Review of Indoor Environmental Quality Evaluation Index Based on Regional Climate Connected Green Building

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Abstract: This article will review and analyses the indoor environment quality indicators in the existing green building rating system, both foreign and Chinese green building standards. Based on the relevance of ‘human climate architecture’, the indoor environment quality indicators which are intuitively perceivable, health related and connected to regions and climates will be sorted out, to establish the foundation for further indoor environmental quality index classification research.

1. Introduction
The green building has initially formed a point-to-face development trend in China after more than 10 years’ continuous advancement. The concept of green building start to impressively touch the users, and this has become an important symbol for the construction industry to achieve green development goals. However, the current green buildings pay more attention to resource conservation, architectural space design, construction process control, etc., but ignore the perceptions of the building users and the infection of different regions or climates. Based on this issue, the Nineteenth National Congress of the Chinese Communist has reported the people centered development as a basic strategy, and will promote the healthy development of green buildings focus on ‘people centered development’ to enhance the connotation and quality of the green building.

Green buildings need to provide users a healthy, suitable, comfortable and efficient architectural space to use, the quality of this space is mainly reflected by the compliance of indoor environmental indicators. A suitable and healthy indoor environment will help users feel relax and comfortable, and also improve working efficiency. Therefore, improving the indoor environment quality of green buildings became a significant requirement for owners, properties and users in China and around the word.

This article will review and analyses the indoor environment quality indicators in the existing green building rating system, both foreign and Chinese green building standards. Based on the relevance of ‘human climate architecture’, the indoor environment quality indicators which are intuitively perceivable, health related and connected to regions and climates will be sorted out, so as to establish the foundation for further indoor environmental quality index classification research.

2. Requirements for indoor environmental indicators in global green building standards
To encourage the development of green building and sustainable construction, the green building rating system has been developed by different institutions in different countries, including LEED (Leadership in Energy and Environmental Design) in the United States, BREEAM (Building Research Establishment Environmental Assessment Method) in the United Kingdom, CASBEE (Comprehensive Assessment
System for Built Environment Efficiency) in Japan and WELL in the United States, etc. [1]. This article will select the mainstream green building rating system for analysis.

2.1. LEED standard (v4 edition)
LEED standard was developed by U.S. Green Building Council (USGBC) and is currently considered as the most influential and market-oriented green building rating system in the variety of building environmental protection standards, green building assessment standards and sustainable building assessment standards. The LEED v4 edition was officially published in November 2013 and was implemented in June 2015 [1]. Indoor environmental quality is the second largest indicator section after energy and atmosphere in the LEED (v4 edition) rating system, the indoor environmental quality section mainly including indoor air quality, pollutant control, thermal comfort, daylighting and quality views, etc. The evaluation indicators are listed in table 1, and regional climate connected indicators are mainly including thermal comfort and daylighting.

| Category | Indicator | Purpose of Assessment | Regional Climate Connected |
|----------|-----------|-----------------------|---------------------------|
| **Prerequisite** | Minimum Indoor Air Quality Performance (Prerequisite) | To contribute to the comfort and well-being of building occupants by establishing minimum standards for indoor air quality (IAQ). | No |
| | Environmental Tobacco Smoke Control (Prerequisite) | To prevent or minimize exposure of building occupants, indoor surfaces, and ventilation air distribution systems to environmental tobacco smoke. | No |
| | Minimum Acoustic Performance (Prerequisite) | To provide classrooms that facilitate teacher-to-student and student-to-student communication through effective acoustic design (suits for school project only). | No |
| | Enhanced Indoor Air Quality Strategies (2 points) | To promote occupants’ comfort, well-being, and productivity by improving indoor air quality. | No |
| **Credit** | Low-Emitting Materials (3 points) | To reduce concentrations of chemical contaminants that can damage air quality, human health, productivity, and the environment. | No |
| | Construction Indoor Air Quality Management Plan (1 point) | To promote the well-being of construction workers and building occupants by minimizing indoor air quality problems associated with construction and renovation. | No |
| | Indoor Air Quality Assessment (2 points) | To establish better quality indoor air in the building after construction and during occupancy. | No |
| | Thermal Comfort (1 point) | To promote occupants’ productivity, comfort, and well-being by providing quality thermal comfort. | Yes |
| | Interior Lighting (2 points) | To promote occupants’ productivity, comfort, and well-being by providing high-quality lighting. | No |
| | Daylight (3 points) | To connect building occupants with the outdoors, reinforce circadian rhythms, and reduce the use of electrical lighting by introducing daylight into the space. | Yes |
| | Quality Views (1 point) | To give building occupants a connection to the natural outdoor environment by providing quality views. | No |
| | Acoustic Performance (1 point) | To provide workspaces and classrooms that promote occupants’ wellbeing, productivity, and communications through effective acoustic design. | No |

