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# Formaldehyde monitoring in office buildings located in tropical climates of India

**D E V S Kiran Kumar[1,*], T Jyothi Latha[2], R Suresh[3] and T Arunvel[2]**

[1] The Energy and Resources Institute (TERI-SRC), Bangalore, India
[2] Saint Gobain Research India (SGRI), IITM Research Park, Chennai, India
[3] The Energy and Resources Institute (TERI), New Delhi, India
[*] kirankumar.devs@gmail.com

**Abstract.** Indoor air pollution is a result of complex phenomenon that occurs due to constantly changing interaction of various indoor and outdoor environmental factors. Volatile Organic Compounds (VOCs) are the major pollutants in air conditioned indoors, perhaps having a large subset of hazardous compounds. In this study, formaldehyde (HCHO) was monitored at 30 minute interval using portable photoelectric absorptiometric sensors along with comfort parameters like air temperature, relative humidity and air flow rate at six newly constructed or renovated office buildings located in composite, temperate and warm-humid climatic zones (in various parts of India). Results show that formaldehyde emissions exceeded the limits suggested by LEED guidelines (27 ppb) in all the buildings except in the ones where low emitting green interiors were used. Furniture and interior decorative work were found to be the primary sources of formaldehyde emission than other parameters. A logarithmic relationship ($R^2$=0.65) was established between HCHO and respective age of the building/refurbished time. The analysis also presents that in a scenario of green interiors (low HCHO concentration) and the humidity levels above 60%, the trend of HCHO concentration with indoor moisture exhibits certain time delays in reaching equilibrium due to slow conditioning of HCHO molecules and indoor moisture. The study provides a rational analysis on HCHO emissions in Indian office buildings, which is important to understand possible sources and their effects on HCHO concentration in office indoors. The study data helps to implement required measures to control indoor humidity levels or necessary HCHO mitigation strategies during design and operation process of the air-conditioned office buildings.

## 1. Introduction

Air pollution in office buildings is a result of complex phenomenon that occurs due to constantly changing interaction of various building indoor and outdoor environmental factors [1]. Volatile Organic Compounds (VOCs) are the major pollutants in the air-conditioned indoors, which are perhaps having a large subset of hazardous compounds. Formaldehyde (HCHO) is one such compound, which could be found in indoor furniture, composite wood products, carpets, housekeeping chemicals, room fresheners, cosmetics, polishes as well as tobacco smoking. Literature suggests that among these possible sources, furniture accounts for 42–79% of room's total emissions [2]. The work places perhaps are more polluted than home due to higher furniture density and improper ventilation. In India, an average working adult spends almost 90% of time in enclosed environment (8h at office, 13h at home) [3]; and an estimated average exposure to HCHO per day as per WHO [4] is upto 1.9 ppb of formaldehyde at home and upto 40 ppb at office space. HCHO is an easily soluble compound in water with high reactivity. It is produced as a result of thermal oxidation and chemical reactions with 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 [5]. Recent report by the World Health Organization's International Agency on Cancer (IRAC) [6] highlights HCHO, as the cause of several types of nose and throat cancer. HCHO concentration decrease significantly with time. After initial rapid decline, HCHO concentration decrease at a much slower rate, continuing for years. The concentration would be stable at 1/3rd of the initial concentration, three years after remodelling [7]. In a study carried out by Oak Ridge National Laboratory, it was found that emissions would drop by 37% of initial rate within 2.2 years [8].

Liang W et. Al., developed semi-empirical relation between indoor environmental conditions and emission concentration of HCHO based on the hydrolysis reactions effected by temperature. [9]. In a study carried out by Hodgson et. al., it was perceived that the humidity levels ≤ 50% could help in limiting the HCHO concentration from the wood products [10]. It is understood from the literature that the effect of temperature on indoor HCHO concentration is exponential whereas the effect of relative humidity is linear [5]. Li B et al suggested that the source control is the efficient way to limit the HCHO indoor concentration [11]. The concerns 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. Most of the indoor air quality studies pertaining to HCHO monitoring in India as of now are limited to individual buildings with relatively smaller sample size. Therefore, the present study discusses formaldehyde monitoring carried out in open-plan air-conditioned office buildings where occupancy and furniture densities are in general higher than other regularly occupied spaces.

