from 34% to 70% during a period of 24 hours (Thad Godish 2000). It is however important to note that it could take days or weeks for formaldehyde emissions from composite wood to reach equilibrium after a change in humidity (Myers, 1985). In the study carried out by Alfred Hodgson it was theorised that the humidity levels ≤ 50% can help in limiting the formaldehyde levels from the wood products (Alfred et al, 2005).

It is certain in the indoors that the levels of relative humidity depends on the air temperature. In a conditioned environment, the highest combination of temperature and humidity (30°C, 70% RH) resulted in HCHO concentration that was 5 times greater than the lowest combination (20°C, 30% RH) (Thad Godish 2000). A recent study carried out at the Lawrence Berkeley National Laboratory demonstrated about 10° C increase in temperature increase the formaldehyde by 1.9 - 3.5 times, and a 35 % increase in relative humidity increases the emissions by a factor of 1.8 – 2.6 (Parthasarathy et al, 2010).

1.4 Reaction with environmental parameters (Temp, RH)

Formaldehyde is an easily soluble compound in water with high reactivity. It is produced as a result of thermal oxidation and sometimes due to chemical reactions of a variety of organic materials present indoors. High emission rates from new materials involve mostly the evaporation of free formaldehyde which is significantly affected by temperature and relative humidity (Thad Godish 2000). However, in the long-term, it has minimal dependence on temperature due to low availability of free formaldehyde in older materials (D E Hun et al. 2010). It was observed that the formaldehyde emission rates increased roughly in proportion to the air velocity, indicating that the reactants participating in the hydrolysis process are not significantly depleted with higher velocities (Meera Sidheswaran et al, 2013)

1.5 Impact of pollutants on occupant health & Productivity

Mui et al reported an average of 2-2.5% increment of HCHO exposure risk for every 1°C increment in the air temperature (in the range of 22.5–25.5°C) and for every 10 ppm increment in the CO2 concentration (in the range of 800–1000 ppm) (K W Mui et al. 2009). Due to its high solubility in water and high reactivity with other organic compounds, formaldehyde could efficiently be absorbed into the mucus layers protecting the eyes and respiratory tracts. Although people vary substantially in their sensitivity to formaldehyde, for the most individuals these effects occur at exposure a level ranging from 37 ppb and 3000 ppb (LEED NC V2).

In the initial stages, formaldehyde rapidly reacts and leads to localized irritation. Prolonged or repeated exposures could result in allergic sensitization, respiratory symptoms like coughing, wheezing, and shortness of breath and sometimes decrements in lung function. An acute high exposure may also lead to eye, nose and throat irritation, pulmonary edema and dyspnea. Recent report by the World Health Organization's International Agency on Cancer (IRAC) highlights formaldehyde as the cause of several types of nose and throat cancer. Table 1.1 summarises possible symptoms at different levels of formaldehyde.

Table 1:1 Health symptoms due to indoor formaldehyde exposure

	Pollutant level	Symptom
Formaldehyde	10 ppb	Nasal obstruction and discomfort, lower airway discomfort, and eye irritation
	40-50 ppb	Mild and moderate eye irritation
	>100 ppb	Watery eyes along with burning sensations in the throat and eyes, nausea, and difficulty breathing when healthy adults are exposed to high levels

The issues related to indoor air quality have been given more attention after the advent of green building concept, in order to construct healthy buildings for better occupant comfort and productivity. Fanger et al has observed in laboratory studies that the overall performance of office tasks would increase by 1.9% for every twofold increase in the ventilation rate (Pawel Wargocki et al, 2000).

In this context, various standards and green building guidelines have been reviewed to understand the pollutant limits recommended to maintain good indoor air quality. Table 1.2 summarises the standards and guidelines of different countries for their recommended limits of formaldehyde indoors.

Table 1:2 Summary of formaldehyde limits suggested by Standards and Guidelines

	Standard/ Guideline	Recommended limit/ threshold	Remarks
Formaldehyde	Green building guidelines 2013 (UAE)	80 ppb	
	iAQ Standard, GB/T 18883-2002 (China)		
	JSOH 2010, Japan		
	RSECE, DL 79/2006, Portugal		
	IAQ Exposure guidelines 1995 (Canada)	100ppb	50 ppb (due to health concern)
	WHO 2010/ Europe	80ppb (30 min)	
	NIOAH 2011 (US)	16 ppb	100 ppb (15 min)
	Green Mark 2012 (Singapore)	100 ppb	
	DoESDTHD No. 2012-14 (France)	40ppb	
	IAQM Group 2003 (Hong Kong)	25ppb	
	LEED v4 BDC (US)	27 ppb	16 ppb (due to health concern)
	LEED India CS (India)	40 ppb / hr	
	LEED India NC (India)	27ppb	
	Well Standard 2015 (US)	27ppb	
	This level is a recommended time-weighted average upper limit exposure concentration for a normal eight to 10-hour workday and a 40-hour work week		

1.6 Test Methods and Protocols

Formaldehyde being an easily soluble chemical compound at the room conditions, it is important to identify its concentration as correct as possible. There are several methods and protocols available for formaldehyde air sampling and analysis, and most of them are laboratory based assessments. Table 1.3 presents various methods available for sampling and analysis of formaldehyde in indoors.

Table 1:3 Summary of measurement methods & protocols

	Sampling Procedure	Suggested Sampling time	Analysis Procedure	Limit of detection (ppm)
Formaldehyde	The sampled solution is treated with ferric chloride- sulfamic acid solution to get a blue cationic dye,	8-24 hr	Colorimetric	0.00002
	Draw air through impinger containing aqueous pararosaniline; treat with acidic pararosaniline and sodium sulfite		Spectrometry	0.008
	XAD-2 polymer tubes impregnated with hydroxymethyl piperidine	1-6 hours 0.2-0.3L/min	Gas chromatography with NP detection	0.001
	Expose passive monitor (Du Pont Pro-Tek® Formaldehyde Badge) for at least 2 ppm-h; analyse according to manufacturer's specifications		Chromotropic acid test	0.08
	Badge impregnated with 2,4-dinitrophenylhydrazine (DNPH)	1-6 h Passive diffusion (0.0286 L/min)	HPLC with UV detection	0.0001
	A glass cartridge containing a dual-bed configuration (300/150 mg) of DNPH-coated silica gel adsorbent (SKC Cat. No. 226-119 or 226-120 with ozone scrubber)	Long-term (1 to 24 hours) or short-term (5 to 60 minutes)	HPLC-UV operated at 365 nm following desorption by acetonitrile	0.00002
TVOC	Glass or stainless steel tubes of various lengths and outer diameters (OD) with the central portion packed with ≥ 200 mg of solid adsorbent material(s).		Thermal desorption followed by gas chromatography	<0.0005
	PID uses an ultraviolet (UV) light source to break down VOCs in the air into positive and negative ions. The PID then detects or measures the charge of the ionized gas, with		PID Method	0.005

	the charge being a function of the concentration of VOCs in the air

Tables1.4 & 1.5 present the summary of formaldehyde monitoring studies carried out across India and outside India, including building details, experimental methodologies and major observations.

Table 1:4 Summary of previous studies in India-Unpublished reports from TERI

S. No	Type of Building	Age of the Building	Climate	Season	Parameters Studied	VOC Levels & Methods	HCHO Levels & Methods	Major Observations
1	Office	17 years (Minor renovation for about 1 year)	Composite	Summer	Temp, RH, RSPM , SPM, SO_2, NO2, CO, CO_2, HCHO, HC and bio aerosols	-	0.01-0.15 ppm (Colorimetric method)	High CO_2 levels due to inadequate ventilation/ fresh air intake,
2	Office	Occupied for a few months	Moderate	Summer	Temp, RH, Carbon-di-oxide (CO_2), VOC, CO, SOx, NOx, PM10, and PM2.5	0.025-0.45 ppm (VOC Monitor)	-	High VOC was detected due to possible sources from wall paints and adhesive used to fix floor carpets
3	Office		Composite	Summer	Temp, RH, RSPM , SPM, SO2, NO2, CO, CO2, Lead (Pb), Arsenic (As), Benzo (α) pyrene, O_3	-	ND (Colorimetric method)	High PM levels due to polluted outdoor air intake without proper filtration, Paint was identified as a potential source for lead pollutant, Formaldehyde at Below Detection Limit (BDL)
4	Office (Green rated)	~5 Years	Composite	Summer	PM_{10}, $PM_{2.5}$, SO_2, NO_2 and Temp, RH, NH_3, O_3, CO, CO_2HCHO, Sulphite, Moulds	0 -0.022ppm (VOC monitor)	ND (Colorimetric method)	Inadequate ventilation, Traces of VOCs and H_2S were also found in the indoor air samples, Formaldehyde at

					(TBC and TFC) VOCs and H_2S			Below Detection Limit (BDL)
5	Office		Composite	Summer	Temp, RH, RSPM , SPM, SO_2, NO2, CO, CO_2 and HCHO	-	0.01-0.015 ppm (Colorimetric method)	Measured Pollutants are within the limits recommended by Standards/ below TLV

Table 1:5 Summary of previous studies around the world

S. No	Type of Building	Age of the Building	Climate	Season	Parameters Studied	HCHO Levels & Methods	Major Observations
1	Office		(France) Moderate		CO2, CO, HCHO and NOx	0.02-0.5 ppm	Formaldehyde levels are higher even when air flow rates supplied to into offices are high (55, 100 and 58 m3/h/person)(B Ribot et al, 2003)
2	6 Offices (Smoking & Non smoking)		Eqypt (Composite)		HCHO, benzene, toluene, ethylbenzene, m,p-xylene and o-xylene	0.028-0.13ppm	Regardless of age the higher levels of formaldehyde in smoking offices indicate that tobacco smoking increases the indoor concentration (MI Khoder, 2006)
3	Office		Japan (Humid)		HCHO, n-hexanal and other adehydes	>0.8 ppm (DNPH) silica get	Emissions from the furniture accounted for 42–79% of each room's total emissions (Yamashita et al, 2011)
4	410 houses & 451 offices	Remodelled for 1 year	Beijing (Composite)	Summer & Winter	Formaldehyde and benzene	UV-VIS Spectrometry	The formaldehyde concentration could decrease and maintain stable at 35% of the initial concentration 3 years after remodeling (Lihui Huang et al. 2013)
5	179		6 cities in			0.0001-0.001	(D E Hun et al.,2010)

	residences	the US		ppm HPLC-fluorescence analysis	
6	10 homes & 10 offices	UK	Temp, RH, PM10, VOCs, aldehydes, CO, (NO2	0.08-0.56 DNPH sampling followed by HPLC analysis	Highest level wasalso recorded in the summer (25.7 mgm3), compared to 21.1 mgm3 in spring, 18.2 mgm3 in autumn and 19.4 mgm3 in winter(G Mohle D et al., 2003).
7	43 offices	HongKong	HCHO, Temp. RH, CO2, TVOC and radon		Higher exposure risk of HCHO is associated with poor ventilation and higher temperature (K W Mui et al. , 2009).

2. Research Methodology

The research objectives, hypothesis and approach methodology proposed for the project are described below. Figure 2.1 illustrates the research work methodology followed in the study.

2.1 Objectives

To monitor Indoor Air Quality and identify the presence of Formaldehydes and the VOCs in newly constructed/ renovated air conditioned office buildings

To study the influence of various building and environmental related parameters on the level of monitored indoor pollutants.

2.2 Hypothesis

The research also initiated to develop hypothesis for long term research on the formaldehyde behaviour, reactions with indoor environment parameters and to develop possible solutions to tackle them. An attempt was made in case these hypotheses could be addressed and understood within the scope of the research as mentioned below.

Formaldehyde emission rate changes depending on varying temperature and relative humidity conditions. As the room conditions are not constant this compound tends to constantly emit and absorb by the possible sources within the indoors. The following methodology for air sample collection and analysis was followed for the study.

2.3 Methodology

Although IAQ problem is prevalent in most of the air conditioned buildings, its prominence is seen in Open Plan office buildings. It was proposed to monitor at six open plan office buildings in the cities of Chennai, Bangalore and New Delhi between May 2015 and April 2016 including all the three seasons (monsoon, winter and summer). It was also proposed to study two buildings (new and old) located in the same compound to observe the relation between age of the building and level of HCHO concentration.

