IEQ Direct Reading Instruments – Myths and Realities

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ABSTRACT

In this paper various direct reading instruments and techniques used in air monitoring are reviewed. Principles of operation are described, pointing out advantages and disadvantages of using such instruments. A procedure for inspection activities, and a sampling and analysis approach is outlined. One case study, covering inspection in an office space is presented in detail, describing monitoring of different types of contaminants, possible false positives and calculations related to exposure limits. Inconsistencies in design and construction of ventilations systems are also discussed. It was concluded that direct reading instruments used in monitoring of airborne contaminants have improved significantly, presenting improved sensitivity and selectivity, and capable of detecting concentrations below exposure limits in real time. Despite the improved performance of these instruments, integrated sampling, and review of results by experienced specialists may be required to resolve complex IEQ scenarios.

INTRODUCTION

Direct reading instruments have been used for Indoor Environmental Quality (IEQ) measurements for decades. However, these instruments can produce erroneous or misleading results. Measurements obtained with direct reading instruments are affected by various chemicals, relative humidity, temperature and/or outdoor contaminants. Finding direct reading instruments that are suited to pollutants detection and quantification is an ongoing struggle for indoor environmental quality (IEQ) investigators. Direct reading monitoring technologies have greatly improved since the 1960s. Some technologies developed for pollutants detection in ambient air quality and workplace exposure are well suited to IEQ investigations. Due to technology reliability, many direct reading instruments results were not legally acceptable. However, with significant advances in sensor technology, such instruments are widely used in IEQ investigations these days. A significant development is the approval of direct reading instruments air quality testing for green buildings (U.S. Green Building Council, USGBC 2020).

DIRECT READING INSTRUMENTS

Electrochemical sensors are reliable and most of the time the measurements are precise. However, they may be affected by other chemicals, relative humidity (RH) and other factors in the workplace environment. On the other hand, they provide real time detection. Another consideration is that some of the instruments used in IEQ investigations produce enormous amounts of data, which presents difficulties during the analysis and data interpretation phase. It is not uncommon to see 5760 data points in eight hours of pollutants measurements for a single pollutant. Such databases present significant challenges for industrial hygienists who are tasked with data interpretation and evaluation.

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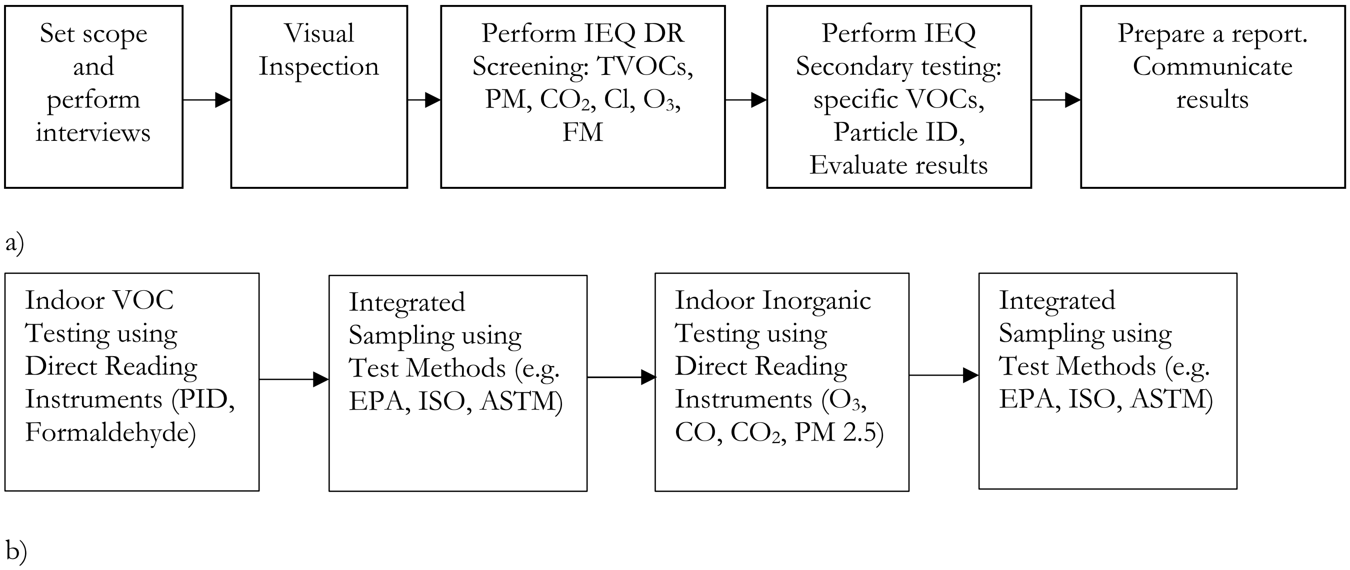

Figure 1 (a) Sequence of activities covering an inspection and (b) contaminant screening and testing (Tier 3, Demonstrate IAQ performance).

