Indoor Air Quality in High-Performing Building Case Studies: Got Data?

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ABSTRACT

In this paper, we review how indoor air quality (IAQ) has been addressed in case studies of high-performing buildings (HPBs), specifically the case studies described in ASHRAE's "High Performing Buildings" magazine. We find that nearly all of the reported case studies address energy performance, both in the design and operation of the building. In contrast, while most case studies mention IAQ design considerations, they generally do not address IAQ in a comprehensive manner nor do they present the impacts of IAQ-related and other design considerations on indoor concentrations or on the health, comfort, and productivity of building occupants. Based upon this analysis, as well as existing standards and guidelines, we discuss what IAQ information should be collected during the early stages of a building's operation to demonstrate its IAQ performance. This information includes: (a) documentation of key IAQ-related design features and their implementation during building construction, commissioning, and initial operation; (b) collection of IAQ performance data, including measured pollutant concentrations and ventilation rates, and (c) assessment of occupant satisfaction using occupant surveys. To facilitate comparisons of IAQ performance among buildings, we provide suggestions

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on how to collect and report this information in a consistent manner.

INTRODUCTION

There has been an increasing level of discussion and activity in recent years related to the reduction of the environmental impacts of buildings, including energy consumption and associated greenhouse gas emissions, as well as land, water and material use. The overarching goal of these efforts is often captured under the broader label of green or sustainable buildings, with some discussions also using the term high-performing buildings (HPBs). A number of programs, standards, codes, and other efforts are in place or under development to promote, and in some cases require, the design and construction of high-performing, green, or sustainable buildings (ASHRAE 2011; USGBC 2009; GBI 2010; ICC 2012; USGBC 2014). As part of these efforts, there has also been a focus on net-zero energy buildings, which are intended to be so energy efficient that the energy they require can be provided on a net annual basis by on-site renewable energy sources (NSTC 2008). Many discussions of net-zero energy buildings also speak to the need for high performance overall, but there is great variability in how they address non-energy issues. ASHRAE, among other organizations, has taken a lead in the support of technology, standards, and other activities to promote high performing, sustainable buildings (ASHRAE 2006), including the development of ANSI/ASHRAE/IES/USGBC Standard 189.1 Design of High-Performance Green Buildings (ASHRAE 2011).

While great progress has been made in achieving sustainable HPBs, it is noteworthy that most discussions of green, sustainable, high performing and certainly net-zero energy buildings tend to focus on energy consumption, which while critically important, is only one aspect of performance and should not be pursued to the neglect of the others. Good indoor environmental quality (IEQ) is also a key goal of HPBs, but is often not factored into sustainable building discussions and programs in a comprehensive and consistent manner (Persily and Emmerich 2012). Given that buildings exist to support the activities and needs of the occupants, efforts to reduce energy use or other environmental impacts that also degrade IEQ can be counterproductive, with potentially significant negative impacts on occupant health, comfort and productivity (Fisk 2000).

As part of its activities to support the design and construction of sustainable buildings, ASHRAE began publication of a new magazine in the winter of 2008, "High Performing Buildings," which is available at http://www.hpbmagazine.org. ASHRAE is to be commended for initiating this quarterly publication, which adds to the literature on HPBs by presenting case studies of different building types from across the world. Perhaps even more commendable is that, in recent years, ASHRAE has sought to present key building information, including energy and water consumption data, in a consistent format that enables comparisons across buildings of different sizes, functions and climates. Grumman and Hinge recently summarized the energy data from 60 of the buildings, with more detailed building characteristics from eight buildings included in earlier issues of the magazine (Grumman and Hinge 2012).

It is our contention, supported by the analysis in this paper, that indoor air quality (IAQ) is often given minimal attention in HPBs, as evidenced by the articles published in "High Performing Buildings," relative to energy, water, and waste considerations. We hasten to add that this is not uniformly true, citing two notable examples to the contrary that concluded: (1) "The highest return on the construction dollar [is] human productivity in the designed space" (Croxton 2012) and (2) “Indoor air quality measurements of the building confirm that careful design of the HVAC systems, proper building material selection, implementation of green building cleaning practices, and regularly scheduled HVAC maintenance can result in excellent IAQ and energy efficiency” (Alevantis et al., 2012). We also note that these two articles, discussed later in this paper, were exceptions among the case studies reviewed, because they provided measurement information on indoor pollutants other than carbon dioxide (CO_2). Readers may also find the recent paper of Newsham et al. informative, because the authors took physical measurements and used a post-occupancy questionnaire to compare 12 green and 12 conventional office buildings (Newsham et al., 2013).