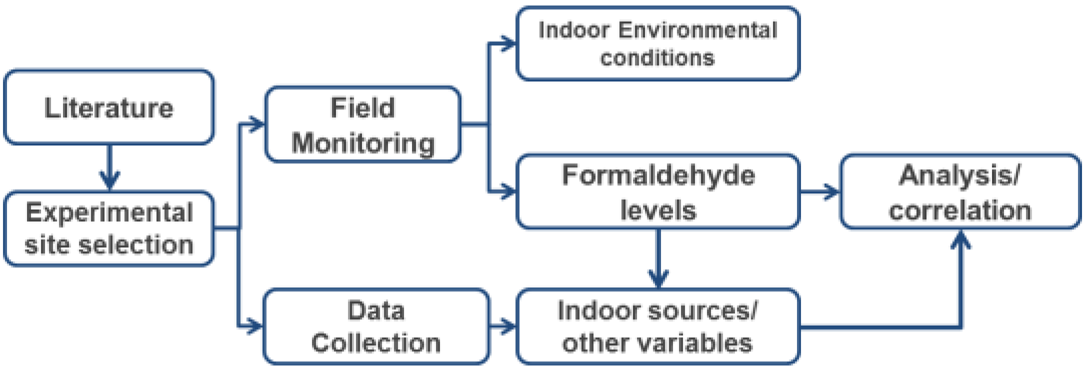


Figure 2.1 Work methodology followed in the study

Monitoring has been completed in six buildings, out of which two were in New Delhi and three were in Bangalore and one was in Chennai. All the six buildings are sealed with glazed facades having different Air-conditioning systems; outside air pollution is high in buildings 1 & 5. All are day time occupied except building 2. Occupancy density is almost similar at works stations, except in building 3, where the measurements are done in a seminar hall. The furniture density is assessed qualitatively and it is high in almost all the buildings. Some buildings are having carpets and the other not. Building related data is thus summarised and presented in Table 2.1.

Carbon dioxide (CO2), Total Volatile Organic Compounds (TVOC) and Formaldehyde were monitored for IAQ along with comfort parameters like air temperature, Relative humidity and air flow rate (from AHU monitored data). The monitoring interval was half an hour for all these parameters. Monitored locations were decided based on the standard protocol- two samples for every 1000 Sqm floor areas. The duration of sample collection was for 8 hours corresponding to office hours. Monitoring period was decided based on the accessibility and availability of instruments; it was about four to five days in Buildings 1 to 4 and about three weeks in building 5 & 6. The monitoring was continued for 24 hours in some cases to observe the variation during day and night respectively.

Table 2:1 Details of Building Related parameters analysed in the study

	Building Details						
	Age of the Building (Years)	Type of AC	Outside pollution	Occupant Density (People/Sq m)	Furni-ture Density	No. of loca-tions	Monitor-ing period
Building 1 (New Delhi)	3	Split AC with mechanical ventilation	High	0.15	High	1 (2nd Floor)	15-19 June'15
Building 2* (New Delhi)	2.5	Central AC with TFA	Low	0.15	High	3 (8th Floor)	22-26 June'15
Building 3 (Bangalore)	15	Spilt AC with infiltration	Low	0.6	High	1 (1st Floor)	28Jul-03 Aug'15
Building 4 (Bangalore)	0.8	Central AC with filtered outside air	High	0.1	High	2 (4th Floor)	04-07 Aug'15
Building 5 (Bangalore)	0.4	VRF (Ducted split) with no fresh air/infiltration	High	0.15	High	1 (1st Floor)	12-25 Jan'16
Building 6 (Chennai)	0.4	VRF (Ducted split) with fresh air system	Moderate	0..02	Mediu m	3 (all floors)	05 Apr 04 May'16

2.4 Instrumentation

The list of instruments used for the monitoring along with their sensitivity details is mentioned in Table2.2. As discussed in the literature, there are several methods and techniques in collecting and analysing the air sample for VOC and Formaldehyde. In this research, sensor based data logging instruments are selected for the monitoring. The monitors are placed at a height corresponding to breathing level of the occupants (approx. 1.4m from the floor level) as suggested by standard protocols. It is proposed to validate the readings of formaldehyde sensor with the lab based sampling and analysis using colorimetric method. The instruments chosen for the monitoring are based on the following techniques.

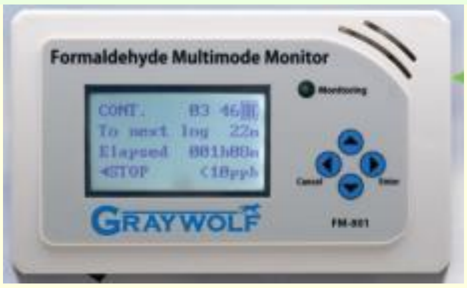
2.5 HCHO- Photoelectric Absorptiometric

Sensor element employs the chemical reaction between formaldehyde and β-diketone impregnated in a porous glass. The concentration of rutidine derivatives yellows the sensor in proportion to the formaldehyde concentration and the duration of exposure.

2.6 VOC- Photoionization Detection

PID uses an ultraviolet (UV) light source to break down VOCs in the air into positive and negative ions. The PID then detects or measures the charge of the ionized gas, with the charge being a function of the concentration of VOCs in the air

Table 2:2 Instruments used for monitoring of IAQ and Indoor environmental parameters.

Instrument	Parameters measured	Sensitivity
 VOC Monitor (RAE make)	VOC (Isobutene equivalent)	0.05 ppm
 HCHO Monitor (Graywolf make)	HCHO	0.02 ppm

 Thermohygro Datalogger (Dickson make)	Air temperature & Relative Humidity	±0.5°C
 Thermohygro Datalogger (Testo make)	Air temperature & Relative Humidity	±0.2°C
 Q-Track Indoor air quality monitor (TSI make)	CO_2	±(3% of reading + 50 ppm
 Active air sampler (SKC make)	HCHO air sampling	
 Spectrophotometer (Systronics make)	HCHO colorimetric analysis	

3. Results and Discussions

3.1. Building 1- New Delhi

It is a four storey (G+3) office building, located in the heart of New Delhi near a busy traffic signal where the ambient air pollution levels are significantly high. This building holds small office spaces on each floor with typical floor plan. The building has been refurbished and the interiors were remodelled for three years. Split AC is used for air conditioning; Ventilation is provided through false ceiling using mechanical intake and exhaust fans along with the .Although the floor area is small, spatial monitoring was done, both horizontally and vertically to observe the variation in formaldehyde levels. The monitoring was also done on all the three floors, first, second and third to see the variation floor wise the results of which are presented in Annexure III. Figure 3.1 presents the typical floor plan of the building showing monitored locations along with the HCHO levels (2 hr average). Continuous monitoring has been done at the location encircled on the floor plan.

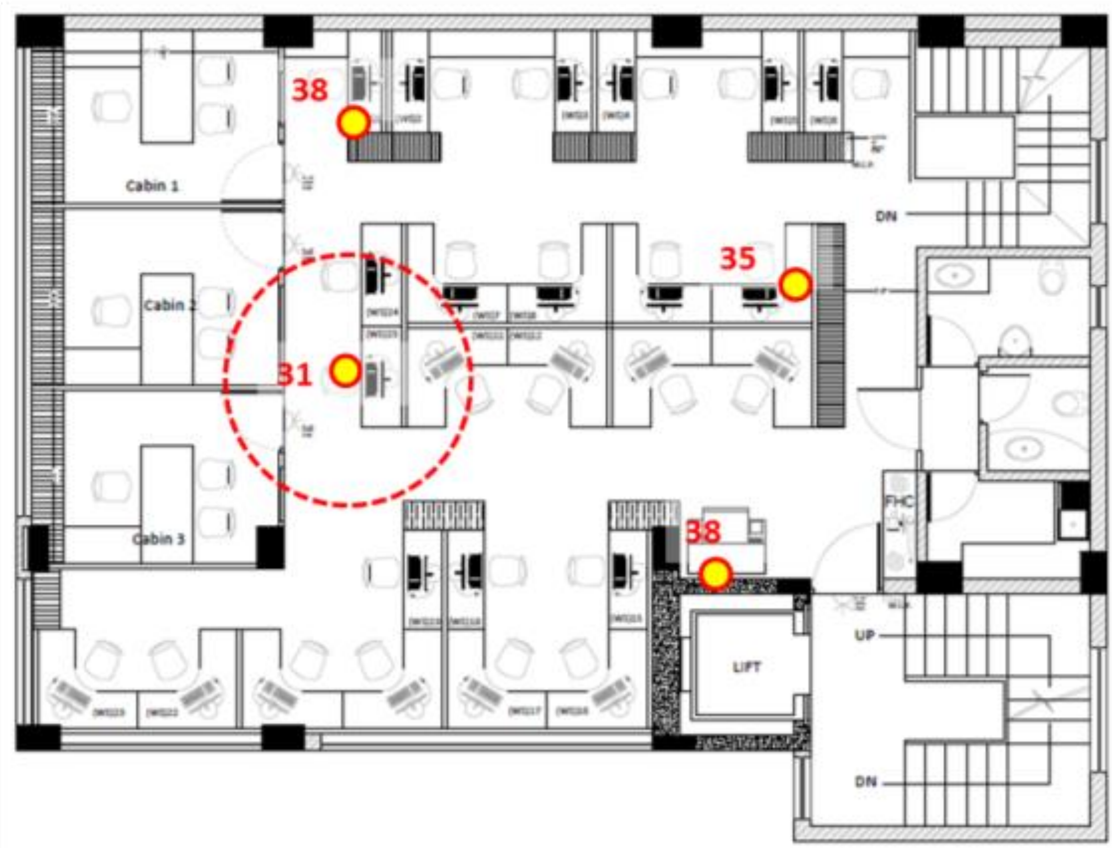


Figure 3.1 Typical floor plan showing monitored locations- Building 1 in New Delhi

There was no significant variation observed in HCHO levels across the floor; However 38 ppb was observed where more books & office bags (leather) are present on the desks. Vertically, as the sensor distance increased from the floor level, HCHO levels got reduced; this may be because of two reasons, floor cleaning chemicals used every morning and the distance from the major furniture (office desks/ work stations) is increased. Higher level at 9:00 AM was observed in the morning, immediately after the floor cleaning activity. 3.2

shows the HCHO levels (2hr average) observed vertically on the monitored floor. Figure 3.3shows the images taken during the monitoring.