## 2. Experimental Setup

An experimental monitoring of formaldehyde and other indoor parameters has been carried out at six office buildings between May 2015 and April 2016. Buildings are chosen in such a way that the major Indian climatic zones would be considered. Out of the six buildings, two are located in New Delhi (Composite climate), three are located in Bangalore (Temperate climate) and one is located in Chennai (Warm-Humid climate). Building characteristics, type of HVAC, occupancy and furniture details are summarised in Table 1. All the six buildings are with glazed facades and having different air-conditioning systems. Building 2 is a 24-hour occupied building whereas all the other buildings are daytime occupied. Buildings 2, 4 and 6 have low emitting green interior products, among which 2 and 4 are LEED [12] rated. Occupancy density was estimated based on the number of occupants with respect to floor area, which was almost same in all the buildings, except in building 3, where the measurements were done in a conference hall. The furniture density was assessed qualitatively based on the number and arrangement of the furniture from the interior drawings, which was high in majority of the buildings.

### *2.1. Instrumentation*

Multiple sensors with integrated common data acquisition system were used for this monitoring trial, which were placed at a height corresponding to breathing level of the occupants (approx. 1.2m from the floor level) as per monitoring protocols [13]. The Photo Ionization Detection (PID) formaldehyde sensor (sensitivity 0.02 ppm) used in the monitoring works based on the chemical reaction between formaldehyde and β-diketone impregnated on a reusable glass cartridge. The concentration of reaction derivatives changes the sensor in yellow colour proportion to the HCHO concentration and the duration of exposure. Air temperature and relative humidity was monitored using portable data logger (Accuracy: ±0.2 °C and ±2.5 %). These three parameters along with airflow rate (air handling unit data) were monitored at 30-minute interval for 8 hours (corresponding to office occupancy hours) for over 5 days in each case. Monitoring was done at two to three locations for building 2, 4 & 6 as the open office floor area is above 1000 Sqm. Figure 1 shows the collage of images of measurement locations at the six buildings.

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**Table 1**. Details of building related parameters analysed in the study

| | Age of the Building (Years) | Type of AC | Outside pollution | Occupant Density (Per/Sqm) | Furniture Density | No. of locations | Monitoring period |
|---|---|---|---|---|---|---|---|
| Building 1 (New Delhi) | 3 | Split AC with ventilation | High | 0.15 | High | 1 (2nd Floor) | 15-19 June'15 |
| Building 2 (New Delhi) | 2.5 | Central AC with TFA | Moderate | 0.15 | High | 3 (8th Floor) | 22-26 June'15 |
| Building 3 (Bangalore) | 5 | Spilt AC with infiltration | Moderate | 0.6 | High | 1 (1st Floor) | 28Jul-03 Aug'15 |
| Building 4 (Bangalore) | 0.8 | Central AC with TFA | High | 0.1 | High | 2 ( 4th Floor) | 04-07 Aug'15 |
| Building 5 (Bangalore) | 0.4 | VRF with no fresh air | High | 0.15 | High | 1 (1st Floor) | 12-25 Jan'16 |
| Building 6 (Chennai) | 0.4 | VRF with fresh air | Moderate | 0.02 | Medium | 3 ( all floors) | 05-30 Apr'16 |


**Figure 1.** Images showing test setup at the six monitored buildings

## 3. Results and Discussions

The study covers six office buildings located in tropical climatic regions of India. Figure 2 shows a typical day hourly profile of HCHO observed during the monitoring in each of these buildings. Dark line represents buildings with less than two years old and dashed line represents the ones with age more than 2 years. It can be observed that the HCHO concentration are beyond the limits suggested by LEED guidelines (27 ppb)[11] in all the buildings except buildings 2 and 6, which are having low emitting green interior products (Figure 2). Low emitting green interiors usually produce low VOC emissions due to the selective adhesives used in the wooden products. Although building 4 is LEED rated and having green interiors, maximum HCHO concentration has reached up to 60 ppb, almost throughout the monitoring period. This could be due to the higher amount of HCHO sources in building 4 compared to the other buildings. These sources include decorative woodworks on walls, ceiling as well as cornices. Regardless of the age of the building, higher HCHO concentration was observed due to high furniture density. There was no noticeable variation in HCHO concentration across the floor in buildings 2, 4 & 6 (where more than two locations were monitored), expect that the HCHO concentration was slightly higher (3to7 ppb) when sensor was close to the office desk. This was possible due to furniture (adhesives used in the medium density fibreboards) being the major source of HCHO emission in the office indoors. Thus, overall from these observations, furniture and interior decorative work seemed to be the primary source of HCHO emissions than other parameters.