METHODOLOGY

We examined all of the case studies included in “High Performing Buildings” since its inception in the winter of 2008 through the winter of 2013, a total of 100 buildings. We focused on those building design characteristics that are intended to directly promote good IAQ (e.g., low volatile organic compound (VOC) emitting building materials and high efficiency filtration) or could be viewed as potentially supportive of good IAQ (e.g., demand control ventilation and dedicated outdoor air systems). We also noted, among other characteristics, the existence of measured energy consumption data for the building, features intended to reduce water consumption (e.g., rainwater harvesting for irrigation and other non-potable purposes), and construction waste being diverted from landfills. In addition, we noted where the performance of the building was compared to a building standard such as ASHRAE Standards 62.1 and 90.1 (ASHRAE 2010a; ASHRAE 2010b).

RESULTS

Before discussing the results of this review of the "High Performing Buildings" case studies, it is important to mention some of the potential limitations of the analyses. First of all, we have limited our review to only the information describing each case study that is contained in the articles in "High Performing Buildings". While the editors of the magazine deserve credit for trying to standardize the information presented in each case study (e.g., sidebars on energy performance, key sustainable features, and lessons learned), due to understandable space limitations, authors may have been limited in their description of some building attributes and performance. Also, in preparing this paper, we have had to interpret the information that was included in the magazine articles and could have misinterpreted some of the details provided. Lastly, and most importantly, it should be emphasized that the case studies included in "High Performing Buildings" are likely among the best examples of HPBs and probably not representative of current new and retrofit construction practice.

Table 1 shows the prevalence of 21 IAQ features in decreasing order of mention in the 100 "High Performing Buildings" case studies. The specific features included in the table were identified during the review in an attempt to capture all of the IAQ-related features described in the case studies. It has long been recognized that the primary approaches for controlling indoor air contaminant concentrations are contaminant source removal or reduction, ventilation, and air cleaning. Besides being fundamental approaches to improving IAQ, HPB standards or programs typically include requirements and/or offer credit for these features (Persily and Emmerich 2012). As such, it is no surprise that many of the items in Table 1 relate to one of these three approaches. Specifically, four of the items are related to source control (low VOC emitting materials, low emitting cleaning materials, formaldehyde-free materials, and carbon monoxide sensors). Eight of the items are ventilation-related (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 building flush out, and monitoring outdoor air intake rates). Two of the features relate to air cleaning (particle filtration efficiency cited and gaseous air cleaning). Most of the other items on the list may be considered 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 IAQ survey, IAQ monitoring program, and indoor contaminant data provided). The general claims show a positive level of awareness of the importance of good IAQ, but data are typically not provided to support that acceptable IAQ was actually achieved.

Some people automatically assume improving IAQ will cost additional energy, e.g., by increasing outdoor air ventilation rates. However, as discussed by Levin and Teichman (1991) and Persily and Emmerich (2012), many of the Table 1 features can be part of strategies that support both the energy efficiency and IAQ objectives of HPB design and operation. Examples of such strategies 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-impacting 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 IAQ performance. Measures that directly relate to 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 and displacement ventilation), could be viewed as being motivated by energy considerations more than IAQ.

Table 2 shows the prevalence of IAQ features interlaced with Energy-, Water- and Waste-related features in decreasing order of mention in the 100 "High Performing Buildings" case studies. In this table, the Energy features are in red text, Water in blue, Waste in brown, and *IAQ in green and italics.* This table shows visually the high prevalence of energy features relative to the other three categories. The reader should note that our analysis did not focus on energy, and therefore only the highest-level energy features are identified. There were a very large number of energy features noted in these case studies that are not included in the table, e.g., increased insulation and day lighting. For comparison, if one averages the highest three prevalence features in each category, the results are 81 for Energy, 51 for IAQ, 50 for Waste and 47 for Water.