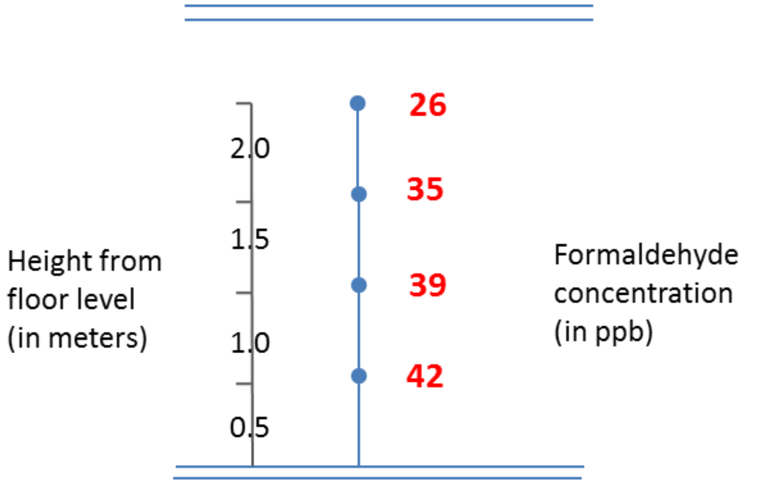


Figure 3.2 Varying HCHO levels vertically on the monitored floor]

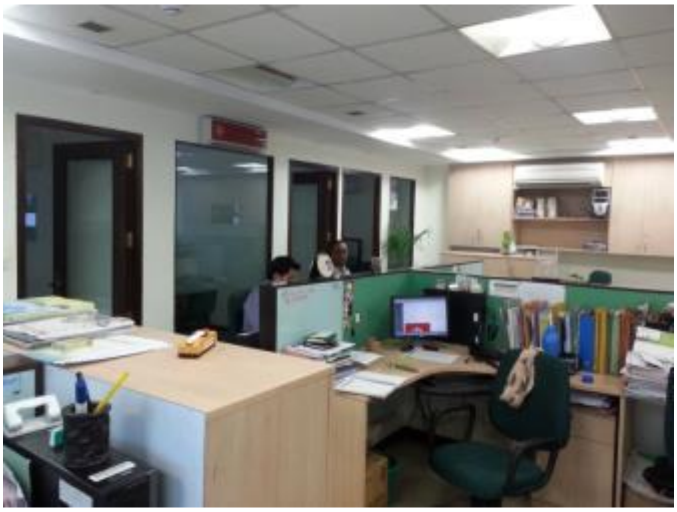


Figure 3.3 Sensor and Interior view of the office

Continuously monitored HCHO results (24 hours) from first floor are analysed for its relation with air temperature and relative humidity. On a 24-hr cycle, HCHO has an exponential relationship with air temperature (with R^2= 0.3) and linear relationship with relative humidity but with a slight lag. Formaldehyde levels seems to high (up to 64ppb) during the night time when the room air temperature is increased upto 29.5°C and when the relative humidity levels were about 50%. The average HCHO level is 33ppb and the standard deviation of the data is 10, whereas the mean, standard deviation of air temperature and relative humidity are 27.2, 1.5 and 49.3, 2.7 respectively. The average HCHO level is just above the LEED recommended limit (27 ppb). Figures 3.4 & 3.5 illustrate the 24-hr profile of HCHO with Air temperature and relative humidity.

Formaldehyde concentration seems to be increasing during the nights till the next day morning, which could be due to accumulation of polluted air in the absence of ventilation/ fresh air system and rise in indoor air temperature. Gypsum false ceiling (porous) doesn’t seem to have a major influence on the HCHO levels. VOCs were not detected in the building during the monitoring period.

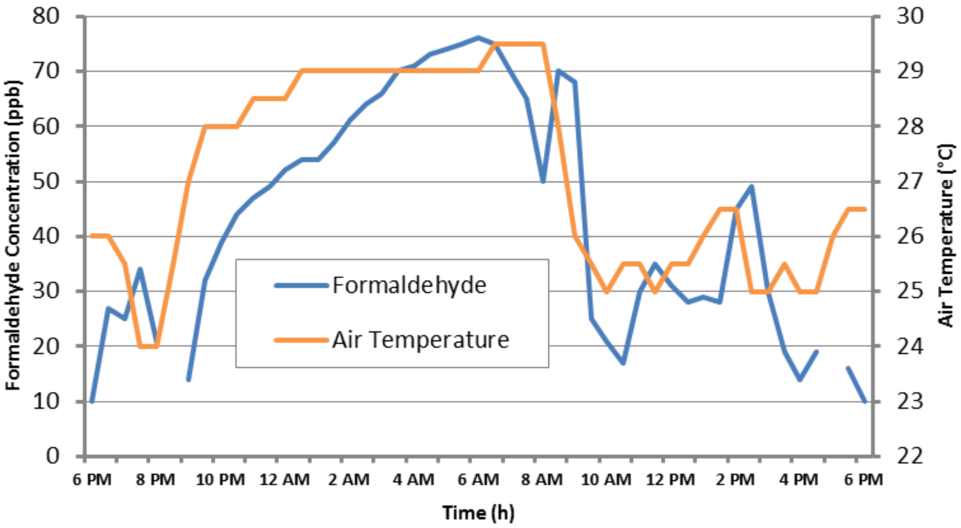


Figure 3.4 Formaldehyde and Air Temperature levels observed in building 1

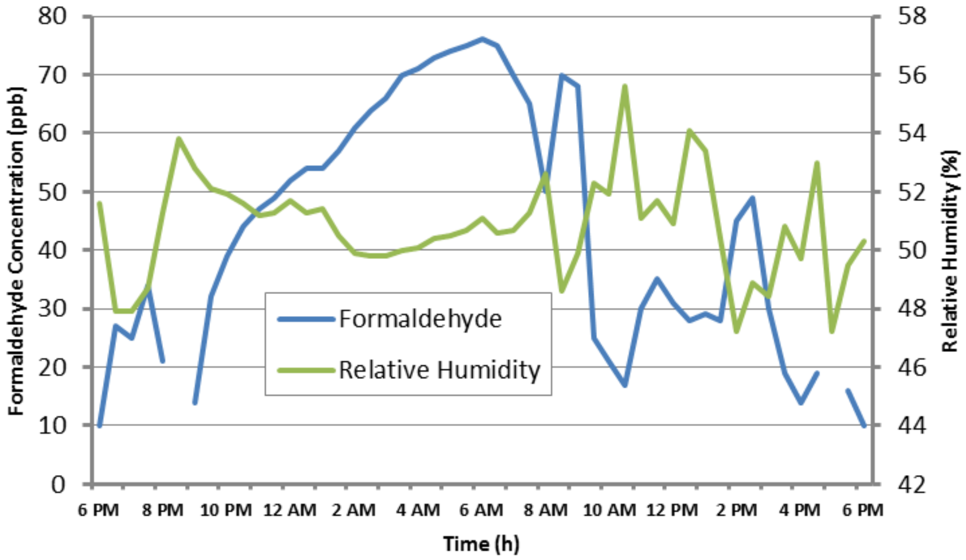


Figure 3.5 Formaldehyde and Relative humidity levels observed in building 1

3.2. Building 2-New Delhi

It is a high-rise (G+12) open plan IT office building, housing day time and 24- hour occupied IT and BPO activities. The building is just two and half years old, located in the outskirts of New Delhi with comparatively lower ambient air pollution levels than the city. The ambient climatic conditions were little warm and humid during the monitoring with average daily temperature and relative humidity 29°C and 70% respectively. The building is LEED NC gold certified and it is assumed that all the interior materials (carpet, ceiling and furniture) are complied with LEED. Fresh air is treated supplied inside the building as part of the centralised HVAC system. The monitoring was carried out at three different locations on the eight floor (Figure 3.6 & 3.7).

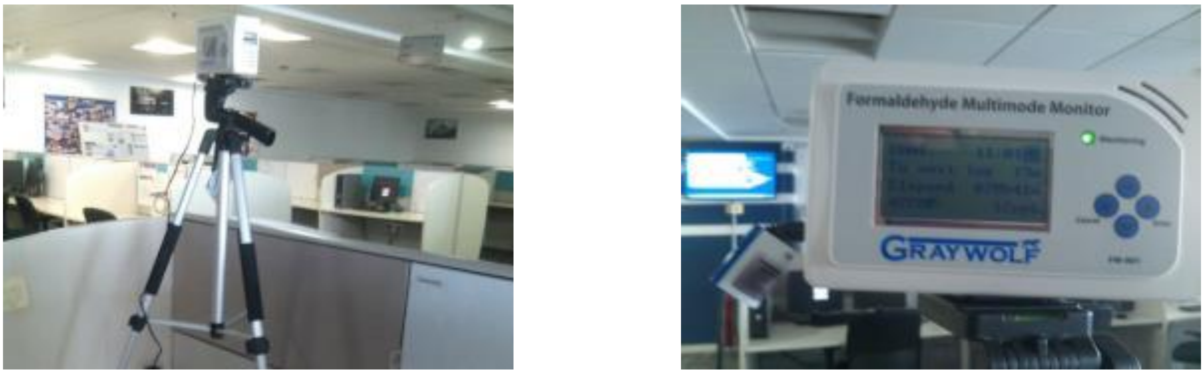


Figure 3.6 Interior view of the office and sensor showing formaldehyde levels during the monitoring

Figure 3.7 Floor plan showing monitored locations- Building 2 in New Delhi

An average of 2 ppb variation was observed between the three monitored locations, location 2 being the highest (18 ppb) and location 1 being the lowest (14 ppb). This could be due to variation in the exposure to furniture in the three monitored locations. Continuously monitored HCHO results (24 hours) from location 2 were analysed for its relation with air temperature and relative humidity. There was no significant variation in HCHO levels throughout the day; this could be due to Treated Fresh Air Unit which is running during the monitoring period. Indoor air temperature shows a similar trend as ambient air temperature confirming the fresh air supply to the building. Maximum HCHO level (30 ppb) was found during the evening because of the high occupant density during the shift changing hours. CO2 levels were found high (up to 1750 ppm) in the evenings during the shift changing hours. Thus, HCHO levels were found to be in the trend of CO_2 levels, confirming that the levels could be high due to occupancy density. Graphs showing relationship between CO2 and formaldehyde levels is presented in the Annexure IV . The average VOC levels were found to be below the LEED specified limit. However, the maximum value has reached upto 1 ppm, which was due to some maintenance activity taken during the monitoring.

The average HCHO level is 18ppb and the standard deviation of the data is 4.3, whereas the mean, standard deviation of air temperature and relative humidity are 23.32, 1.9 and 61.5, 5.4 respectively. However, the mean levels found in the building are considerably lower than the LEED specified limit.

Although the trend of HCHO variation is similar to that of Air temperature, there is no significant trend observed in the variation of HCHO and its relation with Air Temperature as well as Relative Humidity. A very poor correlation was found between air temperature and formaldehyde. Figures 3.8 & 3.9 illustrate the 24-hr profile of HCHO with Air temperature and relative humidity.

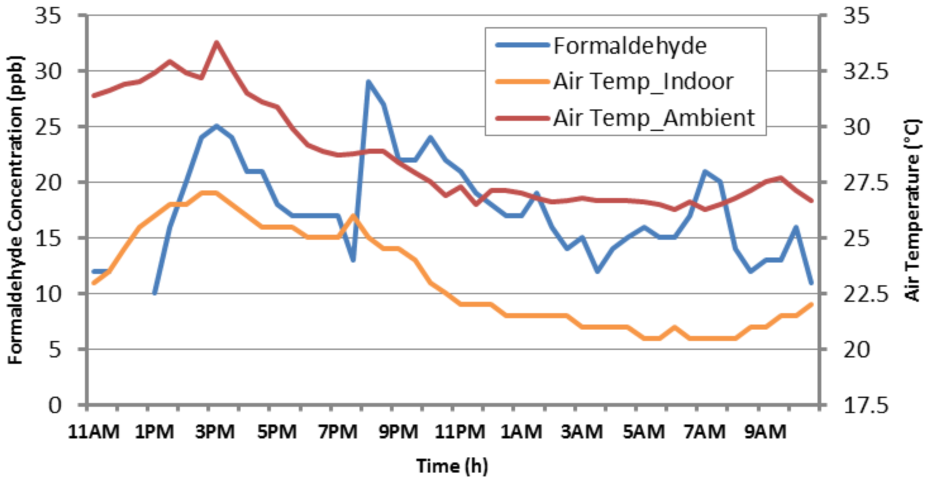


Figure 3.8 Formaldehyde and Air Temperature levels observed in building 2

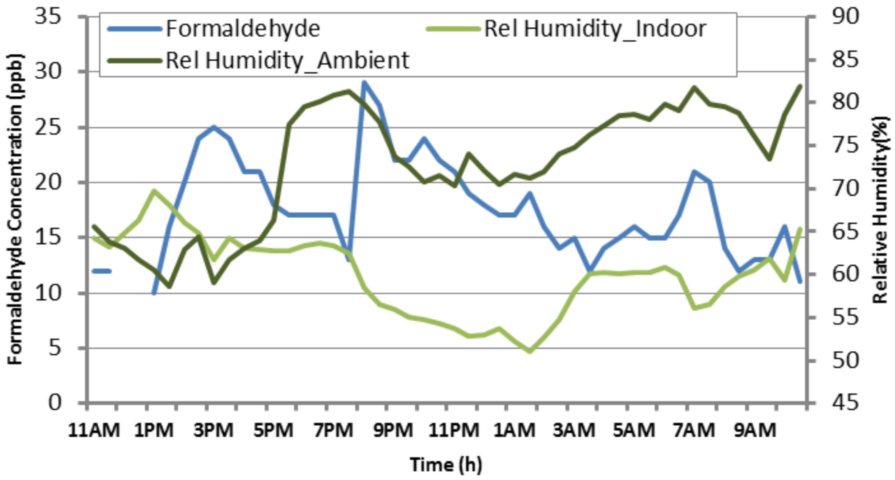


Figure 3.9 Formaldehyde and Relative humidity levels observed in building 2

3.3. Building 3-Bangalore

It is a three storey office building located in a residential area of Bangalore where the ambient pollution is relatively low. Monitoring in this building was majorly done for two purposes; one to validate formaldehyde sensor readings with the lab based colorimetric analysis and the second to observe variation in formaldehyde and VOC levels before and after the varnishing of office furniture. Unlike other buildings, monitoring in this building was carried out in a seminar hall located at first floor level and in a conference room located on ground floor (Figure 3.10).

