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10 Questions

# Ten questions concerning green buildings and indoor air quality

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ABSTRACT

This paper investigates the concern that green buildings may promote energy efficiency and other aspects of sustainability, but not necessarily the health and well-being of occupants through better indoor air quality (IAQ). We ask ten questions to explore IAQ challenges for green buildings as well as opportunities to improve IAQ within green buildings and their programs. Our focus is on IAQ, while recognizing that many factors influence human health and the healthfulness of a building. We begin with an overview of green buildings, IAQ, and whether and how green building certifications address IAQ. Next, we examine evidence on whether green buildings have better IAQ than comparable conventional buildings. Then, we identify so-called green practices and green products that can have unintended and unfavorable effects on IAQ. Looking ahead, we offer both immediate and longer-term actions, and a set of research questions, that can help green buildings to more effectively promote IAQ. This article supports a growing recognition of the importance of IAQ in green buildings, and the opportunities for improvements. As the World Green Building Council [95] and others have emphasized, people are the most valuable asset of organizations, and efforts to improve IAQ can improve health, well-being, productivity, and profitability.



## 1. Ten questions

### 1.1. What are green buildings?

In general, “green buildings” are structures designed to promote efficient use of resources (e.g., energy, water, and materials) and sustainability (e.g. [93], and to reduce the adverse effects of buildings on the environment). A commonly cited definition of green building is provided by the US Environmental Protection Agency [28]: “Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction.”

In recent years, and more specifically, green buildings are typically defined and categorized by green building certification programs. Many countries around the world have their own programs. Early certification schemes include the Building Research Establishment Environmental Assessment Methodology (BREEAM) in the United Kingdom in 1990 [13], and Leadership in Energy and Environmental Design (LEED) in the United States in 1994 [83]. Other major programs include the Deutsche Gesellschaft für nachhaltiges Bauen (DGNB) system in Germany [26], Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan [18], and the Green Star system in Australia [38] [47].

As of October 2016, over 145,000 green certification projects have been completed around the world, using these and other certification schemes [38]. Globally, the percentage of firms with over 60% of their projects certified green is forecast to grow from 18% in 2016 to 37% by 2018, with a greater proportion from developing markets [89].

Today, more than 31 green building certification programs and 55 schemes within those programs (e.g., for different types of buildings) are used in over 30 countries around the world, and some programs (such as BREEAM and LEED) are used in multiple countries [86]. Other programs have emerged with goals to promote indoor air quality and occupant health, such as the WELL

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building standard [87], even if not termed green building. However, it is unclear whether such programs are any more effective than green building programs in promoting healthy IAQ. Despite the prevalence of green building certification programs and several common features, no internationally consistent criteria exist for green buildings. Also, relatively little systematic research has been conducted to determine whether and how elements of green building programs improve IAQ (e.g., [62,79].

In conclusion, green buildings are implemented by various programs and criteria around the world. They typically emphasize efficient use of energy and resources and, to lesser extent, healthy indoor air quality.

### 1.2. What is indoor air quality?

Similar to green buildings, "indoor air quality" has no universal or standard definition. In general, IAQ is related to pollutants (e.g., biological, chemical, and physical) within indoor environments that can affect the health of occupants. IAQ is considered a subset of indoor environmental quality (IEQ); the latter includes factors such as lighting, ergonomics, acoustics, and temperature in addition to pollutants.

Indoor air quality definitions can vary depending on perspectives of the human user, the indoor air of the space, and the sources contributing to the indoor air pollution [12]. A definition provided by the US Environmental Protection Agency [28] is as follows: "Indoor Air Quality (IAQ) refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants."

However, in the US as in many other countries, no federal law specifically regulates IAQ [77], even though people typically spend more than 90% of their time indoors, pollutant levels are typically several times to several hundred times higher indoors than outdoors, and consequently indoor air typically accounts for over 90% of human exposure to pollutants [64]. Some agencies do offer guidelines, such as World Health Organization [90], for the protection of public health from common chemicals in indoor air. For example, the [90] indoor air quality guideline for formaldehyde (30-min average concentration) is 100 μg/m3 (0.08 ppm).

