

## **Comparison of Five Leading Sustainable Building Certifications Concerning Indoor Environmental Assessment Content**

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**DEPARTMENT OF CIVIL ENGINEERING**  
AALBORG UNIVERSITY

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DCE Technical Report No. 269

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by

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# Preface

A large number of sustainable buildings certifications have seen the light in the past few decades driven by international goals to improve the level of sustainability in the built environment. In the last decade, sustainability has moved from being for the visionary elite to being a fundamental part of most modern buildings. This report will investigate indoor environmental topics, which is receiving increased attention in newer certifications unlike the strong environmental focus of the first generation.

In simple terms, environmental sustainability is caring for the planet, economic sustainability is about money, and social sustainability is about people. It seems, however, that the social dimension (containing indoor environment topics) varies widely between certifications concerning both the scope, topics and level of detail. Many comparisons between certifications have been made, but most focus on the environmental aspects or on an overall level. The increasing political focus on human health and well-being calls for an in-depth analysis and comparison of the social sustainability aspect of selected leading certifications.

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The sustainable building certifications on the market today differ widely in scope, structure and content, including national adaptations and variations for building type. This makes it overwhelming for professionals to choose the most appropriate certification scheme; difficult for practitioners to integrate the schemes as part of their design process; and nearly impossible for the various stakeholders to compare results between certifications - and thus between projects.

This publication presents an in-depth comparison of the indoor environmental quality aspect (the most prominent social sustainability aspect) on structure, content and weighting for five selected sustainable building certifications. The aim is to give the readers an insight into what the different certifications do and do not include in their indoor environmental assessment, by calculating how they prioritise indoor environmental aspects, and by giving an overview of the content covered.

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# Introduction

This report gives a general overview of indoor environmental (IE) topics from five leading certifications through a comparison of the scope of the indoor environmental assessment for dwellings. IE topics included in the following investigations are Thermal IE, Acoustic IE, Visual IE and Indoor Air Quality (IAQ). This report supplements the research paper “How should assessment methods for Indoor Environment be designed to facilitate decision support?” (Rohde, Larsen, Jensen and Olena, 2019 - *submitted*). This chapter will briefly motivate the investigations of this report, by highlighting why the topic is relevant and what it could influence.

## **Sustainable building certifications differ – in particular within social sustainability topics**

Sustainable building certification is becoming increasingly popular worldwide, fuelled by increasing demands for environmental sustainability and lately an increased focus on social sustainability. The number of different certifications available has increased rapidly over the last two decades, and some even have several national variations and differences based on building type. Some attempts have been made to guide practitioners in this certification jungle, but often from an overall perspective or with an environmental sustainability focus. This report will focus on social sustainability in regards to both the selection of certifications and the actual analysis of their content.

As this report will show, the differences in topic weights, content and even indoor environmental main areas treated differs considerably between certifications. It is the author’s intention to highlight these differences for two reasons: 1) to make it easier for practitioners to select the right tool for the job based on project-specific conditions and priorities, and 2) to show that meeting the requirements for a sustainable building certifications that address indoor environmental topics does not warrant good overall IEQ.

## **Indoor environmental certification of dwellings**

Most sustainable building certifications were initially developed for medium- and large-scale projects, and while the amount of projects certified globally grows, only very few dwellings are certified. The EPBD requirements (Council of the European Union, 2002) have made energy performance certificates mandatory for all buildings, including dwellings – but has made no requirements for indoor environmental performance. Thus, setting low set point temperatures, adding insulation thickness, optimising for passive solar gains and employing demand controlled ventilation has become common-practice to reach the requirements for low calculated energy consumption. In reality, these initiatives can lead too low comfort temperatures in the heating season, too high temperatures in summer, lowered daylight intake and poor air quality. This again leads to increased heating demands, electricity consumption for artificial lighting and the introduction of cooling demands, resulting in higher energy consumption. Indoor environmental performance is thus not only crucial for the health and comfort of occupants as part of the social sustainability dimensions, but also tied to the performance gap in calculated and actual energy consumption.



# Selected Certifications

This chapter presents the selection criteria for the section of certifications to investigate, followed by a factual overview and a brief presentation of the five analysed certifications.

## Arguments for Certification Selection

This report will investigate and compare five sustainable buildings certifications (BREEAM, LEED, DGNB, WELL and LBC – see below), seeking to provide good coverage of leading certifications, while still allowing for considerable depth of analysis. The certifications chosen fit the following inclusion criteria:

- They assess indoor environmental quality.
- They can be used to assess dwellings.
- They are internationally well known.

Many certifications fit the inclusion criteria above. Five were selected for an investigation to comment on the limitations and potentials of the most used certifications (current practice) and the most recent promising certifications (potential future practice).

