WEALTH OF INTENT, DEARTH OF DATA

As part of its activities to support the design and construction of sustainable buildings, ASHRAE began publishing High Performing Buildings (HPB) in winter 2008. In recent years, the magazine has sought to present key building information, including energy and water consumption data, in a consistent format that enables comparisons across buildings of different size and function in different climatic zones. Grunman and Hinge recently summarized energy data from 60 buildings and more detailed characteristics from eight buildings featured in HPB (What Makes Buildings High Performing, Spring 2012). However, indoor air quality (IAQ) is often given minimal attention in high-performing buildings, as evidenced by our review of 100 case studies published in HPB, 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” (Resourceful By Nature, Spring 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” (Proving Performance, Winter 2012). These two articles were exceptions among the case studies we reviewed, because they provided measurement information on indoor pollutants other than carbon dioxide (CO₂). Readers may 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.3

GOOD INDOOR ENVIRONMENTAL QUALITY (IEQ) is a key goal of high performing buildings, but often is not factored into sustainable building discussions and programs.1 Buildings exist to support occupant activities and needs. Therefore, efforts to reduce energy use or other environmental impacts that degrade IEQ can have potentially significant negative impacts on health, comfort and productivity.2 While critically important, energy is only one aspect of building performance and should not be pursued to the neglect of IEQ.

Methodology

We examined all of the case studies included in HPB from Winter 2006 through Winter 2013, a total of 100 buildings. We focused primarily on those building design characteristics that are intended to promote good IAQ (e.g., dedicated outdoor air...
It has long been recognized that the primary options available to control indoor air contaminant concentrations are contaminant source removal or reduction, ventilation, and air cleaning. Besides being fundamental approaches to improving IAQ, high performance building standards or programs typically include requirements and/or offer credit for these features. As such, it is no surprise that many of the items in Table 1 relate to one of these three approaches.

Specifically, four items are related to source control (low-VOC-emitting materials, low-emitting cleaning materials, formaldehyde-free materials, and carbon monoxide sensors). Eight are ventilation-related (carbon dioxide sensors for demand control ventilation, hybrid ventilation, dedicated outdoor air systems, low volatile organic compound [VOC] emitting building materials and high efficiency filtration). We also recorded, among other characteristics, the energy consumption data for the building, its source(s) of energy, features intended to reduce water consumption (e.g., rainwater harvesting for irrigation and other non-potable purposes), and construction waste diverted from landfills. We noted when the performance of the building was compared to a building standard such as ASHRAE Standard 62.1-2010, Ventilation for Acceptable Indoor Air Quality, and ASHRAE/IES 90.1-2010, Energy Standard for Buildings Except Low-Rise Residential Buildings.

**Results**

Before we discuss the results of our review of the HPB case studies, it is important to mention some of the potential limitations of our analyses. First, we limited our review to only the information contained in the articles. While the editors 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, the authors may have been limited in their description of some building attributes and performance.

Also, in preparing this article, we had to interpret the information in the magazine articles and could have misinterpreted some of the provided details. Last, and most important, it should be emphasized that the case studies included in HPB are likely among the best examples of high-performing buildings and not representative of current new and retrofit construction practice.

Table 1 shows the prevalence of several IAQ-impacting features in decreasing order of their mention in the 100 HPB case studies. It has long been recognized that the primary options available to control indoor air contaminant concentrations are contaminant source removal or reduction, ventilation, and air cleaning. Besides being fundamental approaches to improving IAQ, high performance building standards or programs typically include requirements and/or offer credit for these features. As such, it is no surprise that many of the items in Table 1 relate to one of these three approaches.

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The tight building envelope of the Heifer International headquarters in Little Rock, Ark., allows for an air change rate that exceeded the target. The building’s narrow arc gives every workstation outdoor views and daylight. Additional energy (e.g., by increasing ventilation rates). However, as discussed by Levin and Teichman and Persily and Emmerich, many of the Table 1 features can be part of strategies that can support both the energy efficiency and IAQ objectives of high-performance building 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 were not provided.