2.2. BREEAM standard
The United Kingdom is one of the earliest countries in green building development. The British Building Research Establishment (BRE) has released the first green building rating system: Building Research Establishment Environmental Assessment Method (BREEAM) as early as 1990. The BREEAM international version was released in 2013, and in 2016 BRE launched the latest version of BREEAM.
International 2016, which added a new Methodology section and made large changes. Health and wellbeing is the second largest indicator section after energy in the BREEAM rating system, the health and wellbeing section mainly including indoor acoustic performance, visual comfort, thermal comfort and hazards assessment, etc. The evaluation indicators are listed in table 2, and regional climate connected indicators are mainly including thermal comfort.

| Category                        | Indicator             | Content of Assessment                                                                                           | Regional Climate Connected |
|---------------------------------|-----------------------|---------------------------------------------------------------------------------------------------------------|---------------------------|
| Prerequisite + Credit Visual    | Comfort               | The lamp ballasts, outdoor & indoor lighting manual partitions control are required as assessment criteria. Besides, avoiding energy consumption increases while glare control is also required. Asbestos containing materials prohibition is the prerequisite. Take various strategies both inside and outside the building to control the indoor air quality, the strategies include indoor air quality plan, ventilation control, building products emissions control and tobacco control, etc. | No                        |
| Prerequisite + Credit Indoor    | Air Quality           | Visual comfort: The lamp ballasts, outdoor & indoor lighting manual partitions control are required as assessment criteria. Besides, avoiding energy consumption increases while glare control is also required. Asbestos containing materials prohibition is the prerequisite. Take various strategies both inside and outside the building to control the indoor air quality, the strategies include indoor air quality plan, ventilation control, building products emissions control and tobacco control, etc. | No                        |
| Credit                          | Indoor Air Quality    | Visual comfort: The lamp ballasts, outdoor & indoor lighting manual partitions control are required as assessment criteria. Besides, avoiding energy consumption increases while glare control is also required. Asbestos containing materials prohibition is the prerequisite. Take various strategies both inside and outside the building to control the indoor air quality, the strategies include indoor air quality plan, ventilation control, building products emissions control and tobacco control, etc. | No                        |
| Credit                          | Safe                  | Containment in Laboratories: Proposed detailed requirements for the safety protection of the laboratory.        | No                        |
| Credit                          | Thermal Comfort       | Thermal comfort: Comprehensive considered indoor thermal comfort, indoor temperature and adaptability to different climates for thermal comfort performance evaluation, established thermal model and calculated PMV & PPD as assessment criteria. | Yes                       |
| Prerequisite + Credit Acoustic  | Performance           | Acoustic performance: Mainly considered the indoor ambient noise, sound insulation performance and acoustic performance of the specific room. Appointment the acoustic expert is also be required for reverberation times control of the specific room (meeting rooms etc.). | No                        |
| Credit                          | Accessibility         | Accessibility: The accessibility facilities are required in bicycle lanes, motor vehicle lanes, pick-up & drop-off points and specific rooms inside the building, etc. | No                        |
| Credit                          | Hazards               | Hazards: Mainly assess the impact of natural hazards on the site.                                               | No                        |
| Credit                          | Private Space         | Private Space: The outdoor space (private or semi-private) design is required to enhance occupants’ privacy and a sense of wellbeing. | No                        |
| Credit                          | Water Quality         | Water Quality: Minimum the risk of water contamination.                                                         | No                        |