## Presentation of Selected Certifications

The following contains a brief introduction to the history and ambitions of each of the five selected certifications. The texts below are based on a combination of sources, mainly the official websites and manuals of each certification, as well as some reports, papers and popular articles about one or more certifications. The primary sources applied for each presentation is shown at the end of each paragraph (accessed January 2019). Table 1 below shows general at glance facts for each of the five certifications. Refer the Comparison chapter for quantitative analysis of specifics such as content, structure, and weighting.

### BREEAM

When BREEAM was launched in 1990, it became the world's first sustainability rating scheme for the built environment, and it was the first to be included in building codes (Code for Sustainable Homes). BREEAM has had a significant influence on the strong, sustainable profile of the UK building sector<sup>1</sup>, and has grown to become one of the most extensive international certification standards. BREEAM certification helps clients quantify the environmental impacts of their building, to reduce environmental impacts and to enable high environmental performance to be recognised improving the building value. Despite a range of main categories of which 'Health and Wellbeing' is one, BREEAM is primarily an environmental sustainability assessment. This is evident also from the four main aims listed in the BREEAM manual, none of which are directly related to the indoor environment. Social sustainability is considered a positive by-product of being environmentally sustainable, which is visible one of the many listed objectives: "Reflect the **social and economic benefits** of meeting the environmental objectives covered." (BRE, 2017).



[BREEAM International New Construction 2016 standard]

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<sup>1</sup> Building Research Establishment (BRE) has developed a range of assessments and certifications of dwellings exclusively for the UK market including Home Quality Mark (HQM), Code for Sustainable Homes (CS), and BREEAM UK Domestic Refurbishment. Although highly relevant for IEQ assessment of dwellings, this report compares international certifications only.

## LEED

LEED was initially launched in 1998, developed by the U.S. Green Building Council as a framework for identifying, implementing, and measuring the design, construction, operation, and maintenance of green buildings. LEED is world leading for the built environment on all indicators such as the number of projects, the amount of m<sup>2</sup> certified, and a country/region count. LEED has a very large focus on the environmental dimension of sustainability, but one of the seven overall goals is 'to enhance individual human health and well-being'. IE improvements in the newest version of LEED (v4) includes a focus on unhealthy materials and a performance-based IEQ comfort approach (monitoring).

[LEED – Reference guide for building design and construction]  
[<https://new.usgbc.org/leed-v4>]



## DGNB

DGNB is a German certification founded in 2007 by a multidisciplinary team of experts seeking to promote sustainable building from a broader perspective. DGNB was the first to give Economic and Social aspects equal weighting as the Ecological and even went beyond the three pillars of sustainability of the Rio Declaration to also include Technical Quality and Process Quality (and to some extent Site Quality). In that sense, DGNB is more of a total value sustainability assessment than the predominant environmental sustainability assessments of BREEAM and LEED. It refers to itself as 'the holistic assessment'. DGNB is 'a human-centred assessment tool' with indoor environmental performance is the most significant contributor to Social Quality, making up a considerable part of the overall assessment. DGNB also emphasise other social aspects to a higher degree than LEED or BREEAM, seeking to provide excellent conditions for comfort, health and quality of life. DGNB includes long-term assessment criteria including tools for LCA and LCC.

[<https://www.dgnb.de/en/council/dgnb/index.php>]



## WELL

The WELL Building Standard (WELL v1) was launched in October 2014 as "the first Standard to be focused exclusively on the ways that buildings, and everything in them, can improve our comfort, drive better choices, and generally enhance, not compromise, our health and wellness." (IWBI, 2019). What is different about well is that it is designed to work alongside the more environmentally concerned leading green building standards, adding a dominant social sustainability focus and encouraging 'dual certification'. For instance, the International Well-being Institute has joined forces with the institute that administers LEED certification, and since 2016 they have worked to align credits with the BREEAM standard. "WELL is premised on a holistic view of health: human health as not only a state of being free of disease - which is indeed a fundamental component of health - but also of the enjoyment of productive lives from which we derive happiness and satisfaction." (IWBI, 2019).

[<https://www.wellcertified.com/en/articles/iwbi-launches-well-v2>]  
[<https://v2.wellcertified.com/v2.1/en/overview>]



## LBC

The Living Building Challenge was launched in 2006, and the first projects were certified in 2010. LBC is primarily focused on the social dimension of sustainability, with the most recent version of LBC (v.3.1) aiming to “transform how we think about every single act of design and construction as an opportunity to positively impact the greater community of life and the cultural fabric of our human communities”. LBC describes itself as “...a certification program, advocacy tool, and philosophy defining the most advanced measure of sustainability in the built environment today.” This is reflected in the very ambitious requirements to achieve certification including several near impossible requirements with temporary exceptions to compensate for market limitations, various post-construction documentation demands, and all topics of the standard being mandatory. The indoor environmental contribution to the overall assessment is (content-wise) no larger than for BREEAM and LEED, but most of the topics addressed include strong social ambitions: “Many developments provide substandard conditions for health and productivity, and human potential is greatly diminished in these places. By focusing attention on the major pathways of health, we create environments designed to optimise our well-being.’



