# Indoor Air Quality: The Forgotten, Yet Critical, Element in Sustainable Buildings

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# Indoor Air Quality: The Forgotten, Yet Critical, Element in Sustainable Buildings


## SUMMARY:

In this paper, we consider how high performing, sustainable building programs and designs are currently addressing indoor air quality (IAQ) and how they might improve their treatment of IAQ. As part of this effort, we reviewed 100 case studies of high performing buildings to determine what aspects of IAQ they report on and how often actual IAQ performance data are presented. Based upon this analysis as well as existing standards and guidelines, we discuss what IAQ performance data should be collected during the early stages of a building's operation to demonstrate its IAQ performance. We also present an approach to graphically represent such data that allows one to more easily view the multi-faceted nature of IAQ performance.



**Keywords:** Energy, environmental impact, green buildings, indoor air quality, sustainability


## INTRODUCTION:

There have been increasing discussion and activity in recent years related to the reduction of the environmental impacts of buildings, including energy consumption and greenhouse gas emissions, as well as land, water, and material use (ASHRAE 2011, NSTC 2008, USGBC 2013). However, these efforts do not always stress all aspects of building sustainability, in particular IAQ. Neglecting IAQ while pursuing other goals can result in building environments that negatively impact the health and productivity of occupants and defeat the overall goal of building design (Persily and Emmerich 2012). While IAQ should be addressed in more detail in discussions of high performing, low energy buildings, it is not clear how best to document IAQ design measures and IAQ performance during building occupancy. Design guidance for improved IAQ is available (ASHRAE 2009), and measurement protocols have been published for high-performance buildings (ASHRAE 2010). However, there is no accepted approach to documenting design measures for IAQ or for measuring and presenting IAQ performance.

## METHODOLOGIES:

We reviewed the first 100 case studies in ASHRAE's High Performing Buildings (HPB) magazine to determine how they address IAQ, specifically the types and frequencies of IAQ-related design measures; claims of acceptable or healthy IAQ; and presentation of actual IAQ performance data. Based on the results of this analysis and consideration of existing standards, guidelines, and other documents, we discuss what IAQ performance data should be collected during the early stages of a building's operation to demonstrate its IAQ performance. To support the reporting of IAQ performance data, we discuss a graphical approach to presenting these data.

## RESULTS AND DISCUSSION:

### IAQ in High Performance Building Case Studies

Despite claims of acceptable and even healthy IAQ, existing discussions of sustainable building performance rarely include data on actual IAQ performance. To document this lack of attention to IAQ in sustainable buildings, the first 100 case studies in the HPB magazine were examined for how they address IAQ (Teichman et al. 2013a). We examined all of the case studies from Winter 2008 through Winter 2013, focusing primarily on building design characteristics intended to promote good IAQ, e.g., dedicated outdoor air systems, low volatile organic compound (VOC) emitting building materials, and high efficiency filtration.

Table 1 summarizes the prevalence (number of case studies) of several IAQ-impacting features in decreasing order of mention in the 100 case studies. The basic approaches to controlling indoor air contaminant concentrations are source removal or reduction, ventilation, and air cleaning, and many of the items in Table 1 relate to one of these approaches. Four relate to source control (low VOC emitting materials, low emitting cleaning materials, formaldehyde-free materials, and carbon monoxide sensors). Eight are ventilation-related (carbon dioxide ($CO_2$) sensors for demand control ventilation, hybrid ventilation, dedicated outdoor air systems, displacement ventilation, reference to ASHRAE Standard 62.1, nighttime outdoor air purge, post-construction flush out, and monitoring outdoor air intake rates). Two relate to air cleaning (particle filtration and gaseous air cleaning). Most of the other items are either general claims related to the achievement of good IAQ (claim of good IAQ, anecdotal mention of IAQ improvements, and claim of healthy IAQ) or specific actions taken to verify achievement of acceptable IAQ after construction (post-occupancy survey, IAQ monitoring program, and indoor contaminant data). The general claims show a level of awareness of the importance of IAQ, but data are typically not provided to conclude that acceptable IAQ was achieved.

Some people automatically assume improving IAQ will cost additional energy (e.g., by increasing ventilation rates), but many of the Table 1 features can support both energy efficiency and IAQ objectives of HPB design and operation. Examples include demand-controlled ventilation, dedicated outdoor air systems, displacement ventilation, natural/hybrid ventilation, and construction practices that increase envelope tightness. Source control and air cleaning measures may indirectly be considered energy-related if they are used to justify lower ventilation rates; however, some high performance standards and programs may not allow these approaches.