We cited earlier, in our introduction, quotes from two of the 100 case studies that provided measured IAQ data, other than references to CO_2 monitoring for demand control ventilation (Alevantis, et al. 2012; Croxton 2012). In the Natural Resources Defense Council Building in New York City, measurements were made of formaldehyde, particulate matter, total VOC, and carbon monoxide, all of which were found to be well below values specified in the air testing option under the LEED credit for a Construction Indoor Air Quality Management Plan (Croxton 2012). In addition, screening measurements were made for ethylene dichloride (plastic welding adhesive), 1,2 dichlorobenzene (plastic foam insulation), crystalline silica (joint compound), and chromated copper arsenate (pressure-treated wood). Similarly, in the California Department of Health Building P in Richmond, CA, pre-occupancy testing was performed for individual VOCs (including formaldehyde, acetaldehyde), particulate matter, carbon monoxide, and CO_2 (Alevantis, et al. 2012). All of the concentrations measured were below the California Office of Environmental Health Hazard Assessment chronic recommended exposure levels and below 1 % of the Occupational Safety and Health Administration's permissible exposure limits (OEHHA 2012; OSHA).

In summary, this study of how IAQ was addressed in 100 "High Performing Buildings" case studies showed 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 volatile organic compound (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.

DOCUMENTING HIGH PERFORMANCE IAQ

Despite the need for increased attention to IAQ in HPB design and performance, it is not clear how to document IAQ design measures and IAQ performance in a constructed building. 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 and to assess whether they provided a beneficial impact on IAQ. Based on consideration of the IAQ features identified in the case study, as well as design requirements in Standards 62.1 and 189.1, a number of design measures were identified. While these standards and various rating systems include IAQ measures, they generally do not treat IAQ in a comprehensive manner. Table 3 lists the design features identified for documenting a high performance IAQ design, along with information to include when describing their implementation. Several of these are relevant only if the specific feature is part of the design, e.g. natural ventilation and CO_2 demand control ventilation. The only features that are assumed to be covered in all cases are reference to an IAQ design standard, e.g. 62.1, minimum outdoor air intake rates and particulate filtration levels. In the case of the IAQ standard, there is an entry describing how each requirement is complied with; this particular item needs further development, e.g., the identification of a subset of requirements from the standard to keep the documentation more manageable and focused.

Moving beyond design to construction and commissioning, Table 4 contains additional information to be documented at these stages in the process. The first two items, measurement of system outdoor air intake and exhaust airflow rates, are normally included in testing and balancing activities, but are included here to emphasize the importance of including them in IAQ-specific documentation. Table 4 also includes reporting on control measures during construction, such as keeping the ductwork sealed. This entry could be expanded to list a number of specific features, based perhaps on those contained in the SMACNA (Sheet Metal and Air Conditioning Contractors' National Association) guidelines on IAQ during construction (SMACNA 2007). The table also contains an envelope airtightness measurement, based on the relevance of airtightness to outdoor contaminant entry, moisture management and proper ventilation system operation (Persily and Emmerich 2012). Two of the items in Table 4 are dependent how the building is designed and commissioned. Specifically, if the building employs natural or hybrid ventilation, those systems need to be commissioned, which can be challenging. It is very difficult to measure ventilation rates in naturally ventilated buildings, perhaps less so with hybrid ventilation; therefore the manner in which these systems are commissioned needs to be described. Given these challenges, natural and hybrid commissioning approaches should be developed and tested in the future. Since some sustainable building standards and programs either recommend building flush-out, or include it as an option, Table 4 contains an entry for flush-out if it is employed. Specifically, the flush-out strategy should be described, including its duration and airflow rate.

The final and perhaps most critical stage considered here is the operation of the occupied building. Once a building is occupied, the measurement of IAQ and other aspects of 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 2010c). Two key aspects of performance highlighted in this document are occupant surveys and outdoor air intake monitoring. Rather than claiming "good IAQ," it is far more meaningful to actually ask the occupants what they think using validated questionnaires and other tools as described in the PMP document. The University of California Center for the Built Environment has one such survey as well as a database of results from different buildings (Zagreus et al., 2004; CBE 2013).