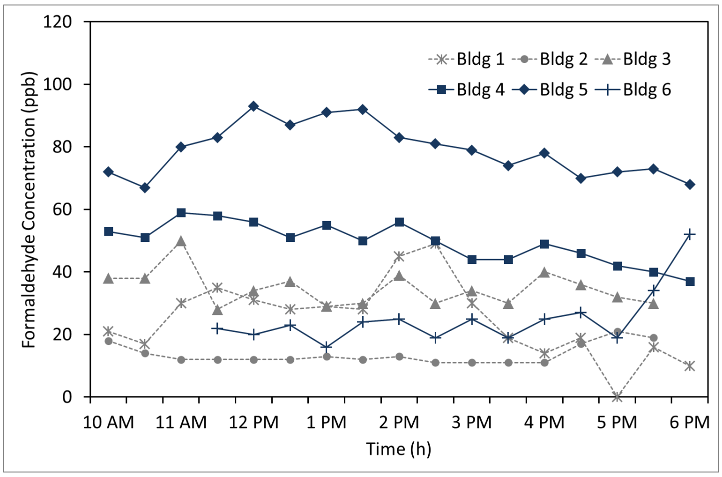


**Figure 2**. Hourly profile of HCHO concentration in the six monitored buildings

Figure 3 illustrates a logarithmic relationship ($R^2$=0.65) that was established between HCHO and respective age of the buildings/refurbished time as observed in this study. It could be noticed that after the first 2 years, average HCHO emissions reduce drastically (Figure 3). In the initial years of the new building interiors, it is 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 HCHO molecules. Thus, high emission rates from new materials involve mostly the evaporation of free HCHO, which is significantly affected by both temperature and relative humidity [14].

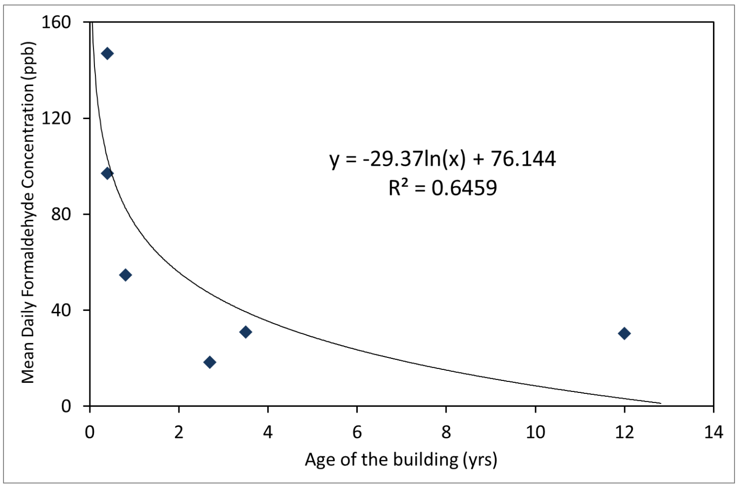


**Figure 3**. Relation between age of the building and HCHO concentration

Table 2 summarises statistical analysis of the HCHO as well as air temperature and relative humidity levels observed in the study. Except building 2 and 4, all the other buildings have poorly distributed HCHO concentration 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 HCHO with levels above the average. Unlike air temperature, variation of relative humidity was quite significant across the studied buildings, which could be possible due to untreated outside air supply, infiltration, high occupancy and other interior sources.