It is worth noting that eight of the ten most prevalent IAQ features in Table 1 are design measures intended to achieve good IAQ. However, good design alone is not sufficient to achieve good IAQ; building operation and maintenance are also key to realizing the intended level of performance. Measures that directly relate to actual IAQ performance, e.g., monitoring, occupant surveys and measured contaminant levels, are much less common. Note also that several of the measures, primarily those related to ventilation (e.g., dedicated outdoor air ventilation), could be viewed as being motivated by energy considerations more than IAQ.

Table 1 Prevalence of IAQ-impacting features mentioned in the 100 HPB magazine case studies

| Feature | Prevalence |
|---|---|
| Low VOC Emitting Materials | 60 |
| Carbon Dioxide Sensors (for demand control ventilation) | 51 |
| Hybrid/Natural Ventilation | 42 |
| Claim of Good IAQ | 36 |
| Dedicated Outdoor Air System | 31 |
| Displacement Ventilation (e.g., under-floor air distribution) | 31 |
| Reference to ASHRAE Standard 62.1 | 25 |
| Filtration Efficiency Cited (e.g., MERV) | 22 |
| Low Emitting Cleaning Materials | 16 |
| Formaldehyde-Free Materials | 14 |
| Post-Occupancy IAQ Survey | 12 |
| IAQ Monitoring Program | 12 |
| Anecdotal Mention of IAQ Improvements | 10 |
| Nighttime Outdoor Air Purge | 10 |
| Claim of Healthy IAQ | 9 |
| IAQ Considered During Construction (e.g., ductwork sealed) | 8 |
| Gaseous Air Cleaning | 6 |
| Air Leakage or Air Change Measurement | 5 |
| Carbon Monoxide Sensors (for controlling garage exhaust ventilation) | 4 |
| Post-Construction Building Flush Out | 4 |
| Indoor Contaminant Data Provided | 2 |
| Monitoring of Outdoor Air Intake Rates | 1 |

In summary, this study considers how IAQ was addressed in 100 high-performing buildings case studies and shows that 45 % of the case studies claimed good or healthy IAQ while only two case studies (2 %) presented actual data on IAQ performance. Similarly, while 60 % of the building case studies claimed they benefitted from the use of low VOC emitting materials, only two case studies (2 %) provided data on indoor VOC levels. The lack of reported IAQ performance data, even in "high performing buildings," may be due in part to the lack of agreement on what IAQ performance data should be collected.

**Reporting IAQ Design and Performance**

Despite the need for increased attention to IAQ in HPB design and performance, it is not clear how to document good IAQ design and actual building performance. While many of the case studies employed sound design features to improve IAQ, just noting that they were used is not adequate to understand how they were implemented. Admittedly, the case studies in the HPB magazine are limited by space and therefore do not contain many details of interest. Table 2 contains a selected set of design features, drawn from those identified in the case studies, along with information that should be included when describing their implementation. Table 3 contains information on IAQ-related measures during construction and commissioning.

Table 2 Information for documenting selected IAQ design features

| Design Feature | Associated Information |
|---|---|
| Standard used for IAQ/ventilation | • Identify Standard used (e.g., 62.1 or 189.1, including year and sections complied with) |
| Design minimum outdoor air intake | • Provide design outdoor air intake rate in L/s per person by major space type |
| If natural or hybrid ventilation | • Describe design, operating principles, and ventilation rates |
| If employing night time purge | • Describe purge strategy, including duration, timing, and airflow rate in air changes per hour |
| If using low VOC emitting materials | • List low emitting label program by building material, or standard complied with (e.g. 189.1)<br>• If quantitative emissions requirements, list values<br>• If qualitative (e.g. HCHO-free), list requirements |
| If using $CO_2$-based demand controlled ventilation | • Describe control strategy, including $CO_2$ setpoint and sensor location approach |
| Particle filtration efficiency | • Provide MERV levels employed |

Table 3 Information for documenting IAQ during construction and commissioning

| Construction/Commissioning Feature | Associated Information |
|---|---|
| Measurements of outdoor air intake | • Provide measured and design values |
| If natural or hybrid ventilation | • Describe commissioning efforts |
| IAQ controls during construction | • List measures employed (e.g., ductwork sealed) |
| Envelope airtightness measurements | • Describe measurement technique and results |
| If post-construction flush out employed | • Describe strategy, duration, and airflow rate |

Once a building is occupied, the measurement of IAQ and other aspects of indoor environmental quality (IEQ) are critical to demonstrating that a HPB is indeed high performing. ASHRAE's Performance Measurement Protocols (PMP) for Commercial Buildings describes many aspects of IEQ performance measurement including thermal comfort, lighting and acoustics, all of which are important for verifying high performance in buildings (ASHRAE 2010). Two key aspects of performance highlighted in this document are occupant surveys and outdoor air intake monitoring. Rather than claiming "good IAQ," it is preferable to ask occupants what they think using validated questionnaires and other tools as described in the PMP document. Measuring outdoor air intake during operation, not just during the commissioning phase, is also critical. In fact, it is required under ASHRAE/IES/USGBC Standard 189.1-2011 (ASHRAE 2011); when reporting the measured values, the measurement methods and system operation conditions must also be reported.