Measuring outdoor air intake during operation, not just during the commissioning phase, is also critical though challenging in many installations (Fisk et al., 2006). In fact, it is required under ASHRAE/IES/USGBC Standard 189.1-2011 (ASHRAE 2011). Table 6 suggests one week of measurement during each season of the year, if continuous measurement is otherwise not required. When reporting these measured values, the weather and system operation conditions need to be reported to allow interpretation of the results, as well as information on the measurement method, location, and uncertainty.

The final piece of IAQ performance is the measurement of indoor contaminant concentrations. Currently there are no widely accepted 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). Nevertheless, contaminant measurements are included in some high performance building programs and standards. Table 5 summarizes IAQ performance measurements in LEED 2009 and the more recent version 4 for LEED (USGBC 2009; USGBC 2014), as well as Standard 189.1-2011 (ASHRAE 2011) and the 2012 IgCC (ICC 2012). Note that for both versions of LEED and for Standard 189.1, 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. In the case of the IgCC, there is an exception to requiring these measurements "… if a similarly designed and constructed building, …, for the same owner and tenant, has been tested … and the testing results …" are in compliance with these levels (ICC 2012). If these levels are not met, the IgCC requires a flush out for 14 days with occupancy permitted 7 days after the start of the flush out.

The ASHRAE PMP document (ASHRAE 2010c) is another notable reference for contaminant concentration measurements, with 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 CO2 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 CO2, 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 6, discussed earlier in the context of occupant surveys and outdoor air intake measurements, also contains a preliminary, candidate list of IAQ measurements for HPBs, which with additional discussion could evolve into an accepted approach to reporting performance. All of the individual contaminants listed are associated with issues related to both measurement and interpretation. Indoor CO_2 measurements, though widespread, are often performed without an appreciation of their meaning and without adequate care regarding instrument calibration and uncertainty (Persily 1997); guidance is available to aid in interpreting these measurements (ASTM 2012). 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).

CONCLUSION

Achieving the important goal of high-performing, sustainable buildings requires the commitment and expertise of all members of the building community, including building owners and managers, architects and engineers, policymakers, and building occupants. These efforts need to consider and integrate the multiple factors that define sustainability, which can be challenging but are essential to the national and global objectives of reducing energy use and other environmental impacts associated with buildings. Such integrated design, from the perspective of IAQ, is discussed in the ASHRAE IAQ Design Guide (ASHRAE 2009). The 100 case studies, which were subject to the analysis presented in the paper, highlight many of the creative approaches being employed, which will hopefully inspire others to continue making progress in this critical area.

However, these case studies, at least as they are presented in the “High Performing Buildings” magazine, do not 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, comfort, and productivity of occupants and therefore defeat the overall goal of building design, including reduced costs. In addition, while building design is key to achieving a HPB, it is critically important to follow these good intentions through construction, commissioning, operation, and maintenance. Only in this way, will HPBs actually perform as designed. Finally, the only way to verify that these goals are being reached is by performing actual performance measurements, which is particularly lacking for IAQ as shown in these case study reports. In the words of W. Edwards Demming: “In God we trust; all others bring data” (Hastie et al., 2009).

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

Feature	**Prevalence** (# of Case Studies)
Low-VOC-Emitting Materials	60
Carbon Dioxide Sensors (for demand control ventilation)	51
Hybrid Ventilation (i.e., for extended periods, the building is naturally ventilated)	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 (e.g., perceived increased productivity)	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

Table 2 Prevalence of IAQ features (*green text and italics*) interlaced with Energy (in red), Water (in blue) and Waste (in brown) features

