



Indoor air quality requirements in green building certifications



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ABSTRACT

Green building certifications aim to achieve sustainable buildings that are healthy, energy-saving, and environmentally friendly. To construct healthy built environments for occupants, a high indoor environment quality (IEQ) has to be maintained. The goal of this paper is to analyze how and to what extent indoor air quality (IAQ), as a subset of IEQ, is taken into account in green building certifications worldwide. Thus, IAQ requirements were reviewed in 31 green building certifications from 30 countries worldwide. These certification programs include 13 countries in Asia, 9 in Europe, 5 in Americas, 2 in Oceania, and 1 in Africa. Fifty-five green building schemes were selected from among the 31 certifications. Rating systems are commonly used in green building schemes to evaluate the capability and level of a building to achieve life-cycle sustainability. The average contribution of IAQ to green building schemes worldwide is 7.5%. Volatile organic compounds (VOCs), formaldehyde, and carbon dioxide (CO₂) are the indoor air pollutants most frequently considered. Ozone (O₃) and semi-volatile organic compounds (SVOCs) are mentioned in less than 6.7% of the certifications worldwide. Emission source control, ventilation, and indoor air measurement are the three main pathways used in green building schemes for IAQ management. All of the certifications include ventilation as a way to manage IAQ. Emission source control is included in 77% of the certifications and is mainly targeted at building material emissions. Indoor air measurement is included in 65% of the certifications but may be optional.

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1. Introduction

Green building, also known as sustainable building, is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle [1]. "Green buildings" refer to the structures created using the principles and methodologies of sustainable construction [2], which aim to construct energy-efficient, healthy, and productive buildings that reduce the significant impact of buildings on urban life and the global environment [3]. The history of green building design began in the late 1980s when sustainability was defined by the United Nations' World Commission on Environment and Development [4]. Pioneering work on green building certification was achieved in the early 1990s in Europe and the United States, including the BRE Environmental Assessment

Method (BREEAM) certification in the United Kingdom, *Haute Qualité Environnementale* (HQE) certification in France, and Leadership in Energy and Environmental Design (LEED) certification in the United States. Following these developments, many additional countries worldwide have joined the green building effort in the past two decades and have developed green building schemes adapted to national economic and environmental conditions.

To achieve sustainability in buildings, green building schemes usually include several categories. The LEED v4 scheme for building design and construction, for example, comprises location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, and regional priority [5]. The categories in the BREEAM scheme for new construction differ slightly from those used by LEED, comprising management, health and well-being, energy, transport, water, materials, waste, land use and ecology, pollution, and innovation [6]. Although the categories vary among different green building schemes, the schemes' detailed requirements share many similar traits.

Indoor environment quality has a significant impact on modern life around the globe. Americans, on average, spend approximately

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90% of their time indoors [7]. Most of the time spent indoors occurs at home (67% on average for the French population) [8]. Indoor air pollutants, such as volatile organic compounds (VOCs), microbes, particles, etc., have negative effects on the health of indoor occupants. According to the “Guidelines for Air Quality” published by the World Health Organization (WHO), the main health effects of indoor air pollution include irritation, respiratory infection, and Sick Building Syndrome (SBS), among others [9]. Hence, to guarantee the health of occupants in buildings, it is important to maintain high indoor air quality (IAQ).

The objectives of this paper are to review recent green building certifications and their schemes worldwide and to analyze how and to what extent IAQ is taken into account. The final goal is to provide a global overview of the IAQ sections included in the considered certifications and to identify possible means of improvement if relevant.

2. Material and methods

2.1. Inventory and selection of green building certifications

To identify and select the green building certifications used in this study, three steps were carried out: (1) Search for green building certifications in scientific peer-reviewed literature, reference books, and on the Internet to include as many certifications as possible. International certifications that are applied in multiple countries, such as LEED, which applies in the USA, Mexico, Brazil, Argentina, Singapore and, until recently, India, are considered to be the same certification and are counted only once. (2) Access the official websites of the identified green building certifications and download the most recent free versions of schemes released within the past six years. For certifications that have different schemes for different types of buildings, e.g., new, existing, residential, and non-residential buildings, all the schemes are reviewed and considered as different requirements that are applied to different conditions in the certification. (3) Examine each scheme to see whether it has an IAQ section, and choose the final schemes for detailed analysis. Schemes for which a full-text version was not accessible or not free of charge were excluded.