[The Living Building Challenge Standard 3.1]

[LBC 3.1\_Beauty\_Petal\_Handbook]

Acronym / Full Name	Version Analysed	Institute / Origin / Certification launch	Certifications in total
<b>BREEAM</b> / Building Research Establishment Environmental Assessment Method	BREEAM International New Construction 2016 - fully-fitted dwellings (BRE, 2017)	BRE - Building Research Establishment (1921) / United Kingdom / 1990	> 566,000 certifications <sup>II</sup> / ? m <sup>2</sup> / 80 countries
<b>LEED</b> / Leadership in Energy and Environmental Design	LEED for Homes v4 (USGBC, 2019)	USGBC - US Green Building Council (1993) / USA / 1998	> 94,000 projects <sup>III</sup> (> 40,000 certified) / 600 million m <sup>2</sup> <sup>IV</sup> / 165 countries
<b>DGNB</b> / Deutsche Gesellschaft für Nachhaltiges Bauen	DGNB System - New buildings criteria set - version 2018 (DGNB, 2018)	DGNB – German Sustainable Building Council (2007) / Germany / 2007	> 2,200 projects (certified and precertified combined) <sup>V</sup> / 61,7 million m <sup>2</sup> / 21 countries
<b>WELL</b>	WELL v2 Pilot (IWBI, 2019)	IWBI -International Well- building Institute (2013) / USA / 2013	1,280 projects <sup>VI</sup> (1,137 registered and 143 certified) / 24,7 million m <sup>2</sup> / 43 countries
<b>LBC</b> / Living Building Challenge	Living Building Challenge Standard 3.1	International Living Future Institute (2009) / USA / 2010	380 projects <sup>VII</sup> (317 registered and 73 certified – of which 15 achieved Living Certification) / ? m <sup>2</sup> / 23 countries

Table 1: At glance facts for the five certifications selected for analysis in this paper

<sup>II</sup> <https://www.breeam.com/>

<sup>III</sup> <https://new.usgbc.org/leed>

<sup>IV</sup> <https://www.usgbc.org/articles/us-green-building-council-releases-annual-top-10-states-leed-green-building-capita>  
#m2 (per January 2018)

<sup>V</sup> [https://www.dgnb-system.de/en/current\\_issues/press-releases/2017/dgnb-witnesses-record-number-of-certifications](https://www.dgnb-system.de/en/current_issues/press-releases/2017/dgnb-witnesses-record-number-of-certifications)

<sup>VI</sup> <https://www.wellcertified.com/en/articles/iwbi-launches-well-v2>

<sup>VII</sup> <https://living-future.org/contact-us/faq/>

#certifications, #countries (accessed January 2019)

#projects, #countries (accessed January 2019)

#certifications, #m2, #countries (per September 2017)

#certifications, #m2, #countries (accessed January 2019)

#certifications, #countries (per May 2017)

# Comparison Procedure

The certifications investigated in this report will undergo a comparison of a range of quantitative criteria. These criteria are grouped under two main headlines, shown below.

1. Assessment Content
  - a. IE main categories (thermal IE, visual IE, acoustic IE and air quality)
    - i. IE sub-categories within health and comfort (e.g. radiant temperature, draft, relative humidity)
  - b. User influence on own IE
  - c. Well-being criteria
  - d. Interaction effect criteria (refer to p20)
2. Weighting and Scoring
  - a. Certification structure
  - b. IE content vs overall certification index
  - c. Relative influence of main categories, plus user influence category
  - d. Minimum Requirements

Data will be recalculated, renamed, or otherwise treated to allow for comparison under equal conditions, as explained in the following sections.

## Assessment Content

The comparison of assessment content the selected certifications are scanned for all specific criteria, parameter threshold levels, and other indicators relevant for a holistic indoor environmental assessment of a dwelling (see the 'What is Indoor Environment in this Report' chapter below for more information).

### **1a+1b: IE main categories and user influence on own IE**

All relevant certification criteria are categorised by which IE aspects they influence, and then regrouped and renamed to ease comparison across certifications and shown in a combined table.

### **1c+1d: Well-being and Interaction effect criteria**

The classification exercise above is followed by an overview of whether the different certifications include parameters for the other IE-related topics 'occupant Well-being' and 'Interaction effects'. For this paper, well-being refers to positively contributing IE parameters, while Interaction effects refer to the complex network of inter-related IE effects (Bluyssen, 2009) as summarised in a recent ASHRAE Guideline (ANSI/ASHRAE 62.2, 2016).