2.3. CASBEE standard

CASBEE standard (also known as Comprehensive Assessment System for Built Environment Efficiency) was developed by Japan Sustainable Building Construction in 2001 and has a certain influence around the world. There are three core concepts in CASBEE: (1) Consider the full life cycle assessment of the building when analyzing building basic data; (2) Evaluate the built environment in terms of environmental quality (Q) and environmental load (L); (3) Use Built Environment Efficiency (BEE) to determine the evaluation level [2]. The environmental quality of building section in CASBEE including four categories: sound environment, thermal comfort, lighting & illumination and air quality, the indicators are listed in table 3. Regional climate connected indicators are mainly including room temperature control, humidity control, air conditioning type, daylight and ventilation.
Table 3. Indoor environment quality indicators in CASBEE \[3\]

| Category            | Indicator               | Content of Assessment                                                                 | Regional Climate Connected |
|---------------------|-------------------------|---------------------------------------------------------------------------------------|----------------------------|
| Sound Environment   | Noise                   | (1) Background noise level; (2) Equipment noise countermeasures.                       | No                         |
|                     | (1) Sound insulation performance of the opening; (2) Sound insulation performance of the floor. |                           | No                         |
|                     | Sound Insulation        | Sound absorbing materials use of walls, floor or ceiling.                              | No                         |
|                     | Room                    | (1) Equipment capacity/room temperature setting; (2) Envelop performance; (3) Zoned control; (4) Temperature and humidity control; (5) Consideration of air conditioning outside standard time. | Yes                        |
|                     | Temperature Control     |                                                                                        |                            |
|                     | Humidity Control        | Equipment capacity / room temperature setting.                                        | Yes                        |
|                     | Type of Air Conditioning System | Type of Air Conditioning System.                                                        | Yes                        |
| Lighting &          | Daylight factor         | (1) Daylight factor; (2) Daylight devices.                                             | Yes                        |
| illumination        | Anti-glare Measures     | (1) Glare of lighting facility; (2) Daylight control.                                  | No                         |
|                     | Illuminance Level       | (1) Illumination level; (2) Uniformity of lighting design.                             | No                         |
|                     | Lighting Controlability | Control area.                                                                          | No                         |
|                     | Source Control          | (1) VOC (Volatile organic compounds); (2) Mineral fibre; (3) Insects, mildew etc.; (4) Legionella. | No                         |
|                     | Ventilation             | (1) Ventilation volume and local ventilation for the pollutant; (2) Natural ventilation performance; (3) Consideration of external air extraction; (4) Air supply and ventilation duct plan. | Yes                        |
|                     | Operation Plan          | (1) CO2 monitoring; (2) Tobacco control.                                              | No                         |

Note: The assessment content is evaluated at 5 levels, the assessment phase is divided into two stages: design stage and construction stage.

2.4. WELL building standard

The first building assessment standard which focuses on human health and wellbeing in the built environment, the WELL building standard, is released by Delos in October 2014. Then, in March 2015, the Green Business Certification Inc. (GBCI) and the International WELL Building Institute (IWBI) formally introduced the WELL building standard into China. From the perspective of medical, The WELL building standard is based on the research of common human diseases and major human body systems, to explore the relationships between human health and the built environment, and to guide the building design and operation in a targeted manner. The WELL building standard is a performance based building assessment standard that pays more attention to the internal built environment healthy, and the standard focuses more on building occupants than the building.

The WELL building standard is divided into seven sections based on health concepts: air, water, nourishment, light, fitness, comfort and mind, and there are 102 indicators in these seven sections. Each indicator is designed to meet the specific needs of the health, comfort or mind of the occupants, and is divided into several parts, which are usually designed to the specific building type. This means for one specific building, only certain parts of the indicators may apply, depends on the type of the building. There are one or more requirements in each part, indicating the specific parameters or metrics that need to be met. For a construction project, all the requirements of the applicable parts need to be met to obtain compliance for a specific indicator. In the WELL rating system, the indoor environment is composed of
five sections: air, light, fitness, comfort and mind. The evaluation indicators are listed in table 4, and regional climate connected indicators are mainly including air, light and comfort.