IEQ professionals should be very careful while working with direct reading instruments. Some of the sensors are affected by chemical mixtures or humidity in indoor environments. Therefore, misleading, or so called "mystery" results should be further evaluated. For instance, copy machines and laser printers emit particulate matter (PM) and Ozone (O_3) during extensive use. During printing operations particulates are transferred onto paper and fused by heat or pressure. Most of the toner cartridges use carbon black particles in a resin binder (Bar-Sela and Shoenfeld 2008). Ozone is generated from the reaction of charged ions and electrons with atmospheric gases in an electrophotographic process of the copier and from the corona wire (coil that provides a positive charge in the surface of the drum of the copier) (Tipayarom and Tipayarom) In addition, copiers and printers produce Volatile Organic Compounds (VOCs) (USEPA 2014).

VOC's analysis is performed to achieve selective and/or highly sensitive detection of a wide variety of organic compounds. The selective determination of aromatic hydrocarbons or organo-heteroatom species is achieved by photoionization detection (PID). This type of detection uses ultraviolet light to ionize the molecules of the analytes based on their ionization potential. The ions produced by this process are collected by electrodes. The current generated is therefore a measure of the analyte concentration. A photoionization reaction is presented in Equation 1 below.

$$R + hv \rightarrow R^{+} + e^{-} \qquad (1)$$

If the amount of ionization is reproducible for a given compound, pressure, and light source then the current collected at the PID's reaction cell electrodes is reproducibly proportional to the amount of that compound entering the cell. The reason why the compounds that are routinely analyzed are either aromatic hydrocarbons or heteroatom containing compounds (like organosulfur or organophosphorus species) is because these species have ionization potentials (IP) that are within reach of the UV lamp used in the instrument. The available lamp energies range from 7.3 to 11.7 eV. With the enhancement of technology, some of the latest developments offer monitoring using dual UV lamps or prefiltering of air sampled to improve selectivity.

According to EPA VOCs are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short and long-term effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. VOCs are emitted by a wide array of industries and products numbering in the thousands.
Direct reading instruments could be used to evaluate the exposure to PM, O_3 and VOCs. However, it may be advisable to employ/contract an experienced IH to do the sampling. Data collected during sampling of all three pollutants should be carefully evaluated since some of the O_3 sensors are affected by VOCs and other pollutants. Let's review one case study.

CASE STUDY

Due to office employees' complaints, an air quality investigation was requested. Based on the conversations with the management and office workers, the authors were informed that the only recent change in the office was the new copy machine, new subflooring, and improvements to the ventilation system. The new copy/printer was installed in the corner of the office. Copying and printing equipment usually generates O_3 when high voltage charging devices produce an electrostatic discharge during a copy/print run. In standby mode no O_3 should be produced. In addition, the supply air vent and the ductwork were replaced with brand new flexible ductwork. Subflooring was partially replaced with plywood and engineered hardwood flooring was installed on top of it.

Direct reading measurement systems were used to test the air. The tests showed the presence of trace concentrations of VOC's, Chlorine, Ammonia, Formaldehyde, and noticeable concentration of Ozone. It is a common perception that O_3 direct reading instruments would display exact concentration based on the instrument's 30 seconds response time. It turned out that some O_3 sensors are affected by VOCs, Chlorine, and outer pollutants. At the time of the survey, O_3 concentration significantly spiked during constant documents printing. However, it was estimated that approximately 50% of the measured O_3 concentration could be attributed to the cleaning of office surfaces with alcohols and bleach (Chlorine). An example of a time plot using O_3 sensor data is shown in Figure 2.