Feature	**Prevalence** (# of Case Studies)
Site Energy Use Intensity	94
Comparison to Building Energy Standard (e.g., ASHRAE 90.1)	77
Reference to Building Rating Standard (e.g., LEED)	73
Source Energy Use Intensity	66
Xeriscaping (e.g., drought-resistant plants)	66
Recycled Construction Materials	60
Low-VOC-Emitting Materials	*60*
Rainwater Retention and/or Use	59
Carbon Dioxide Sensors	*51*
Construction Waste Diverted	47
ENERGY STAR Rating	45
Photo-Voltaic Array	44
Energy Recovery (e.g., enthalpy wheel)	43
Hybrid Ventilation	*42*
Claim of Good IAQ	*36*
Regionally-Sourced Construction Materials	33
Dedicated Outdoor Air System	*31*
Displacement Ventilation (e.g., under-floor air distribution)	*31*
Calculation of Carbon Dioxide Emissions Avoided	26
Reference to ASHRAE Standard 62.1	*25*
Green Roof	24
Recycling Program (e.g., for paper, glass, plastics)	24
Comparison to Building Water Use Reference Value (e.g., EPAct)	22
Filtration Efficiency Cited (e.g., MERV)	*22*
Contaminated Site (e.g., Brownfield)	17
Low-Emitting Cleaning Materials	*16*
Formaldehyde-Free Materials	*14*
Forest-Certified Wood	13
Nearly Achieving or Exceeding Net Zero Annual Energy Use	12
Permeable Paving	12
On-Site Wastewater Treatment	12
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*
Cooling System Condensate Captured	6
Gaseous Air Cleaning	*6*

Air Leakage or Air Change Measurement	*5*
Wind Turbine (on site)	4
Carbon Monoxide Sensors	*4*
Post-Construction Building Flush Out	*4*
Monitoring of Outdoor Air Intake Rates	*1*
Indoor Contaminant Data Provided	*1*

Table 3 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) • Describe how each requirement was complied with

Design minimum outdoor air intake	• Provide design outdoor air intake rate in L/s per person by major space type
	  o For each space type, list # of occupants, minimum outdoor air requirement in L/s•person, and Zone Air Distribution Effectiveness (per Standard 62.1).
	  o For each system, list System Ventilation Efficiency (per Standard 62.1).

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) • If quantitative emissions requirements, list values • 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 o Report # of sensors employed, or average m^2 of floor area per sensor
Particle filtration efficiency	• Provide MERV levels employed
If using gaseous air cleaning	• List target pollutants and removal efficiencies
If requiring low-emitting cleaning materials	• Describe cleaning materials and specification details, including labeling or purchasing program
If using carbon monoxide sensors for controlling garage exhaust ventilation	• Describe control strategy, including CO setpoint and sensor location approach o Report # of sensors employed, or average m2 of floor area per sensor

Table 4 Information for documenting IAQ during construction and commissioning

Activity	Associated Information
Measurements of outdoor air intake	• Provide measured and design values for each system o Describe measurement device employed, measurement location, and uncertainty
Measurements of exhaust airflow rates	• Provide measured and design values for each system o Describe measurement device employed, measurement location, and uncertainty
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, including standard followed, and results
If post-construction flush out	• Describe strategy, duration, and airflow rate

Table 5 Existing recommendations for reporting IAQ performance

Contaminant	LEED 2009* Maximums	LEED v4* Maximums	Standard 189.1-2011*	IgCC 2012
Formaldehyde	33 μg/m^3	33 μg/m^3	9 μg/m^3 **	27 μg/m^3
PM10	50 μg/m^3	50 μg/m^3	150 μg/m^3 (24 h)	150 μg/m^3 (24 h)
PM2.5		15 μg/m^3	35 μg/m^3 (24 h)	35 μg/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	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	29 compounds listed, generally two times corresponding CDPH values
***TVOC	500 μg/m^3	500 μg/m^3		500 μg/m^3
4-PCH (SBR carpet)	6.5 μg/m^3			2.5 μg/m^3

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

Table 6 Candidate IAQ performance data to be collected in HPBs

Parameter	Notes
Occupant acceptance	• Identify survey employed • Conduct surveys within 30 days of occupancy and approximately 1 year after occupancy, and • Report fraction of building occupants surveyed and results of survey

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
	  o Describe weather and system operating conditions during measurement
	  o Describe measurement device employed, measurement location, and uncertainty

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 • For naturally ventilated buildings, measure in occupied space • 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 • 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 • Include definition of TVOC and measurement method • 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 • 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 • 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 • Include average outdoor concentrations with indoor values
Radon	• Measure in lowest ground-contact spaces at least once per season