All the certifications have a section that evaluates IAQ. Ultimately, 31 certifications from 30 countries worldwide (13 in Asia, 9 in Europe, 5 in Americas, 2 in Oceania, and 1 in Africa) were retrieved, comprising 64 schemes that are applied to different types of buildings. Most of the green building schemes are written in English. The remaining schemes are written in the local language (e.g., French, Italian, and Chinese). Of the 64 schemes, one Vietnamese scheme was excluded because of language limitations, and eight other schemes were excluded because they were not accessible. A total of 55 schemes are reviewed in this paper, as shown in Table 1. The countries and certifications do not match one to one. Some countries, such as Canada and the United States, have several different green building certifications, and some certifications, such as LEED and BREEAM, are applied in multiple countries, as shown in Fig. 1.

Table 1
Summary of the green building certifications and schemes considered.

	No. of countries/regions	No. of certifications	No. of schemes
Asia	13	13	30
Europe	9	9	14
Americas	5	5	7
Oceania	2	3	3
Africa	1	1	1
SUM	30	31	55

2.2. Green building schemes

A green building scheme is a method used to evaluate sustainability during construction and/or throughout a building's life-cycle. Some certifications include different schemes designed to certify different types of buildings for design and/or performance. Two general methods are used to classify buildings into different types. One method is to classify buildings into two major categories, i.e., new buildings and existing buildings. New buildings include buildings that are under design, under construction, or recently completed. Existing buildings include buildings that are fully built, under repair, or under renovation. The other classification method categorizes buildings into non-residential and residential buildings. Non-residential buildings include offices, shopping malls, schools, etc. Residential buildings include apartments and houses. By combining the two methods, there are nine possible types of buildings, as shown in Table 2. A green building certification has at least one scheme that can be applied to one type of buildings. However, for most of the certifications, some different schemes apply to different types of buildings. Table 2 lists all the schemes identified in this study, according to the countries where the certifications are created or most commonly applied.

Within a scheme, several major categories are used for the evaluation, such as water efficiency, energy, and IEQ. This study focuses on the IAQ section, which includes the sources and species of indoor air pollutants, as well as methods that can be applied to maintain high IAQ. The IAQ section is typically included within the IEQ category, or sometimes in the health and well-being category. Related sections in green building IEQ schemes, such as thermal comfort, acoustic performance, and lighting/views, are not included in this study.

2.3. Scheme review method

A total of 55 schemes were considered for the detailed review. There are two steps in the review procedure, as shown in Fig. 2. In step 1, the objectives are to analyze how and to what extent IAQ is taken into account in green building certifications. IAQ sections and rating systems in green building schemes were reviewed. A statistical analysis was performed to quantitatively analyze the contribution of IAQ in green building certifications, as well as the target indoor air pollutants and the methods that are commonly employed for IAQ management. For certifications that have more than one scheme for different types of buildings, an average value is used to represent the contribution of IAQ. To analyze indoor air pollutants and IAQ management in different schemes within a certification, all the pollutants listed in the different schemes are combined, yielding the most comprehensive coverage of indoor air pollutants considered within the certification. In step 2, detailed analysis focuses on IAQ management. Methods and standards were reviewed to analyze the requirements for controlling the emission sources of indoor air pollutants, as well as those for ventilation and indoor air measurement. For certifications with more than one scheme for different types of buildings, all the IAQ management methods are considered together when discussing the methods used to maintain high IAQ.

3. Results

3.1. Contribution of IAQ in green building certifications

3.1.1. Rating methods in green building schemes

Rating systems are universally used in green building schemes. To achieve building sustainability, the requirements can be divided

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