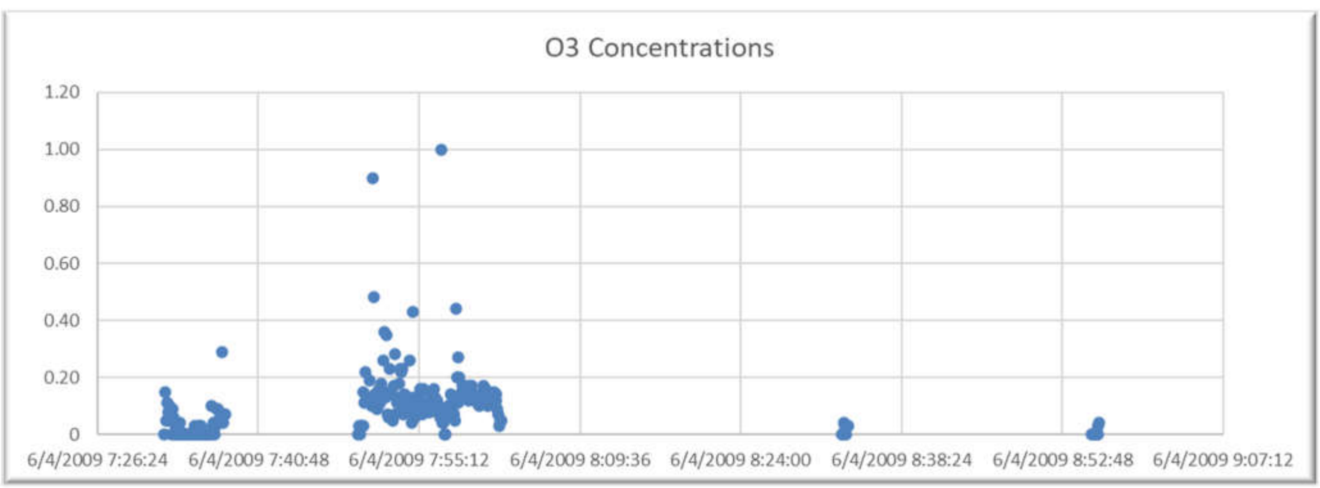

Figure 2 Time plot using O_3 sensor data.

Additional O_3 samples were collected utilizing traditional IH methods. Subsequent laboratory analysis showed that the actual O_3 concentration was <0.036 ppm. However, one of the disadvantages of traditional sampling methodology is that the assessor will not be able to see the spikes in concentrations. Therefore, it is always advisable to perform both direct reading instruments and traditional testing to compare the results.

In addition, various particles, fiberglass fibers and print ink particles were present in the air. Particulate matter (PM) could be measured with various direct reading instruments. Some of the most commonly used particulate measurement systems offer six channel particle sizes measurements. These direct reading instruments are capable of measuring the mass concentration of 2.5 and 10 µm particle sizes. Since 2018 the USGBC allows the use of direct reading monitoring devices to monitor PM 2.5 µm particle sizes concentrations. However, in some cases, the types of particles should be further evaluated. There is no direct reading instrument that will show what kind of particles are affecting the air quality. Still the best "direct reading" instrument for particle identification is the human eye. An experienced microscopist can identify the types of particles. Two examples are presented in figures 3 and 4.