The final piece of IAQ performance is the measurement of indoor contaminant concentrations. Currently there are no accepted recommendations or requirements for indoor contaminant measurements in HPBs. In addition, reference values to which these measurements should be compared are even more challenging to define. For these reasons, some question the value of measuring indoor contaminant concentrations unless there is a very specific reason for doing so (ASHRAE 2009). Table 4 summarizes IAQ performance measurements in LEED 2009 and LEED Version 4 (USGBC 2009 and 2013), as well as Standard 189.1-2011 (ASHRAE 2011). All of these measurements are presented as alternatives to pre-occupancy building flush out, with LEED offering extra points for either a flush out or for making these measurements and Standard 189.1 requiring one or the other.

Table 4 Existing recommendations for reporting IAQ performance

| **Contaminant** | **LEED 2009* Maximums** | **LEED v4* Maximums** | **ASHRAE/IES/USGBC Standard 189.1-2011*** |
|---|---|---|---|
| Formaldehyde | 33 $\mu g/m^3$ | 33 $\mu g/m^3$ | 9 $\mu g/m^3$ under **CDPH |
| PM10 | 50 $\mu g/m^3$ | 50 $\mu g/m^3$ | 150 $\mu g/m^3$ (24 h) |
| PM2.5 | | 15 $\mu g/m^3$ | 35 $\mu g/m^3$ (24 h) |
| Carbon monoxide (CO) | 10.3 $mg/m^3$, <= 2.3 $mg/m^3$ above outdoors | 10.3 $mg/m^3$, <= 2.3 $mg/m^3$ above outdoors | 10.3 $mg/m^3$, <= 2.3 $mg/m^3$ above outdoors |
| Ozone | | 0.147 $mg/m^3$ | 0.147 $mg/m^3$ (8 h) |
| Individual VOCs | | **CDPH | **CDPH |
| ***TVOC | 500 $\mu g/m^3$ | 500 $\mu g/m^3$ | |
| 4-PC (SBR carpet) | 6.5 $\mu g/m^3$ | | |

* Alternatives to pre-occupancy flush out
** Table 4-1 in CDPH/EHLB/Standard Method V1.1 (CDPH 2010)
*** Total volatile organic compounds

The ASHRAE PMP document (ASHRAE 2010) is another notable reference for IAQ performance measurements, which has three levels of performance evaluation: Basic, Intermediate and Advanced. Under the Basic level, the only contaminant for which measurement is recommended is carbon monoxide, and only if combustion sources are located in or near the building. In that case, the PMP document suggests the EPA National Ambient Air Quality Standard for CO as the relevant reference value (EPA 2012). Under the Intermediate level, the PMP adds the measurement of indoor $CO_2$ concentrations, noting that levels “exceeding design condition concentrations should be reported,” though the meaning of these levels is not clear. Finally, the Advanced level adds continuous measurement of $CO_2$, PM2.5 and TVOCs, as well as design contaminants in cases where the ASHRAE Standard 62.1 IAQ Procedure is employed to design the building (ASHRAE 2013).

Table 5 contains a preliminary, candidate list of IAQ measurements for HPBs, which with additional discussion can evolve into an accepted approach to reporting performance. The measurement of TVOCs and individual VOCs is particularly challenging given questions related to defining TVOC and its usefulness as a metric, as well as the selection of specific VOCs to measure (ASHRAE 2009).

Table 5 Candidate IAQ performance data to be collected in HPBs

| **Parameter** | **Notes** |
|---|---|
| Outdoor air intake | • Measure in each ventilation system in each operating mode (minimum outdoor air, economizer, etc.) for one week at least once per season |
| Carbon dioxide | • Measure in main return of each air handling system; report peak hourly value for each day of one week at least once per season<br>• For naturally ventilated buildings, measure in occupied space<br>• Include outdoor concentration with indoor values |
| Carbon monoxide | • Measure in main return of each air handling system; report peak hourly value for each day of one week at least once per season<br>• For buildings with underground parking garages, also measure in garage and indoor spaces adjacent to garage |
| TVOC | • Measure in two occupied space locations for each air handling system after at least 4 h of occupancy; report value once per season<br>• Include definition of TVOC and measurement method<br>• TVOC as an IAQ metric is problematic; see the discussion in the ASHRAE Indoor Air Quality Guide (ASHRAE 2009) |
| Individual VOCs | • Measure in two occupied space locations for each air handling system after at least 4 h of occupancy; report value once per season<br>• Individual compounds, with the exception of formaldehyde (below), can be based on contaminants of concern based on indoor or outdoor sources. Table 4-1 in CDPH/EHLB/Standard Method V1.1 provides a list of compounds to consider (CDPH 2010). |
| Formaldehyde | • Measure in two occupied space locations for each air handling system after at least 4 h of occupancy; report value once per season |
| PM2.5 | • Measure in two occupied space locations for each air handling system; report average value over occupied portion of day for one week at least once per season<br>• Include average outdoor concentrations with indoor values |
| Ozone | • Measure in two occupied space locations for each air handling system; report peak hourly value over occupied portion of day for one week at least once per season<br>• Include average outdoor concentrations with indoor values |
| Radon | • Measure in lowest ground-contact spaces at least once per season |