During our review of 100 HPB case studies, we also came across many noteworthy building features and/or interesting observations. Inclusion of these statements does not imply we checked their veracity. During our review of 100 HPB case studies, we also came across many noteworthy building features and/or interesting observations. Inclusion of these statements does not imply we checked their veracity. Ventilation
- In one of the few buildings in which an envelope airtightness measurement was made, the actual building air change rate (>0.5 h⁻¹) significantly exceeded the target (0.2 h⁻¹) (Passing on the Gift, Winter 2008). (Note that the reference pressure for the measurement and target were not provided.)
- Composting toilet exhaust systems were designed to draw air down through the toilets instead of at the ceiling thereby removing odors. (Conservation Gateway, Winter 2008).
- Exhaust emissions were modeled to determine the optimal location of outdoor air intakes (Making the Walk, Summer 2008).
- Many buildings employing hybrid ventilation send a signal to building occupants that natural ventilation has become optimal; others interlock the opening of windows with the shutting off of mechanical ventilation systems (Green Show-And-Tell, Fall 2012).
- Lab-quality, central CO₂ sensors were determined to be better than room CO₂ sensors, only 27% of which were determined to be accurate within ±20% (The Right Fit, Winter 2011).

Water
- Energy costs make up 80% of a typical water bill; 7% to 8% of U.S. energy is used to move and treat water (Rainwater: The Untapped Resource, Summer 2008).
- Municipal water systems typically use 4 ppm of chlorine to treat water; rainwater systems for non-potable use can be chlorinated to just 0.25 ppm (Rainwater: The Untapped Resource, Summer 2008).
- One building used a self-contained biological filtration system that collected rainwater, used fish to fertilize the water, and then filtered the water through greenhouse plants (A Building That Teaches, Winter 2013).

Energy
- A swimming pool was used for load shifting of excess heat (Rx for Platinum, Winter 2009).
- In one building, biodiesel fuel was made from recycled fry oil, and a glycerin byproduct was used for shower gel (Golden Arches Green Performance, Fall 2009).
- Laptop computers (25 kW to 50 kW) were used to replace computer stations (150 kW to 175 kW) (Small Steps, Big Savings, Fall 2009).
- Energy use intensity comparisons should be made on an energy/person/hour x climate factor basis, as opposed to energy/area/year (Resourceful By Nature, Spring 2012).

Building Operation
- In one building, it was agreed that the owner would pay for capital expenses (e.g., a new boiler), the property manager for operation and maintenance expenses (e.g., a lighting retrofit), and the tenant for sustainability initiatives (e.g., photovoltaics and storm water management) (Cooperative Solutions, Fall 2009).
- Employees were allowed to wear shorts in one building when the interior temperature exceeded about 27°C (81°F) (Rx for Platinum, Winter 2009).
- The public display of building data led to suggestions from people who had never been in the building (Dark Adapt, Winter 2011).
are used to justify lower ventilation rates; however, some high-performance standards and programs may not allow these approaches.

Eight of the 10 most prevalent IAQ-improving 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, operator surveys and measured contaminant levels, are much less common. 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 as well as IAQ.

**Table 2 shows the prevalence of the IAQ features compared to energy-, water-, and waste-related features in decreasing order of their mention in the 100 case studies. This table shows the high prevalence of energy features relative to the other three categories. Our analysis did not focus on energy, and therefore, only the highest-level energy features are identified. An unusually large number of energy features are not included in the table (e.g., increased insulation and daylighting). 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.**

**Addtional Results**

Earlier, we discussed quotes from two of the case studies that provided measured IAQ data other than references to CO2, monitoring for demand control ventilation. In the Natural Resources Defense Council in New York City (Resourceful by Nature, Spring 2012), measurements were made of formaldehyde, particulate matter, total VOC, and carbon monoxide, all of which were measured well below values specified in the air testing option under the LEED credit for a Construction Indoor Air Quality Management Plan.2 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 (Proving Performance, Winter 2012), pre-occupancy testing was performed for individual VOCs (including formaldehyde and acetaldehyde), particulate matter, carbon monoxide, and CO2. 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.6,7**

**Conclusion**

This case study analysis highlights many of the creative approaches used in sustainable buildings, which will hopefully inspire others to continue making progress in this critical area. In addition, integrated design, from the perspective of IAQ, is discussed in the ASHRAE IAQ Design Guide.10
However, these case studies, at least as they are presented in HPB, 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 occupant health, comfort, and productivity, which defeats the overall goal of building design, including reduced costs.

In addition, while building design is key to achieving a high-performing building, it is critical to follow these good intentions through construction, commissioning, operation, and maintenance. Only in this way, will high-performing buildings 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.”

References
7. OSHA. Permissible Exposure Limits. Occupational Safety & Health Administration, U.S. Department of Labor.

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