Ambient climatic conditions were moderate and the recorded maximum temperature during the monitoring was 30°C. The building is 15 years old and the interiors are done in the monitored location for about ten years. Interiors of the seminar hall (locaiton1) are having a carpet and wooden wall clad for acoustical purpose. Split AC is provided for air conditioning purpose and there is no separate fresh air intake other than infiltration while opening and closing the doors.

Formaldehyde was collected using an active air pump using prescribed chemical solutions in the standard sampling method (James P, 1989) for eight hours during the day time when the hall was occupied. The collected air sample was analysed using colorimetric method (Figure 3.11). The results of colorimetric analysis are presented in Annexure I along with the formaldehyde sensor readings.

Formaldehyde concentration was found almost six times higher than the normal level when the spilt AC was on in the morning; this could be due to reaction mechanism of accumulated formaldehyde where there is a sudden change in the indoor air temperature. There is a very good exponential correlation found between air temperature and formaldehyde (R^2=0.78). The average HCHO level is 30.3ppb and the standard deviation of the data is 27.3, whereas the mean, standard deviation of air temperature and relative humidity are 24.3, 1.4 and 56.7, 6.4 respectively. Figures 3.12 & 3.13 illustrate the 24-hr profile of HCHO with Air temperature and relative humidity.

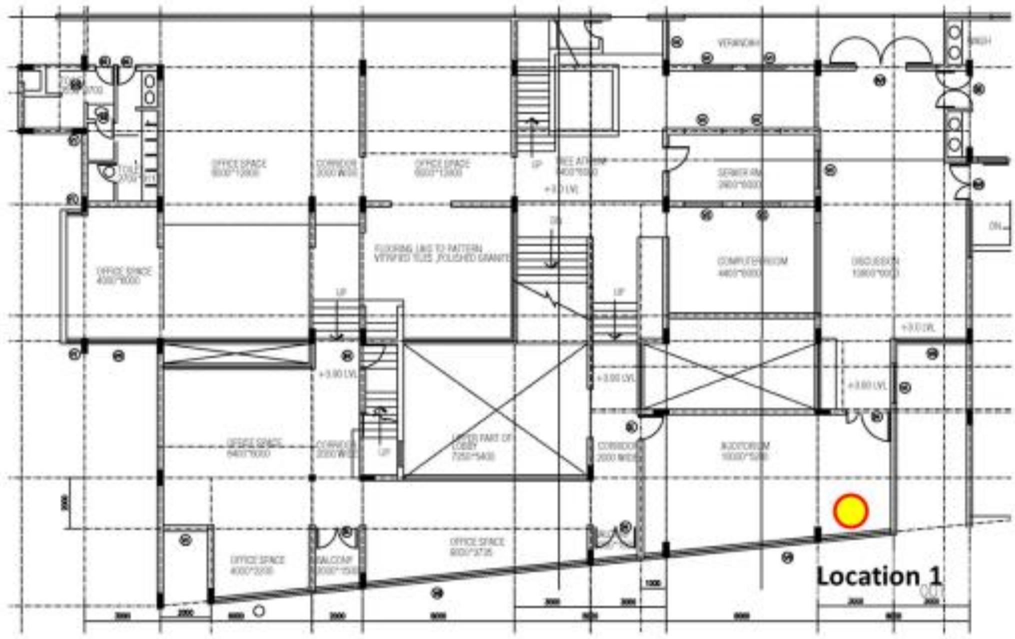


Figure 3.10 Floor plan showing monitored location- Building 3 in Bangalore

Figure 3.11 Colorimetric formaldehyde sampling along with data logger; Spectrophotometer used for colorimetric analysis in lab

Average CO2 levels were found significantly high (2576 ppm) due to high occupancy during the daytime. Formaldehyde levels were above the average level (slightly higher than the LEED specified limit) throughout the day except for a few hours during the night when there was no occupancy and when the air conditioning was off. The levels were found higher during the day time when the space was occupied and when high relative humidity levels were found inside the space. Thus, the impact of occupancy was understood to be more dominant in this case. Variation in HCHO along with CO_2 levels is presented in Annexure IV.

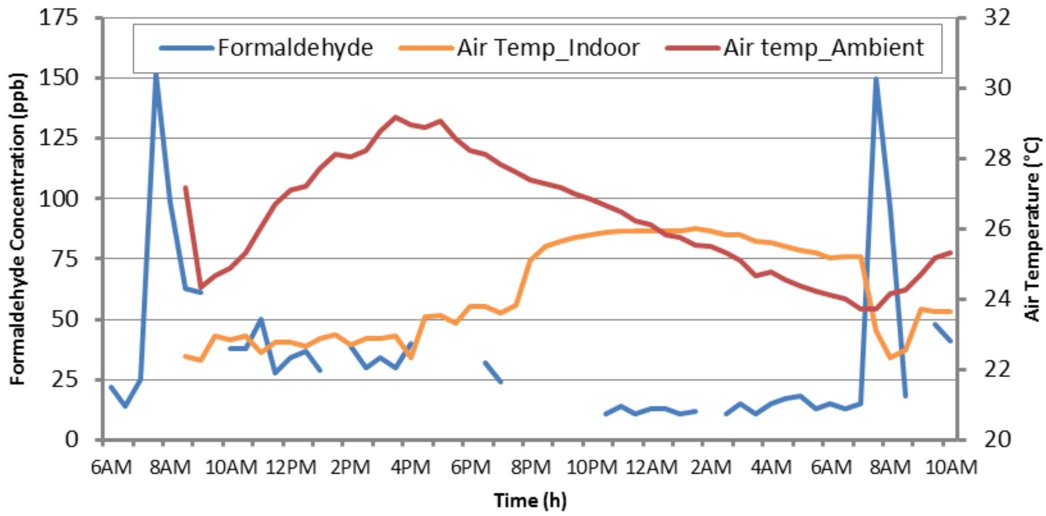


Figure 3.12 Formaldehyde and Air Temperature levels observed in building 3

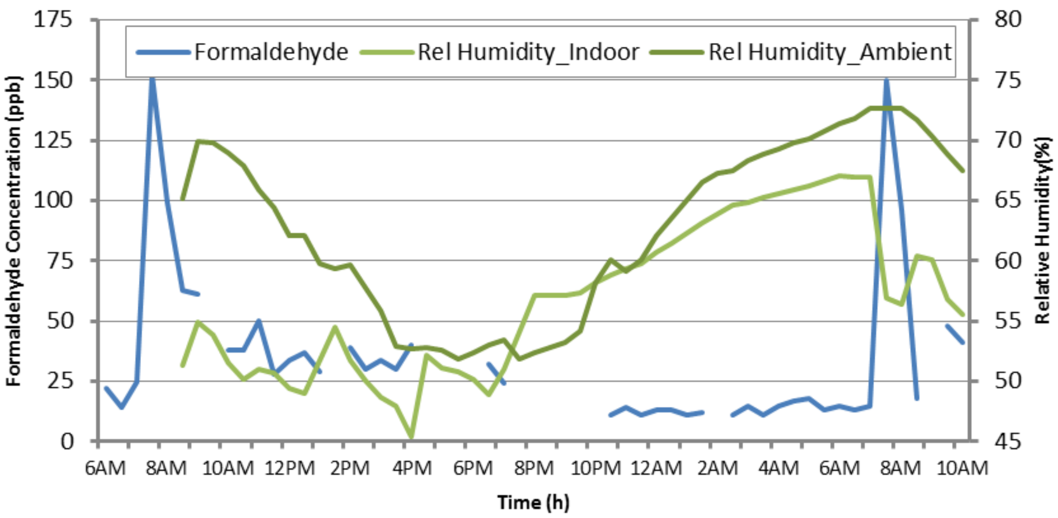


Figure 3.13 Formaldehyde and Relative humidity levels observed in building 3

3.4. Building 4-Bangalore

This is a seven storey (G+6) open plan IT office building located on a busy traffic route in Bangalore with significantly high ambient air pollution. Interiors of the monitored floor are refurbished for about eight months with highly decorative with wall clad, wall papers, ceilings and carpets. The building is a LEED Commercial Interiors platinum rated building and so the inter materials were chosen based on the LEED guidelines. Air conditioning is provided using a centralised variable air volume system with provision of filtered outside air supply. The monitoring was carried out on the fourth floor and two work station zones are selected for air quality measurement as indicated in the floor plan (Figures 3.14 & 3.15).

No variation was observed in the formaldehyde levels (24 hr average) monitored in both the locations. It was understood from the measurements of this building that formaldehyde level has a direct relation with indoor air temperature as well as relative humidity. During the day time, air temperature and relative humidity were observed at a very minor variation between 22.5 and 23.5°, 68.8 and 72.6 respectively. As observed in building 1, HCHO has a direct relationship with relative humidity with a slight lag. Figures 3.16 & 3.17 illustrate the 24-hr profile of HCHO with Air temperature and relative humidity.

Thus the sensitivity of formaldehyde variation with indoor environmental conditions was evidently noticed. Formaldehyde reached peak level immediately after the AC was put on. This could be due to accumulation of formaldehyde in the space and its reaction to the immediate change in the temperature.

On a 24-hr cycle, HCHO has an exponential relationship with air temperature (with R^2= 0.4). HCHO levels were high (up to 75 ppb) during the night time when the air temperature was relatively high. This could be possible because of the higher emission rates possible at higher temperatures.