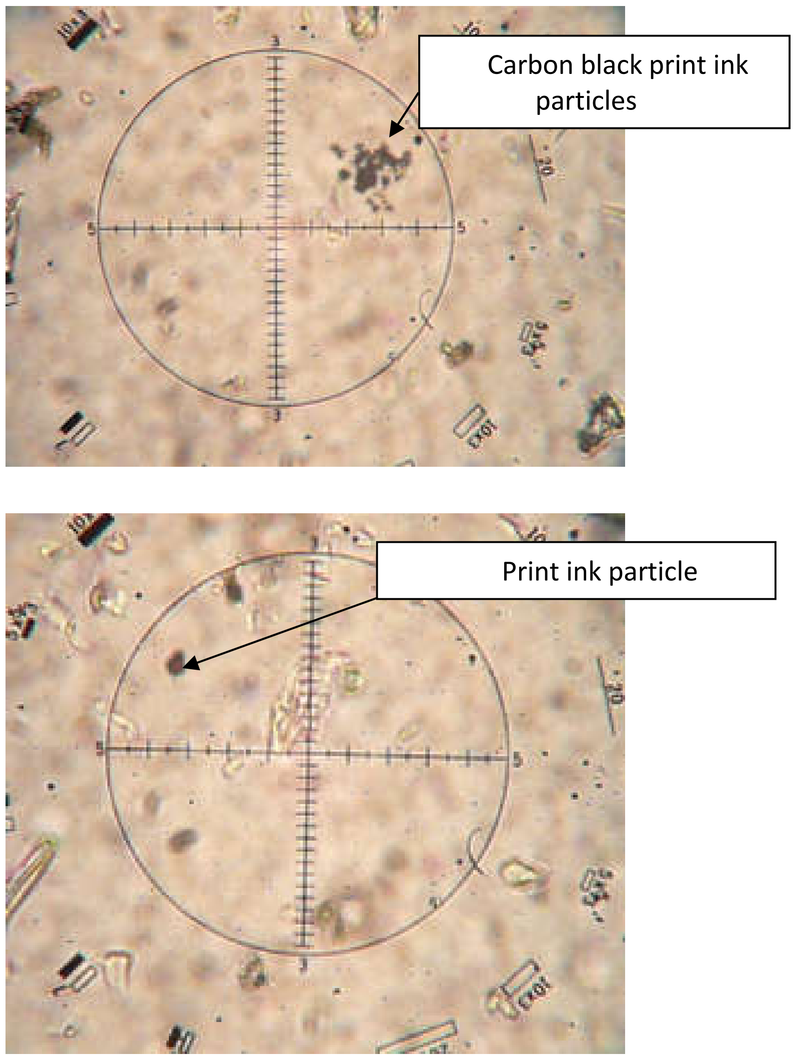

Figure 3 Examples of carbon black print ink and print ink cartridges identified under microscope.

It is readily visible that some of these particles form agglomerates. Such agglomerations present challenges for direct reading instruments and the monitoring should be supplemented with a microscopy evaluation.
Going back to the earlier mentioned flex ductwork, it was apparent that during the installation fiberglass fibers were dispersed into the air. Such fibers, depending on the size, were more likely detected as "particles" by the dust

monitoring device. While US OSHA currently has a permissible exposure limit (PEL) for airborne particulates not otherwise regulated (PNOR), which includes fibrous glass, the agency does not have a specific PEL for the fiberglass. However, the ACGIH recommended airborne exposure limit is 1 fiber/cubic centimeter (cc). Relying only on a dust monitoring system, an industrial hygienist may easily miss the fact that some of these fibers are smaller than 2.5 µm in size. Additional concern may be phenol-based formaldehyde binders commonly used in batt fiberglass insulation and flooring materials. An example of aldehyde binder on fiberglass fiber is presented in Figure 3.

Figure 4 Yellow Acoustic Ceiling Tile Glass Fiber (source: MicrolabNW).

There were no affordable and reliable direct reading instruments for formaldehyde until 2008. One exception is the availability of detector tubes for formaldehyde that were available in the 1980s. Formaldehyde can be measured with direct reading instruments these days. For instance, one of the available formaldehyde meters, for continuous or portable measurement, has a range from 10 ppb (parts per billion) to 1000 ppb. These very low levels of detection (actual limits of detection down to <5 ppb) are essential for IEQ measurement of formaldehyde and are typically not achieved by alternative continuous measurement technology.
This instrument utilizes a reusable sensor cartridge that relies on the chemical reaction between formaldehyde and ß-diketone in a porous glass. The yellowing that results from this reaction is measured via photoelectric photometry with accurate readings to <20 ppb HCHO, without significant cross-sensitivity from typical background compounds (Graywolf, n.d.).

The air quality in the above-described case study is a very complex issue. VOC's levels are in the parts per billion ranges. Chlorine (OSHA PEL 1 ppm), Formaldehyde (PEL 0.75 ppm), and Ozone (PEL 0.1 ppm) did not fluctuate significantly and were within acceptable ranges. Please see the results presented in Table 1. The readers can see that none of the individual substances exceeded the established limits by US OSHA.