**Graphical Approach to Presenting IAQ Performance Data**

Regardless of the contaminants measured in HPBs, or any buildings for that matter, it is very challenging to present these data in an easily understandable fashion. This is due in part to the potentially large number of contaminants of interest, the difficulty in determining reference values for comparing the measurements, and ultimately the lack of metrics to quantify IAQ performance. Teichman et al. (2013b) describe a graphical approach for presenting IAQ performance data. In this approach typically twelve IAQ parameters (e.g. contaminant concentrations) are plotted in equal angular sectors within a circle whose perimeter is defined by the health benchmark or reference value for each parameter. If the concentration is less than its reference value, the length of the sector is proportionately shorter than the reference value. If the concentration exceeds its reference value, the length is proportionately longer. To distinguish a small, but non-zero value from the absence of a reference value, the length of the sector is one quarter of the reference value. Similarly when the concentration exceeds its reference value by more than 50 %, we graph the parameter one and half times the length of the reference value.

Figure 1 illustrates how this approach can be used to display IAQ performance data. The data plotted are a combination of data from the EPA Building Assessment Survey and Evaluation study (Girman et al. 1995) and the California Energy Commission Small and Medium Size Commercial Buildings study (Bennett et al. 2011), with each specific value in the figure being the higher of the $95^{th}$ percentile values in each study. The reference values are as follows: (a) 1800 $\mu g/m^3$ for $CO_2$ despite the fact that $CO_2$ is not a comprehensive indicator of IAQ and there are many problems with its measurement and interpretation (Persily 1997); (b) PM2.5 and PM10 (EPA 2012); and (c) individual VOCs (OEHHA 2013). Note that the OEHHA reference values are for chronic exposures, except HCHO, which is for 8-h as there is no chronic value.

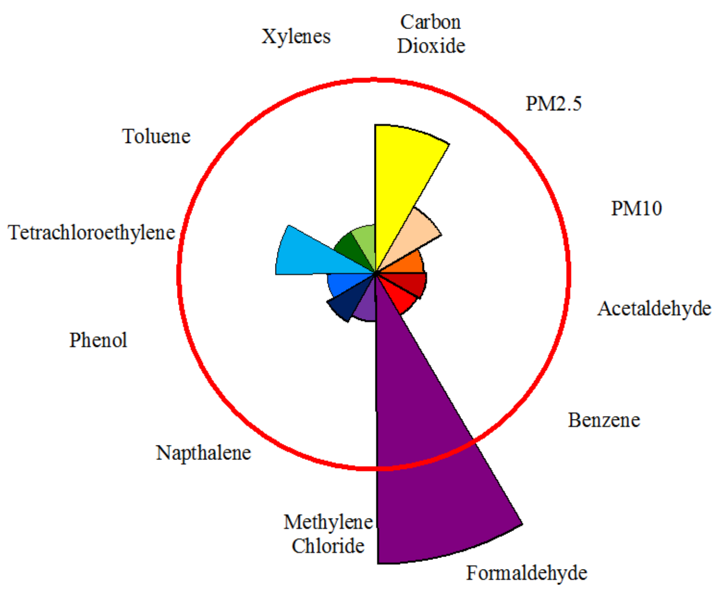


Figure 1 Example of graphical approach for displaying IAQ performance data

As noted in Teichman et al. (2013b), this graphical approach can be expanded to also include information on energy, water, and waste performance, proving an easy-to-view display of the overall environmental footprint of a building.

## CONCLUSIONS:

Achieving sustainable buildings requires consideration and integration of the multiple factors that contribute to the environmental impacts of buildings. Many sustainable building programs and discussions do not address IAQ as thoroughly as other aspects of building performance. Neglecting IAQ while pursuing other sustainability goals can result in building environments that negatively impact the health and productivity of occupants and thereby defeat the overall goal of building design. Reporting IAQ design features in sufficient detail to understand how IAQ is being addressed, followed by IAQ performance measurements in the occupied building, will help to bring IAQ to its deserved prominence in discussions of sustainable buildings.

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