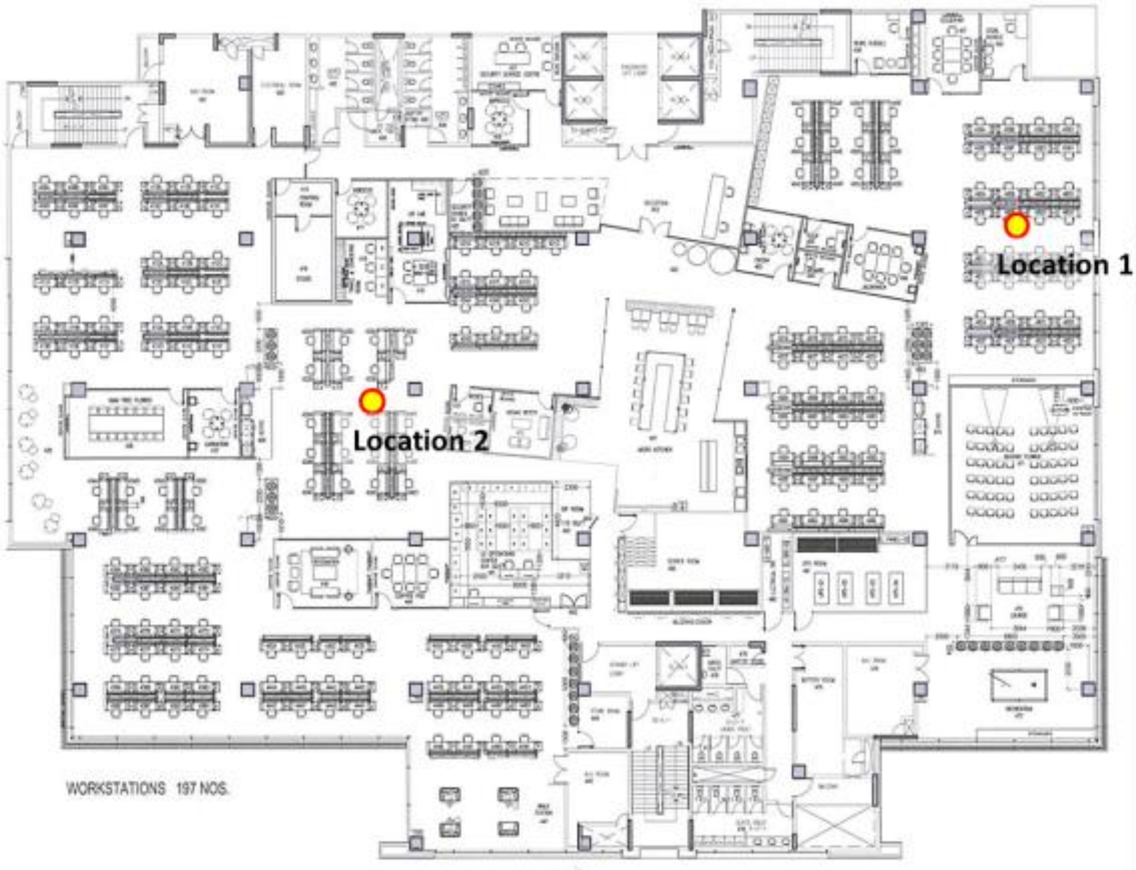


Figure 3.14 Floor plan showing the monitored locations at Building 4-Bangalore

Figure 3.15 Interior view of the office with monitoring instrumentation in location 1 and 2

The average HCHO level is 54.7ppb (24 hr) and the standard deviation of the data is 9.56, whereas the mean, standard deviation of air temperature and relative humidity are 23.78, 0.24 and 70.6, 1 respectively. Although the building is LEED rated, the mean levels are found higher than the LEED specified limit; this is due to high density of interior furniture. Thus furniture including carpets & ceilings seemed to be dominant in the HCHO emissions observed in this building.

No VOCs (in the detectable limit) were found in this building. An attempt was made to see the relationship between supply air flow rate and the formaldehyde levels, which is presented in the Annexure V. CO2 data was used to estimate the occupancy rate and its relationship with HCHO is also shown in the Annexure IV.

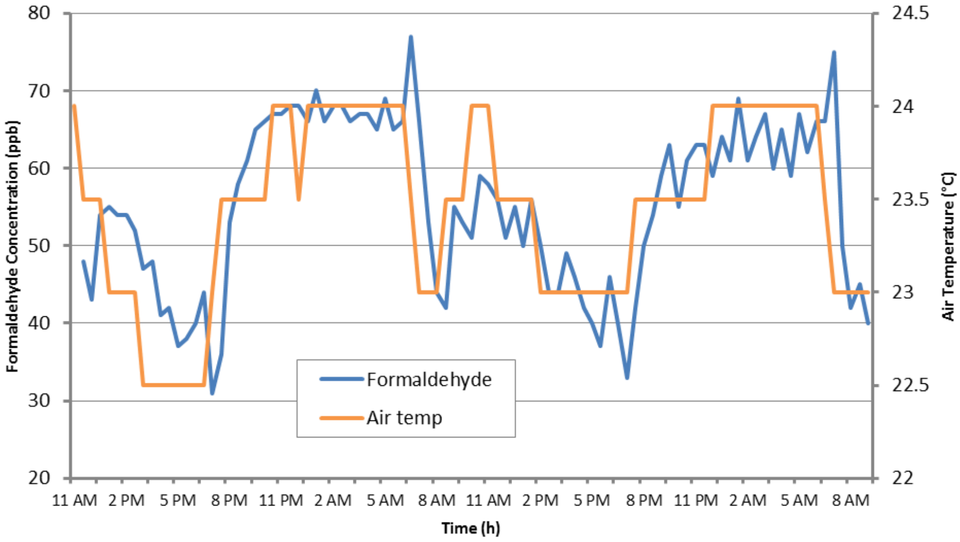


Figure 3.16 Formaldehyde and Air Temperature levels observed in building 4

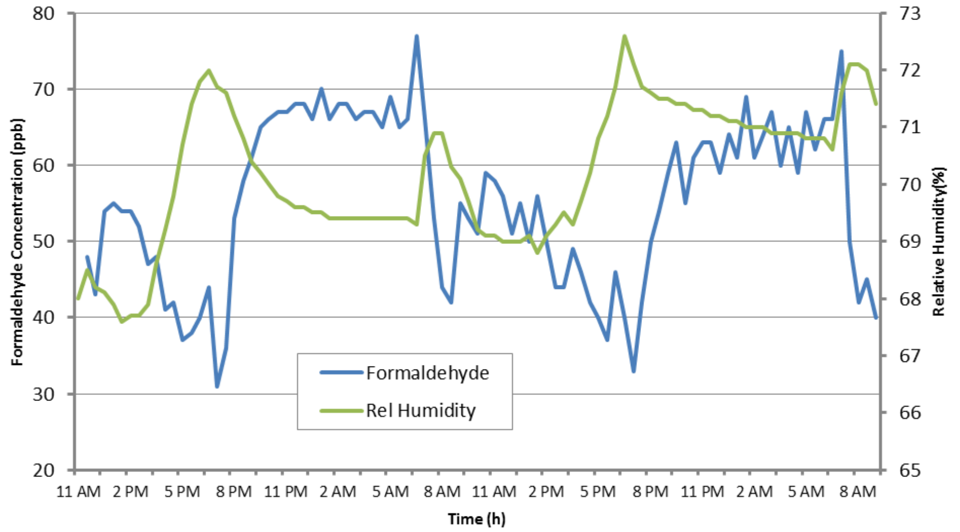


Figure 3.17 Formaldehyde and Relative humidity levels observed in building 4

3.5. Building 5-Bangalore

It is a five storey (G+4) office building, located in the heart of Bangalore on a busy traffic route with significantly high ambient air pollution. Ducted split AC system (VRF) is provided for air conditioning the space with no fresh air circulation. The monitoring was carried out on first and second floor level and the location is indicated. First floor is having typical office furniture with no floor carpets but false ceiling, whereas second floor is having an extensive woodwork with high partition, wall clad, carpet and false ceiling. The Interiors were done 4 months ago on first floor and 18 months on second floor by the time of monitoring. This gave an opportunity to observe the variation in formaldehyde emission with respect to age of the furniture. Figure 3.18 present typical floor plan of the office where the monitoring was carried out.

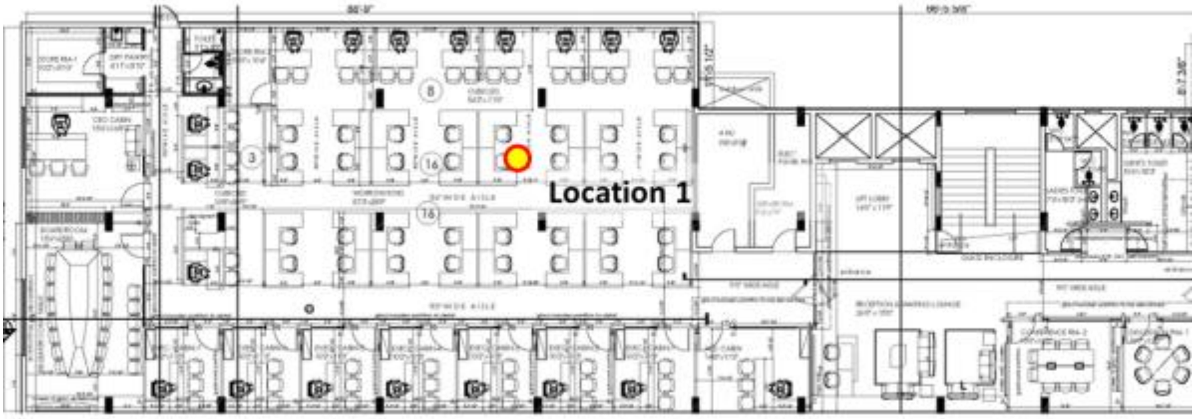


Figure 3.18 Floor plan showing the monitored locations at Building 5-Bangalore

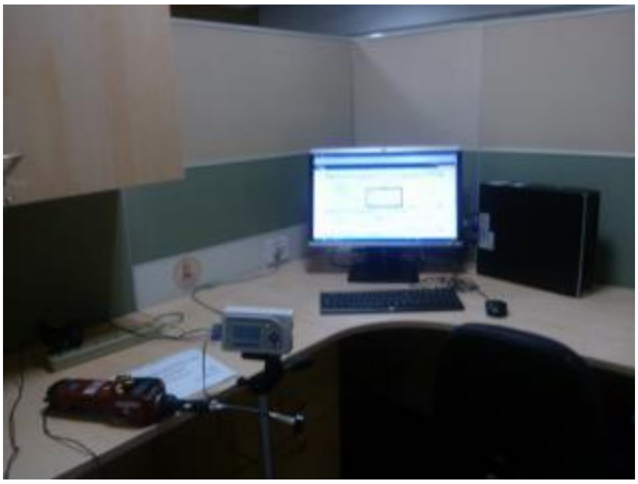


Figure 3.19 Interior view of the office with monitoring instrumentation in location 1 and 2

Formaldehyde concentration was found high (up to 180ppb) during the nights at first floor level, when the temperature was more or less constant at 23.5°C. These high emissions could be due to the new furniture and paints used inside the space and lack of fresh air supply inside the building. At first floor level, formaldehyde levels were 90ppb (10 hr avg) and 147 ppb (24 hr-avg); it was above 50 ppb throughout the monitoring period. It was interesting to note that although interiors of second floor was older than the first floor, formaldehyde level was more or less same; this was due to more furniture density on the second floor compared to first floor.

The mean and standard deviation of HCHO data collected in this building is 147ppb (24 hr) and 41.1, whereas the mean, standard deviation of air temperature and relative humidity are 23.4, 0.33 and 70.5, 2.6 respectively.

The monitoring was repeated on the first floor during the winter season, immediately after 10 days of re painting and varnishing done for the interiors. The maximum HCHO level was observed as 236 ppb with a mean level of 111ppb. There was a poor correlation observed between HCHO and relative humidity levels (R^2=0.06) during the occupied hours when the humidity was controlled between 50% and 55%. Whereas, the relation improved (R^2=0.4) when the levels are above 60%. Figures 3.20 & 3.21 illustrate the 24-hr profile of HCHO with Air temperature and relative humidity with and without occupancy.