**Table 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 | 64.0 | 12 | 31.0 | 9.90 | 29.4 | 22.5 | 27.2 | 1.50 | 56.5 | 43.2 | 49.3 | 2.7 |
| Bldg 2 | 2.7 | 29.0 | 10 | 18.3 | 4.34 | 26.6 | 20.7 | 23.3 | 1.90 | 73.1 | 52.4 | 61.5 | 5.4 |
| Bldg 3 | 5.0 | 150 | 11 | 30.3 | 27.3 | 26.0 | 22.3 | 24.3 | 1.40 | 67.1 | 45.4 | 56.7 | 6.4 |
| Bldg 4 | 0.8 | 75.0 | 33 | 54.7 | 9.60 | 24.2 | 23.2 | 23.8 | 0.24 | 72.6 | 68.8 | 70.6 | 1.0 |
| Bldg 5 | 0.4 | 179 | 48 | 147 | 41.1 | 24.0 | 22.5 | 23.4 | 0.33 | 73.6 | 61.8 | 70.5 | 2.6 |
| Bldg 6 | 0.4 | 52.0 | 16 | 25.0 | 9.00 | 23.0 | 22.0 | 22.5 | 0.20 | 70.5 | 62.4 | 68.3 | 2.4 |

The experimental data was further analysed to observe the impact of indoor environmental parameters on HCHO concentration. When the data was segregated based on the HVAC systems used in the building, HCHO concentration was found higher in the buildings with split air conditioning having no humidity control. This gives an inference that the rate of HCHO emission have strong relationship with relative humidity especially with the levels above 60%. This phenomenon was observed especially in buildings with interiors below 2 years old. However, HCHO seem to be in better correlation with temperature, when the average relative humidity was lower than 60%.

The data was scattered and found no good correlation in buildings 1, 2 and 3 (> 2years old) and therefore only buildings 4, 5 and 6 were analysed further for detailed investigation. Table 4 presents regression coefficients found form the analysis of buildings 4, 5 and 6. HCHO being exponentially correlated with temperature, components of Arrhenius equation (1/T & ln k) were derived. HCHO was found to have poor correlation ($R^2$ 0.38) with temperature between 22 and 26°C. However, a modest correlation was found with relative humidity in the range 50-70% ($R^2$ 0.58 & 0.54) in building 5 and 6. The mean temperature and relative humidity data is found more or less similar in both the buildings (building 5- 23.5 & 68%, building 6-23.3 & 62.3%) whereas the mean HCHO was 114.4, 39.3 ppb in buildings 5 & 6 respectively.

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 6 where green materials were used in the interiors and emissions were relatively low but the humidity levels are high. This was because, in a scenario of green interiors (lower HCHO concentration) when the humidity levels are above 60%, the reaction exhibits certain time delays in reaching equilibrium due to slow conditioning of HCHO molecules and indoor moisture. Low emitting green interiors therefore help to reduce the harmful VOC components in the indoor air and improve the quality of environment.

**Table 3.** Summary of regression analysis.

| | Arrhenius | | Temperature | | RH | |
|---|---|---|---|---|---|---|
| | No. of samples | $<R^2>$ | No. of samples | $<R^2>$ | No. of samples | $<R^2>$ |
| Bldg 4 | 155 | 0.37 | 155 | 0.38 | 94 | 0.00 |
| Bldg 5 | 240 | 0.00 | 240 | 0.00 | 188 | 0.58 |
| Bldg 6 | 148 | 0.36 | 106 | 0.42 | 93 | 0.54 |

## 4. Conclusions

The study covers formaldehyde monitoring along with comfort parameters like air temperature, relative humidity and air flow rate at six newly constructed or renovated office buildings located in composite, temperate and warm-humid climatic zones (in various parts of India) during May 2015 - April 2016. It provides a rational analysis on HCHO emissions in Indian office buildings. Key observation made from the analysis of the monitored data are-

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- Formaldehyde emissions were found to be exceeded the limits suggested by LEED guidelines (27 ppb) in all the buildings except in the ones where green interiors were used moderately.
- Furniture and interior decorative works were found to be the primary source of HCHO emission than other parameters.
- A logarithmic relationship ($R^2$=0.65) was found between HCHO and respective age of the building/refurbishment; HCHO concentration drastically reduces after around 2 years of age.
- Unlike air temperature, relative humidity varied quite significantly across all the studied buildings, which is likely due to untreated outside air supply, infiltration, high occupancy and other internal sources.
- A good relationship was found between HCHO concentration and indoor relative humidity. However, from the regression analysis it was concluded that the trend of HCHO concentration with indoor moisture exhibits certain time delays, especially when the HCHO concentration was lower due to usage of green interiors.

It is therefore important to understand possible sources and how they affect the HCHO concentration in office indoors. Further, it is necessary to take required measures to control indoor humidity levels or implement appropriate HCHO mitigation strategies during design and operation of office buildings.

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