Table 1. Table Title Is Always in Mixed Case

	Chlorine (PEL=1 ppm)	Formaldehyde (PEL=0.75 ppm)	Ozone (PEL = 0.1 ppm)
Concentration (C)	0.21	0.11	0.077
PEL	1	0.75	0.1
C/PEL	0.21	0.15	0.77

However, exposure to chemical mixtures is a more complicated issue. The U.S. Federal Occupational Safety and Health Administration (OSHA) suggests that in case of a mixture of air contaminants an employer shall compute the equivalent exposure as in Equation 2 (OSHA, n.d.) where: Em is the equivalent exposure for the mixture; C is the concentration of a particular contaminant; L is the exposure limit for that substance specified in Subpart Z of 29 CFR Part 1910; and the value of Em shall not exceed unity (1).

$$Em = \left(\frac{C_1}{L_1} + \frac{C_2}{L_2} + \frac{C_3}{L_3}\right) + \cdots \left(\frac{C_n}{L_n}\right) \quad (2)$$

The readers can see that none of the individual substances exceeded the established limits set by US OSHA. However, the exposure to the mixture calculated using Equation 1 is 1.13. Therefore, the mixture limit was exceeded. Such calculations are not uncommon for experienced industrial hygienists. However, direct reading instruments do not take into account exposure to mixtures. Therefore, relying simply on direct reading instruments to evaluate complex IEQ issues should be considered insufficient.

Sometimes, a team of experienced IEQ professionals is needed for more a complete assessment. For instance, a complication factor in the presented case study was the fact that the supply linear vent was installed very close to the return air grille. This allows short circuiting, which means some of the supply air is captured by the return air grille before the supply air can mix in the room air. Please see depiction on Figure 5 for details.

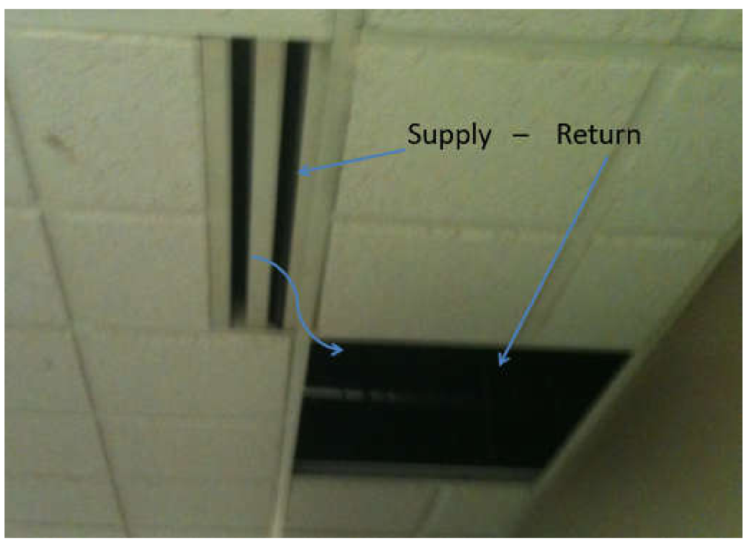

Figure 5 Inproper position of input and output of HVAC system.

As mentioned earlier, due to renovation efforts, a new flex duct was installed above the ceiling tiles. The flex duct contains significant amounts of fiberglass and aldehyde binder. A closer look will reveal that the flex duct was not even fitted properly allowing introduction of loose fiberglass fibers to be introduced in the air stream due to duck leakage. Please see depiction on Figure 6 for details.

Figure 6 New flex duct was installed above the ceiling tiles

The installation technician decided to shorten the flex duct and installed the supply air close to the return air grille without realizing that such arrangement does not provide the proper ventilation rate.

Ventilation rates can be easily assessed with direct reading instruments as well. Some of these instruments are combined with CO and CO_2 sensors. Ductwork pressure testing should have been performed to determine how well ducts are constructed to prevent air leakage. An experienced IEQ professional would have addressed insufficient ventilation, duct sealing and elevated CO_2 levels. However, such a variety of direct reading instruments are not always readily available. In the above-mentioned scenario, measurement of single parameters would probably lead to wrong conclusions.

CONCLUSION

Direct reading instruments were improved greatly during the last few decades. However, experienced industrial hygienists should evaluate the results to reduce errors. If any "mysterious" results were obtained a secondary detection method should be employed. Experienced IEQ professionals should be aware of chemical interactions and interferences leading to erroneous results from direct instruments readings. IEQ evaluations should be considered from a system perspective to avoid incomplete assessments and misleading conclusions.

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NOMENCLATURE

Em = exposure to the mixture
Ci = concentration of a particular contaminant
Li = exposure level of a particular contaminant

Subscripts

m = mixture
1,2,3, …, n = numbers in sequence

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