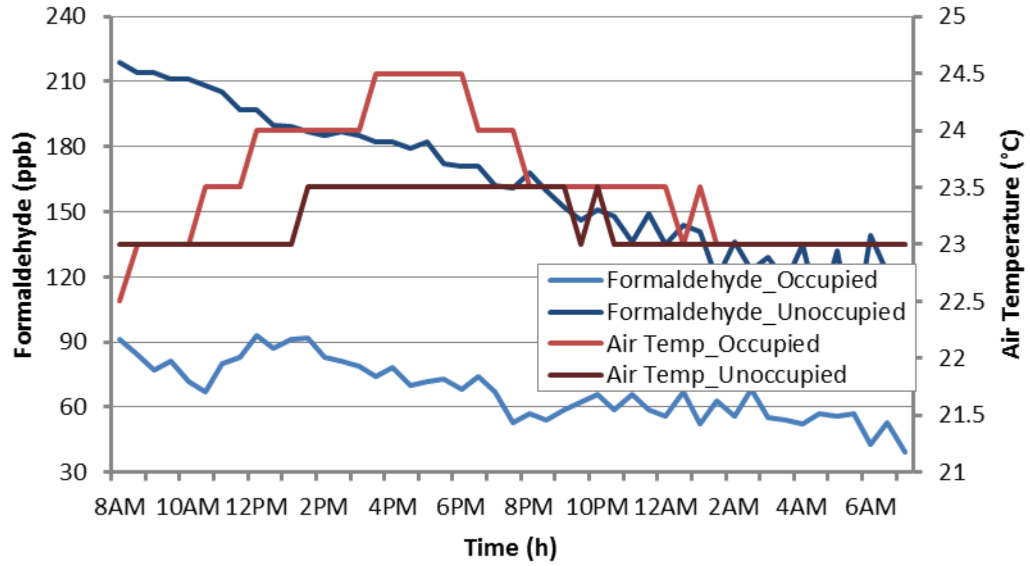


Figure 3.20 Formaldehyde and Air Temperature levels observed in building 5

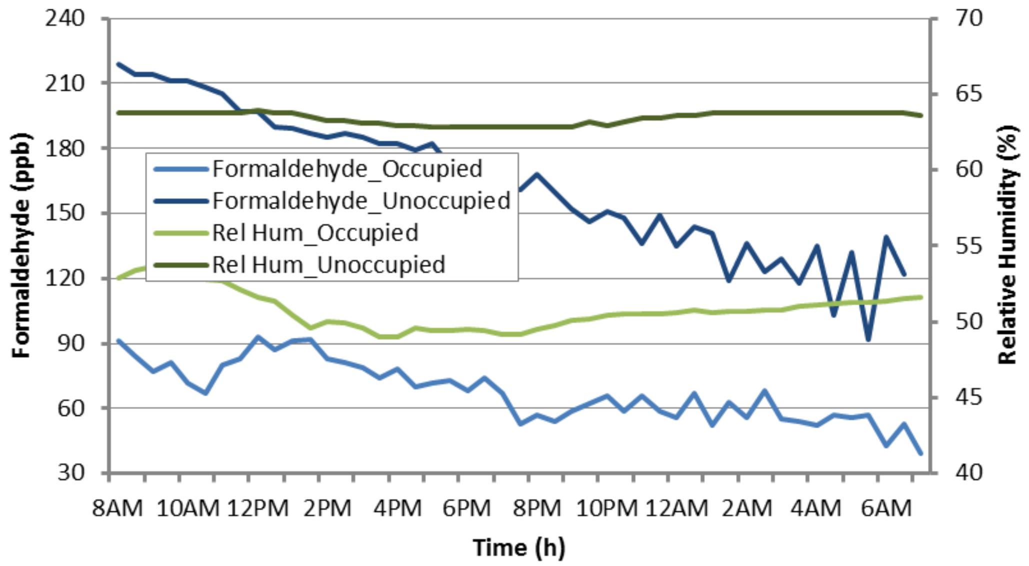


Figure 3.21 Formaldehyde and Relative humidity levels observed in building 5

3.6. Building 6-Chennai

It is a four storey (G+3) office building, located at ramanujan info city next to the highly vegetated IIT madras campus in Chennai. Variable Refrigerant Flow (VRF) with fresh air circulation is provided for air conditioning the space. The monitoring was carried out on all the floor levels including labs and meeting rooms. Low emission and LEED certified materials have been used in the office furniture including partitions, wall clad, carpet and false ceiling. The Interiors were done 4 months before the monitoring was carried out.

Unlike in other buildings, the monitoring was carried out only during occupied hours and not in 24-hours cycle. Formaldehyde concentration was found up to 52ppb at work stations during air-conditioned occupancy when the temperature was more or less constant at

22.5°C. The furniture density in the measured floor is relatively low compared to other buildings. The mean and standard deviation of HCHO data collected in this building is 25ppb (10hr) and 9, whereas the mean, standard deviation of air temperature and relative humidity are 22.5, 0.2 and 68.3, 2.4 respectively.

4. Analysis Summary & Conclusions

Summary of monitoring of formaldehyde (HCHO) and other indoor environmental parameters is presented in this chapter. The study covers six office buildings located in composite, moderate and warm-humid climatic zones of India. Two of the surveyed buildings are LEED rated and one among them is 24-hr occupied office. Building characteristics, HVAC details and other independent parameters affecting HCHO like occupancy and furniture density are summarised in Table 2.1 of Chapter 2.Table 4.1 provides a comprehensive data of formaldehyde levels (10 hr & 24 –hr average) including VOCs and other environmental parameters monitored at all the six locations studied in this research. It was observed that HCHO levels were beyond the limits suggested by standards (27 ppb) in all the buildings except buildings 2 & 6 (Figure 4.1).

Table 4:1 Summary of formaldehyde measurements

	Monitored Parameters									
	Air Temp (°C)		RH (%)		HCHO (ppb)		TVOC (ppm)		CO_2 (ppm)	
	10 hr	24 hr	10 hr	24 hr	10 hr	24 hr	10 hr	24 hr	10 hr	24 hr
Building 1 (New Delhi)	25.8	27.2	47.6	49.3	23.7	30.9	0	-	955	-
Building 2* (New Delhi)	25.2	23.2	67.0	61.5	18.2	18.3	0.28	-	1495	-
Building 3 (Bangalore)	22.9	24.3	50.7	56.7	38.3	30.3	0	0	2576	-
Building 4 (Bangalore)	23.7	23.8	69.7	70.6	48.9	54.7	0	0	957	-
Building 5 (Bangalore)	23.1	23.4	68.6	70.5	83.8	147.2	0.42	0.5	-	-
Building 6 (Chennai)	22.5	-	68.3	-	25	-	-	-	-	-

Emissions in buildings with green interiors were found comparatively low (Buildings 2 &4). Although building 4 is green rated, due to the density of interior wood work maximum formaldehyde level was found to be 74 ppb. It was noted that in Building 5, although interiors of second floor was older than the first floor, formaldehyde level was more or less same due to higher furniture density on the second floor. Thus, in buildings 3, 4 & 5 furniture seemed to be the dominant source of formaldehyde emission than other parameters.

Formaldehyde levels shot up in the mornings as observed in Buildings 1, 3 & 4. This was due to floor cleaning activities and the reaction mechanism of formaldehyde with indoor air where there was a sudden change in temperature. As observed in the analysis at individual building level, HCHO has an exponential relation with air temperature. It is however probable that HCHO is produced as a result of thermal oxidation and sometimes due to chemical reactions with variety of indoor parameters like moisture, air flow rate, occupancy and CO_2 (Thad Godish 2000).

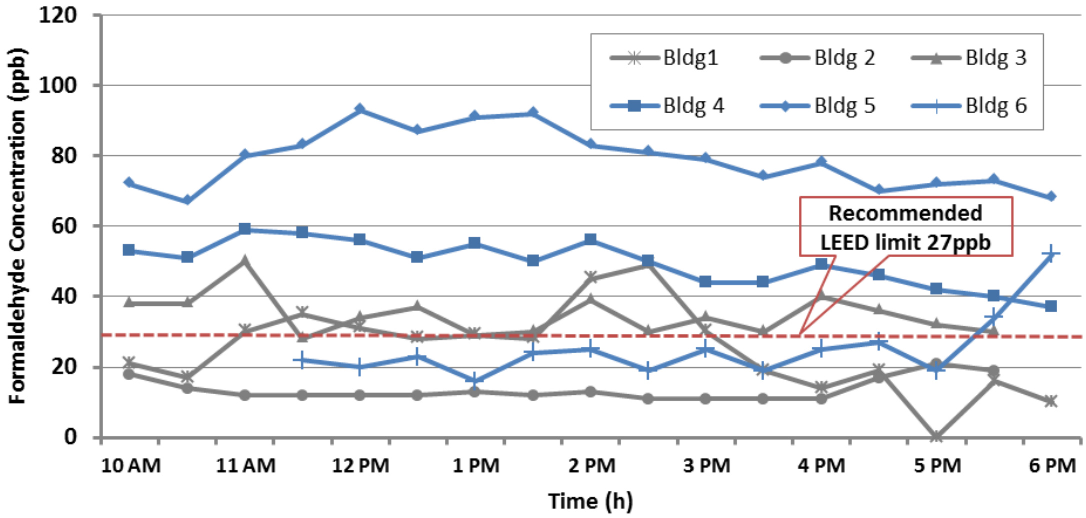


Figure 4.1 Profile of formaldehyde levels in the monitored buildings

Table 4.2 summarises statistical analysis of the formaldehyde as well as air temperature and relative humidity. Except building 2 and 4, all the other buildings have poorly distributed formaldehyde levels with respect to air temperature and relative humidity across the day. Building 5 which is the most recently renovated among all, have higher emissions of formaldehyde with levels above the average.

Table 4:2 Summary of statistical analysis of HCHO and indoor environmental conditions

	Age of the Building (Years)	Formaldehyde				Air Temperature				Relative Humidity			
		Max	Min	Avg	SD	Max	Min	Avg	SD	Max	Min	Avg	SD
Bldg 1	3.5	64	12	31	9.9	29.4	22.5	27.19	1.5	56.5	43.2	49.3	2.7
Bldg2	2.7	29	10	18.3	4.34	26.6	20.7	23.32	1.9	73.1	52.4	61.5	5.4
Bldg 3	12	150	11	30.3	27.3	26	22.3	24.3	1.4	67.1	45.4	56.7	6.4
Bldg 4	0.8	75	33	54.7	9.56	24.2	23.2	23.78	0.24	72.6	68.8	70.6	1
Bldg5	0.4	179	48	147	41.1	24	22.5	23.4	0.33	73.6	61.8	70.5	2.6
Bldg 6	0.4	52	16	25	9	23	22	22.5	0.2	70.5	62.4	68.3	2.4

Unlike air temperature, relative humidity was varying quite significantly in all the buildings, which could be possible due to untreated outside air supply, infiltration, high occupancy and other interior sources.

Further, data was compared to observe the impact of various other indoor parameters on HCHO concentration. Formaldehyde was in better correlation with temperature for data set logged in composite climate (New Delhi with R^2=0.45) compared to the one in moderate climate (Bangalore with R^2=0.22). Similar pattern was observed for formaldehyde in relation with relative humidity; however the HCHO levels are ranging across the varying relative humidity levels. When the data was segregated based on the HVAC systems used in the building, HCHO concentration was in better correlation with the relative humidity levels found in the buildings with Split air conditioning having no humidity control. This gives an inference that the rate of HCHO emission is higher with high relative humidity especially with the levels above 60%. When HCHO levels were correlated with age of the building interiors as well as whether the air conditioning is put on or off, it was noticed that HCHO has better correlation with relative humidity in air conditioned spaces having interiors below 2 years old compared to the spaces that are non-air conditioned and above 2 years old.

A logarithmic relationship (R^2=0.6) was found between HCHO and respective age of the building/refurbished time. As understood from the literature, it was also noticed that after three years, the average HCHO emissions reduce drastically (Figure 4.2). In the initial years of the building interiors, it is very much possible to have continuous release and absorption of HCHO from various sources in the building; as this process reduces in the long-term and HCHO emission would have minimal dependence on temperature due to low availability of free formaldehyde molecules. Thus, high emission rates from new materials involve mostly the evaporation of free formaldehyde which is significantly affected by both temperature and relative humidity (D E Hun et al. 2010).