Table 4. Indoor environment quality indicators in WELL [4]

| Category | Indicator                                                                 | Regional Climate Connected |
|----------|---------------------------------------------------------------------------|----------------------------|
| Air      | Air quality standards, Smoking ban, Ventilation effectiveness, VOC reduction, Air filtration, Microbe and mold control, Construction pollution management, Healthy entrance, Cleaning protocol, Pesticide management, Fundamental material safety, Moisture management, Air flush, Air infiltration management, Increased ventilation, Humidity control, Direct source ventilation, Air quality monitoring and feedback, Operable windows, Outdoor air system, Displacement ventilation, Pest control, Advanced air purification, Combustion minimization, Toxic material reduction, Enhanced material safety, Antimicrobial activity for surfaces, Cleanable environment, Cleaning equipment. | Yes                        |
| Light    | Visual lighting design, Circadian lighting design, Electric light glare control, Solar glare control, Low-glare workstation design, Color quality, Surface design, Automated shading and dimming controls, Right to light, Daylight modelling, Daylighting fenestration. | Yes                        |
| Fitness  | Interior fitness circulation, Activity incentive programs, Structured fitness opportunities, Exterior active design, Physical activity spaces, Active transportation support, Fitness equipment, Active furnishings. | No                         |
| Comfort  | ADA accessible design standards, Ergonomics: visual and physical, Exterior noise intrusion, Internally generated noise, Thermal comfort, Reverberation time, Sound masking, Sound reducing surfaces, Sound barriers, Individual thermal control, Radiant thermal comfort. | Yes                        |
| Mind     | Health and wellness awareness, Integrative design, Post-occupancy surveys, Beauty and design, Biophilia, Adaptable spaces, Healthy sleep policy, Business travel, Building health policy, Workplace family support, Self-monitoring, Stress and addiction treatment, Altruism, Material transparency, Organizational transparency, Innovation feature. | No                         |

3. Requirements for indoor environmental indicators in Chinese green building standards

Compared with other countries, the green building and its rating system started to develop at a later time in China. The green building standard mainly includes <Assessment Standard for Green Building> GB/T50378-2019 and <Assessment Standard for Healthy Building> T/ASC02-2016, etc. This article will select the national or industry green building rating system for analysis.

3.1. Assessment Standard for Green Building

The Ministry of Housing and Urban-Rural Development of the People’s Republic of China has published the first green building evaluation standard <Assessment Standard for Green Building> GB/T50378-2006 in March 2006 and revised this standard twice in April 2014 and March 2019, respectively. The current national standard <Assessment Standard for Green Building> GB/T50378-2019 was launched in March 2019 and was officially implemented in August 2019 [5]. China’s green building evaluation system mainly includes six sections: safety and durability, health and comfort, occupant convenience, resources saving, environment livability, promotion and innovation, the health and comfort section include four environmental quality categories: indoor air quality, water quality, sound and daylighting, indoor thermal environment, the indicators are listed in table 5. Regional climate connected indicators are mainly including indoor thermal environment, envelop structure thermal performance, thermal environment adjustment device, daylighting and glare, natural ventilation and adjustable shading facilities.
### Table 5. Indoor environment quality indicators in *<Assessment Standard for Green Building>*

| Category | Indicator: Content of Assessment | Regional Climate Connected |
|----------|---------------------------------|---------------------------|
| Prerequisite | (1) Ammonia, formaldehyde, benzene, VOC, radon and other pollutants (include smoking) control; | No |
| | (2) Anti-collision of air and pollutants from the kitchen, dining room, printing room, bathroom, garage and other hazardous areas; | No |
| | (3) Water supply and drainage system design and water quality guarantee; | No |
| | (4) Background noise level and sound insulation performance; | No |
| | (5) Illumination quantity, quality and safety guarantee; | No |
| | (6) Indoor thermal environment contentment; | Yes |
| | (7) Envelop structure thermal performance; | Yes |
| | (8) Onsite independent control of the thermal environment adjustment device; | Yes |
| | (9) CO concentration monitoring device. | No |
| Indoor Air Quality | (1) Indoor air pollutants control; | No |
| | (2) Decoration hazard control. | No |
| Water Quality | (1) Supply water quality control; | No |
| | (2) Water storage facilities sanitation guarantee; | No |
| | (3) Identification design of water pipelines, equipment and facilities. | No |
| Credit | Sound and Daylighting | No |
| | (1) Background noise level; | No |
| | (2) Sound insulation performance; | No |
| | (3) Daylighting design and sunlight glare control. | Yes |
| Indoor Thermal Environment | (1) Indoor thermal environment contentment and thermal comfort; | Yes |
| | (2) Natural ventilation performance; | Yes |
| | (3) Adjustable shading facilities. | Yes |