While air quality regulations in the US [29], European Union [30], Australia [9] and other countries regulate "ambient air," the term has been interpreted as "outdoor air," or air external to buildings, excluding indoor air. While outdoor air quality can affect the indoors, and indoor air contains pollutants from both outdoor and indoor origin, indoor air quality is concerned with the air within buildings and other indoor spaces, regardless of the sources of pollutants.

Indoor air quality is difficult to measure and assess for many reasons; among them: (1) The lack of consistent metrics, standards, and consensus on what constitutes favorable IAQ; (2) The diversity and complexity of pollutants found indoors that can affect human health and well-being, even at exceptionally low levels; (3) The inadequate understanding of links between pollutant levels indoors, exposures to those pollutants (both individually and in mixtures), and their effects (both acute and chronic); (4) The range of health effects related to indoor pollutant exposures, and that the same pollutant exposure can affect different humans in different ways; (5) The question of whether the pollutants being measured are the ones that really matter; and (6) The lack of requirements to measure and monitor IAQ, leading to a lack of awareness of potential problems and remedies.

In conclusion, attention to IAQ is often voluntary from a regulatory perspective, though important from a health and well-being perspective. While some agencies offer guidance, no consistent metrics or regulations exist for determining and assuring the health of indoor air environments.

### 1.3. Do green building certification schemes address IAQ?

Since the birth of green building certification schemes, IAQ has been included as one of their default elements. Currently, IAQ is included, in some way, in all schemes presently in use. However, we lack systematic information on how many of the credits addressing IAQ are actually exploited during the certification process and, if all are awarded, whether this would significantly improve IAQ.

The categories that include IAQ in various schemes are differently termed. For example, in BREEAM, IAQ is included in the category for health and well-being, in LEED and Green Star in the category called indoor environmental quality, while in DGNB in the category describing socio-cultural and functional quality. In addition to credits for IAQ, categories that include IAQ also provide credits for other aspects related to IEQ, such as for daylight, artificial light, acoustic and thermal environment.

The contribution of credits for IAQ in green building schemes is on average 7.5%, and spans from about 3% to 11%, based on a recent evaluation of 55 green building schemes in 30 countries [86]. The relatively small percentage of credits for IAQ may be considered as inadequate incentive to pursue these credits, or even as inadequate representation of the importance of IAQ. On the other hand, green certification schemes include many components, and any single component (with the exception of perhaps energy performance) may not receive a large percentage of credit.

It is useful to examine how IAQ is addressed in the certification schemes and which aspects are awarded. Credits are received for measures related to source control (mainly attained through selection of low emitting building materials and products, but also by use of green cleaning products and policies, and low emitting equipment), for ventilation (mainly by specifying minimum ventilation requirements or referring to relevant standards or codes prescribing ventilation, and also specifying requirements such as minimum filtration levels, location of main air intakes, and main exhaust outlets), and for conducting indoor air quality measurements (either before or during occupancy, or during both periods). Among the 55 certification schemes reviewed by Ref. [86]; 100% of them award credits for ventilation, 77% award credits for source control and 66% for conducting IAQ measurements.

Credits are also received if levels of specific pollutants are targeted. The most frequently addressed pollutants are volatile organic compounds (VOCs), formaldehyde, and carbon dioxide ($CO_2$). These three pollutants are included in at least 65% of the schemes reviewed by Ref. [86]. In addition, requirements are defined for levels of asbestos, microbes, ETS, carbon monoxide (CO), total VOCs (TVOC), sulphur oxides ($SO_x$), nitrogen oxides ($NO_x$), radon, particles, ammonia, ozone and semi-volatile organic compounds (SVOCs) but the requirements for these pollutants are present less frequently in the schemes than for the three pollutants mentioned above, and none are mandatory.

In addition to direct credits for IAQ, credits in other categories can indirectly affect IAQ. For example, site selection can influence outdoor air quality. Thus, the building envelope quality and tightness, as well as type of ventilation, can affect the migration of pollutants between indoors and outdoors, and energy-efficient systems can improve or impair IAQ depending on outdoor air quality. Credits for these criteria generally do not add to the total credit for measures for promoting IAQ.

Many certification schemes allow "trading" of credits across different categories and, with few exceptions (e.g., DGNB), it is the total number of credits awarded that determines the level of building certification, not the credits received in each category. Consequently, in some schemes, the highest certification level can