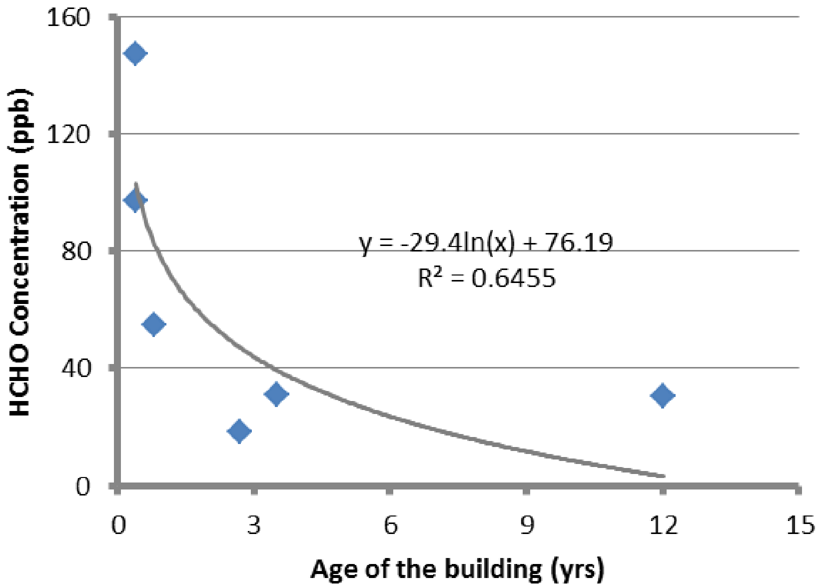


Figure 4.2 Relation between age of the building and HCHO concentration

Table 4.3 presents regression coefficients and equation derived from the data collected in buildings 4, 5 and 6. HCHO being exponentially correlated with temperature, components of Arrhenius equation (1/T & ln k) were derived and a good correlation (R^2 0.37 & 0.9) was found from the data collected in Building 4 & 6. Similarly, HCHO was found in good correlation (R^2 0.38) with the temperature data between 22 and 26°C in Building 4 and with relative humidity data in the range 50-70% (R^2 0.58 & 0.54) in Building 5 & 6. The mean temperature and relative humidity data is found more or less similar in all the three buildings (Building 4- 23.3, 57%, Building 5- 23.5 & 68%, Building 6-23.3 & 62.3%) whereas the mean HCHO was 57,114.4, 39.3 ppb in buildings 4, 5 & 6 respectively. The data was scattered and found no good correlation in buildings 1, 2 & 3. Interestingly the relation was found to be directly proportional in building 5 where both HCHO and Relative humidity levels were found high (>100 ppb & >60%) whereas it was inversely proportional in Buildings 4 & 6 where green materials were used in the interiors and emissions were relatively low but the humidity levels are high. This gives an inference that in a scenario of green materials being used in the interiors and when the humidity levels are above 60%, the reaction exhibits certain time delays in reaching equilibrium.

Table 4:3 Summary of regression analysis

	Arrhenius		**Temperature**		**RH**		**Multi regression**	
	No. of samples	$<R^2>$	No. of samples	$<R^2>$	No. of samples	$<R^2>$	Equation	$<R^2>$
Bldg 4	155	0.37	155	0.38	94	-	Y=-329.2+15.03T+0.5H	0.4
Bldg 5	240	-	240	-	188	0.58	Y=-795.9+18.3T+8.5H	0.6
Bldg 6	148	0.94	106	0.42	93	0.54	Y=124.4+8.15T-4.4H	0.62

Another major observation was that the reaction rate of sensor used for monitoring is higher at higher levels of formaldehyde. The data logging equipment used for monitoring is good when the variation of formaldehyde emissions are studied with reference to indoor environmental conditions. The accuracy of the sensor is +/- 4ppb when the HCHO levels are below 40ppb and +/- 10% above 40ppb. There is a lot of uncertainty found in the data recorded below 10ppb and more than 200ppb. The sensitivity of this method of monitoring formaldehyde is relatively poor when compared to conventional time average lab based methods. Hence it is recommended to validate the data logger results with the standard DNPH measurements in the future scope of study.

Almost all studies dealing with formaldehyde's relation with air temperature and relative humidity reviewed as part of literature are either lab based controlled chamber experiments or specific product based evaluations. Due to the complexity of multiple formaldehyde sources possible inside the indoor environment, it would be difficult to establish the actual relationship between HCHO under varying air temperature and relative humidity conditions.

Thus, based on the above analysis, although we could arrive at considerable level of understanding on the HCHO concentration in air conditioned Indian office buildings and its behaviour with indoor environmental variables as proposed in the objectives of the project, it is recommended to find out the threshold of temperature and relative where the HCHO reactivity is high in a laboratory (environmental chamber) set up, keeping the other variables constant.

Annexure I Validation of HCHO using colorimetric method (Building 3)

Summary of HCHO concentration measured using colorimetric method using active air sampling as well as the photoelectric absorptiometric sensor with data logger is presented in the table below.

Comparison of lab based and photoelectric sensor based reading for HCHO

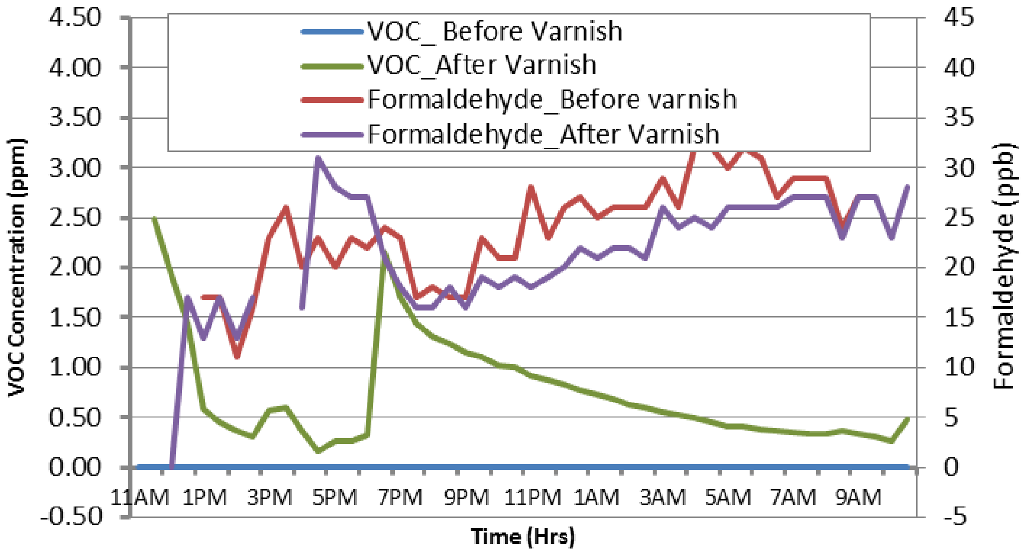
	Formaldehyde Level – 8 hour Average (ppb)	
Location	Colorimetric Method (Active sampling using bubbling method)	Gray Wolf monitor)Photoelectric Absorptiometric method
Location 1	27.6	44.0 (4 hr)
Location 1	25.0	28.6 (8 hr)
Location 2	24.7	15.2 (8 hr)

Observation

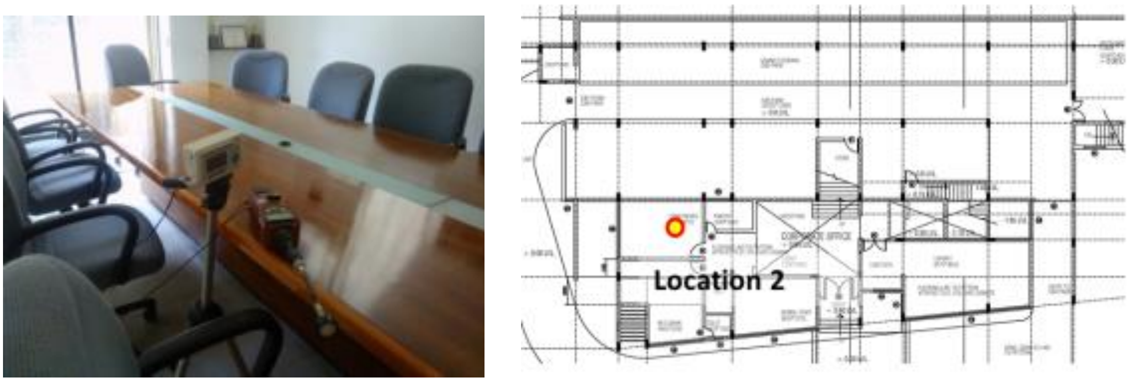
HCHO result from the sample collected in location 1 was not same as the data logger values as the duration of measurement was not same. This could be possible due to variation in humidity levels as well. Similarly, for the sample collected in location 2 it could be the change in the sensor location which resulted in different HCHO levels. Thus the results from colorimetric are not so promising to validate the readings from Graywolf sensor used in this project. However, it is suggested to collect more samples to conclude the validity of the sensor readings.

Annexure II VOC & HCHO with new varnish in Conference room

TVOCs and HCHO were continuously monitored for 24 hours before and after varnishing (wood polishing) in an unconditioned conference room (un occupied) located in Building 3. The below figure presents the variation of the parameters observed during the measurement.



Comparision of TVOC and HCHO before and after varnishing



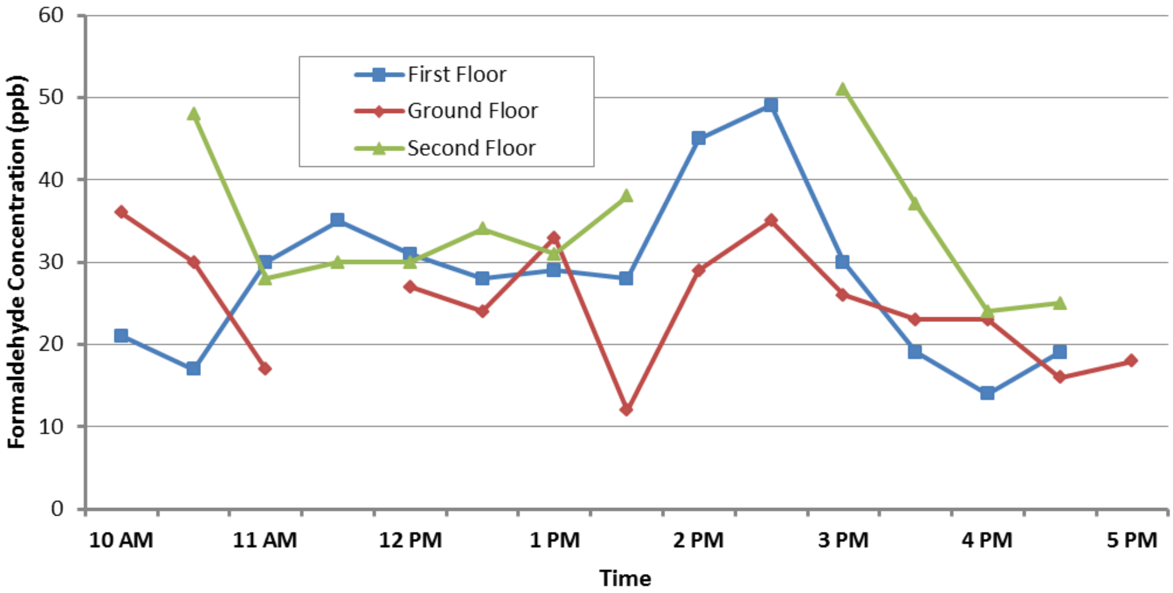
Location of sensors for measurement of TVOC & HCHO in the conference room

Observation

VOC concentration has increased upto 2 ppm from 0 ppm after varnishing was done on the conference table. Varnishing doesn’t seem to have any direct impact on the Formaldehyde concentration; in fact lower values were found after varnishing. This could be due to sealing of exposed table surface.

Annexure III Formaldehyde Concentration: Floor wise

The figure below presents hourly variation in HCHO levels observed floor wise in Building 1 located in New Delhi.