### 3.2. Assessment Standard for Healthy Building

The Architectural Society of China released the industry standard *<Assessment Standard for Healthy Building>* T/ASC02-2016 in January 2017 [6], and the Chinese Society for Urban Studies (CSUS) has carried out healthy building evaluation work, has issued *<Healthy Building Certificate Management Method>* and *<Healthy Building Assessment Management Method>* as an individual third party. The first batch of healthy building evaluation activities has carried out by CSUS in March 2017. China’s healthy building evaluation system mainly include five sections for environmental quality: air, comfort, exercise, humanity and service, the indicators are listed in table 6. Regional climate connected indicators are mainly including inner surface condensation, heat insulation performance, daylighting and indoor thermal environment.

### Table 6. Indoor environment quality indicators in *< Assessment Standard for Healthy Building >*

| Category | Indicator | Content of Assessment | Regional Climate Connected |
|----------|-----------|-----------------------|---------------------------|
| Prerequisite | Pre-assessment of pollutant concentration, Indoor particulates, Building materials, Harmful substances in furniture. Contamination prevention, Kitchen exhaust design, Outdoor pollutant blocking, Harmful substances in decoration materials, Harmful substances in furniture. | No |
| Air | Concentration limit | Indoor particle concentration, Radioactive material and CO2 concentration. | No |
| | Purification | Air purification devices. | No |
| | Monitoring | Air quality monitoring system, CO monitoring system, Indoor air quality survey. | No |
| Comfort | Prerequisite | Environmental noise control, Background noise control, Sound insulation performance, daylighting environment, Illumination environment; | No |
| Category          | Subcategory                                                                 | Chinese  | International  |
|-------------------|-----------------------------------------------------------------------------|----------|----------------|
| Sound             | The inner surface temperature of the building envelope, Background noise control, Sound insulation design, Acoustic performance, Equipment vibration and noise design. | Yes      | No             |
| Lighting          | Automatic lighting control, Outdoor lighting comfort.                        | Yes      | No             |
| Thermal Environment | Indoor thermal environment, Natural ventilation performance, Indoor air humidity control, Dynamic adjustment of the HVAC system. | Yes      | No             |
| Ergonomics        | Restroom layout, Adjustable equipment screen, Adjustable furniture, CO monitoring system. | No       | No             |
| Prerequisite Outdoor | Fitness area design, Fitness equipment supply.                              | No       | No             |
| Exercise          | Indoor fitness space design, Stair use encourages, Green travel service.    | No       | No             |
| Equipment Prerequisite Outdoor | Fitness equipment supply.                                                   | No       | No             |
| Communication    | Outdoor open space design, Playground design, elderly activity area design, Public service cafeteria design. | No       | No             |
| Mind              | Artistic facility design, Green plant design, Entrance lobby aesthetic design, Psychology adjustment support. | No       | No             |
| Elderly Support   | Elderly care, Accessible lift installation, Medical service facility.       | No       | No             |
| Property Promotion and Innovation | Outdoor weather data display.                                               | No       | No             |
|                    | Smoke ban, HVAC system inspection and cleaning.                            | No       | No             |
| Human Service     | Indoor air quality improvement, Indoor PM2.5 concentration control.         | No       | No             |

4. Conclusion

Both Chinese and international green building evaluation standards adapt indoor environment quality evaluation index as an important part, the indoor environment quality usually includes indoor acoustic environment, indoor light environment, indoor heat environment, natural ventilation and daylighting. Besides, the temperature control, humidity control, air conditioning type, and regional climate connected indicators in CASBEE standard, and the inner surface condensation, thermal insulation performance in Chinese green building standards can also be considered as regional climate connected indicators.

The subsequent study needs to classify the indoor environment quality indicators by analyzing the coupling factors between various indicators and architectural design, and by analyzing the influence of different indicators in different spaces. The classification can be used to evaluate the indoor environment quality of the green buildings, and a design technology system that corresponds with this classification can be established.

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