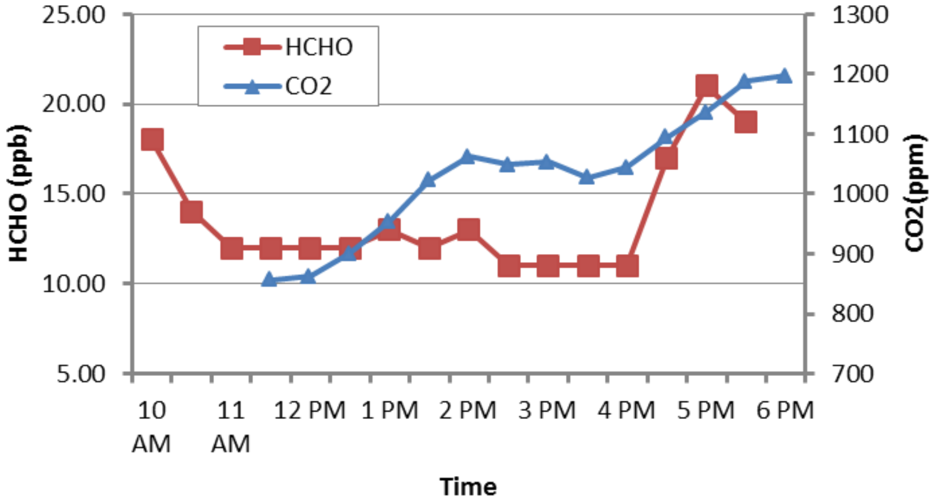


Floor wise HCHO levels observed in Building 1

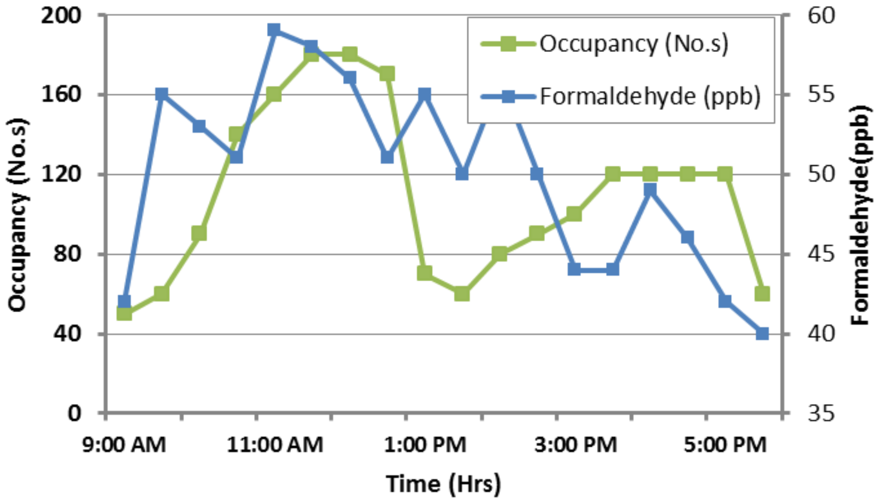
Observation

Mean formaldehyde level seems to be increased from Ground floor to Second Floor (25 ppb to 34ppb); this could be due to more infiltration and occupant movement on the ground floor compared to other floors.

Annexure IV Occupancy and Formaldehyde



Relation between CO_2 & HCHO as observed in building 3



Relation between CO_2 & HCHO as observed in building 4

Observation

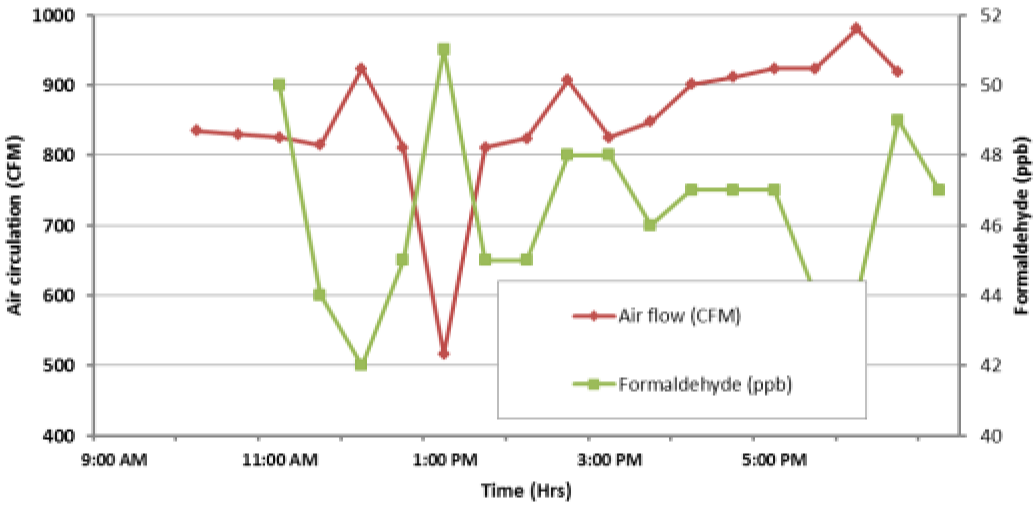
CO_2 levels were found high (up to 1200 ppm) as the pollutant gets accumulated in the evenings during the shift changing hours in Building 2. HCHO levels follow the trend of CO_2, confirms that the levels could be high due to occupancy density. In building 3, formaldehyde don't seem to have a direct relation with CO_2.

In building 4, occupancy was estimated based on the typical movement of occupants during office hours. As the occupancy density becoming low in the afternoon, formaldehyde levels show a little reduction (from 59 ppb to 40 ppb).

However, it is suggested to carry out more measurements possibly in controlled condition to conclude the behaviour of formaldehyde in the presence of more CO_2.

Annexure V Air circulation rate & Formaldehyde

Air circulation was maintained between 800 to 900 cfm in response to CO2 sensor. There is minor variation in formaldehyde levels throughout the day and thus no significant relation with the air flow rate.



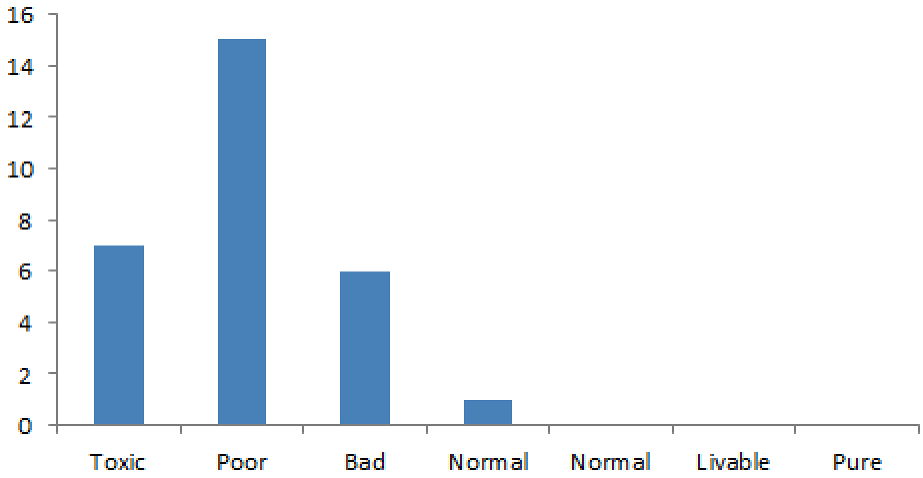
Hourly variation of HCHO and air flow rate in building 4

Observation

Air circulation was maintained between 800 to 900 cfm in response to CO2 sensor. There is minor variation in formaldehyde levels (between 42 ppb and 50 ppb) throughout the day and thus no significant relation with the air flow rate. More controlled studies are suggested to conclude the behaviour of HCHO with air movement.

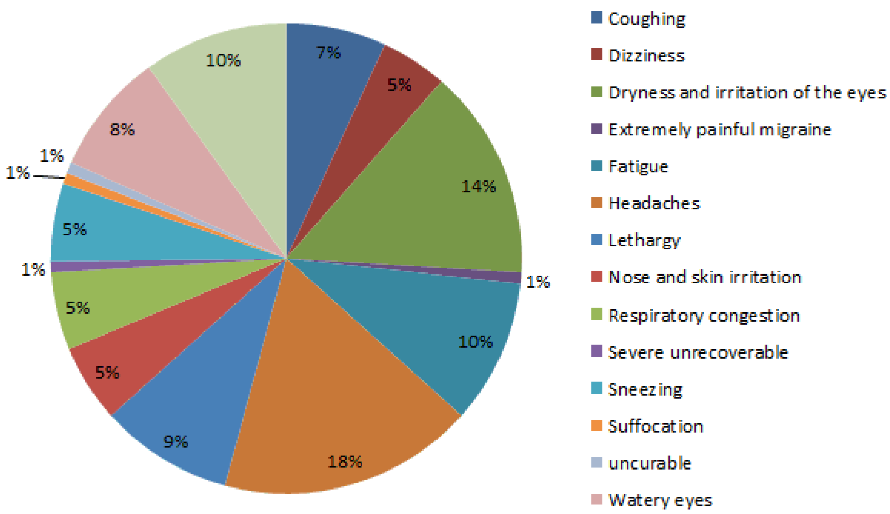
Annexure VI Occupant feedback on IAQ

A short survey was conducted in building 1 to get occupant feedback on IAQ and understand their awareness on VOC & Formaldehyde emissions. Building 1 houses a research institute, 29 out of 38 researchers participated in the survey felt that the air quality was toxic, poor or bad as shown in the figure below. About 2/3rd of the researchers who work in building and environmental sciences aspects are aware about pollutants like Formaldehyde and VOCs and their health impacts.



Occupant feedback on indoor air quality in Building 1

Since the air quality was bad as found in this survey, the occupants were asked further on the kind of health symptoms they have. Almost all the researchers felt that they were having some health issues as a result of the poor to toxic levels of air quality and these issues varied from coughing, to dizziness to headaches and migraines. The below figure presents % distribution of health issues found among the surveyed occupants. About 50% of the researchers had some allergies, migraine and other health issues; they felt that their conditions were being aggravated due to poor air quality, so much so, that about 45% of the people surveyed said that they have also gone to visit the doctor because of these ailments.



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Concerned divisions / project related brief note to be included here

Sustainable Building Science: Overview

One of the prime areas of activity within the Energy Environment Technology division is adoption of efficient and environment-friendly technologies in new and existing buildings. The activities of this area focus primarily on energy and resource use optimization in existing buildings and design of energy efficient sustainable habitats.

The Centre for Research on Sustainable Building Science (CRSBS) comprising architects , planners, engineers , environmental specialists , specialised in urban and rural planning, low energy architecture and electro-mechanical systems, water and waste management and renewable energy systems has been offering environmental design solutions for habitat and buildings of various complexities and functions for nearly two decades. The group also undertakes LEED facilitation for buildings.

The Green Rating for Integrated Habitat Assessment (GRIHA) cell, also comprising professionals from the above-mentioned fields is actively involved in facilitation of green rating for buildings under the GRIHA framework. Inputs from CRSBS feed into the processes undertaken at GRIHA cell. The different services offered by the Sustainable Building Science (CRSBS and GRIHA) are as follows:

Environmental design consultancy

- Specialised environmental design consultancy and building performance analysis are conducted. A wide range of computations and simulation tools including DOE2, TRNSYS, ECOTECT, RADIANCE, FLOVENT, AGI32, LUMEN DESIGNER, BLAST, Phoenics, RETScreen are used to assess the environmental and cost impact of the design decisions.

LEED and GRIHA facilitation

- The team has experience in technically facilitating LEED accreditation [LEED India for New Construction (LEED India NC) and LEED India for Core and Shell (LEED India CS)] for buildings. The group also assists and administers GRIHA, an indigenous green building rating system for buildings, developed at TERI. GRIHA has now been now endorsed by the Ministry of New and Renewable Energy, Government of India, as the national building rating system for India.

Energy audits and energy management programs

- Energy conservation studies for a large number of buildings are conducted. There exists a vast experience in conducting energy audits and evaluating a whole range of building upgrade options including envelope retrofit and system retrofit or changes in operational patterns. In addition to establishing operating efficiency of electrical, HVAC, lighting and thermal systems, recommendations to improve upon the same by suitable retrofit measures or by refinement of operational practices are also offered. The group also has expertise in development of energy management programs for service industries like hotels and the corporate sector.

Capacity building

- Capacity building for architects, building developers and service engineers on issues such as energy efficiency in building envelopes and systems has been undertaken. Over 1000 architects, developers and engineers in the area of green buildings, energy efficiency and sustainability aspects of built environment have been trained through training programmes, refresher courses, seminars and workshops.

Policy inputs

- Several policy initiatives at central and state governments' level towards mainstreaming high performance buildings in India have been successfully completed. Senior members of the group are members of the Committee of experts for development of the Energy Conservation Building Code (ECBC) of India (2007). The manual for environmental clearance of large construction for the Ministry of Environment and Forests, Government of India has also been developed at CRSBS.

Climate Change related projects

- Climate change is increasingly being recognized as a major global challenge. The group has provided inputs to the National Mission on Sustainable Habitat (a part of the recently released India's National Action Plan on Climate Change). Project Design Documents (PDD) are prepared in order to facilitate trading in carbon through the Clean Development Mechanism (CDM).