## Weighting and Scoring

As mentioned above, the weighting and scoring topic is divided into three parts, to give an overview of the investigated certifications overall structure, as well as how they prioritise IE vs complete certification, and how they apply relative IE category weights. Finally, a list of mandatory (or knock-out) criteria is provided and discussed concerning the findings of both the content and the weighting/scoring analysis. A short clarification of the investigations on the weighting and scoring topics will be given below.

### **2a: Certification structure**

Certification structure is mapped for each certification in a combined table including topics levels, weighting factors (in any), accumulation of points, certification levels and additional requirements. Each certification has its own unique set of terms, which make comparison difficult. Instead, these content terms have been classified based on topic coverage on a scale from general/wide to specific/narrow on three levels: Topic Groups, Main Topics and Sub-topics. While the

table shows the architecture of the certification as a whole, the words in grey highlight give key information on the indoor environmental contribution (such as 7 Petals in total in LBC, of which 1 Petal is IE related). The purpose of the table is to give an overview of the different levels of aggregation used by each certification as a simplified mapping of how the parts add up to an overall assessment.

## 2b: IE content vs overall certification

This index shows the combined influence of all IE topics on the overall score of the complete certification (including IE topics). This is done by adding the maximum points obtainable for IE topics in a given certification, adding issue weights (if any), and comparing this to the theoretical maximum score total for that certification. The purpose of this index is to show the overall focus of each certification at a glance.

$$\text{IE content vs overall certification index} = \frac{\sum (\text{all IE topics}_{\text{max score}} * \text{weight factors})}{\sum (\text{all topics}_{\text{max score}} * \text{weight factors})}$$

## 2c: Minimum requirements

Each certification operates with specific requirements for some topics as indicated in the additional certification requirements in the bottom part of the Certification Structure table. The specific IE criteria affected by these minimum requirements are highlighted (\*) in the Assessment Content table. This section also includes brief comments on how the minimum requirements match the certification prioritisation in general.

## 2d: Relative influence of main categories

This index shows the relative influence of the four main IE categories and a fifth category of 'user influence', within a given certification. The relative influence is evaluated by adding the maximum points obtainable for each IE category, applying relative category weights (if any), and comparing this to the theoretical maximum score for IE topics - after indexing the sum of maximum IE points to 100%. The purpose of this index is to show how each certification prioritises between IE topics.

$$\text{Relative influence of main category index} = \frac{\sum (\text{single IE topic}_{\text{max score}} * \text{weight factors})}{\sum (\text{all IE topics}_{\text{max score}} * \text{weight factors})}$$

## Assumptions for weighting and scoring Comparisons

Please refer to Appendix 1 for assumptions made concerning the quantitative comparison of the certifications in the Comparison chapter below. Assumptions are generally related to handling mandatory criteria, relative weights and the exclusion of Innovation credits.

# What is Indoor Environment in This Report?

This report gives readers an overview of what content the investigated certifications include in their assessment of indoor environment. This report approaches indoor environment from a holistic perspective with attention to the four main IE categories; Thermal, Acoustic, Visual, and Indoor Air Quality. This report includes both Comfort criteria and Health effects – as well as the Well-being of occupants.

This chapter address conditions and assumptions for the investigation under two headlines. The first headline covers how local variations of certifications result in minor adjustments in content, scoring and weighting for some criteria depending on the location of the certified project. The second headline explains the reasons for the inclusion/omission of specific criteria based on the typology of the assessed project – in this case, a multi-story dwelling.

## Contextual Considerations

Many countries have developed building sustainability certifications adapted to the local climate and building regulations, as well as the current economic and political landscape. Some of the larger international certifications even have a range of national variations adapted to the specific contexts of individual countries. Many certifications standards address these regional or local differences on some level. The sections below give a summary of how the five investigated certifications tackle this.

**BREEAM** provides weightings adapted for local conditions based on information by ‘local experts’ compiled by a BREEAM Assessor using the ‘BREEAM International Weightings’ form (available from the BREEAM Assessor Extranet). Local conditions (such as culture, economy, climate and work practice) can also affect issue assessment methods in BREEAM, such as setting the top benchmark for rainwater recycling to match local precipitation conditions. As there are no ‘international weightings’, this report uses the UK weightings (note: content is unaffected by this).

**LEED** is designed to be globally consistent to have a common international platform for comparison and knowledge sharing. LEED recognises global and regional differences LEED by introducing Alternative Compliance Paths (ACP’s) to accommodate more challenging conditions (compared to projects in the U.S.). Projects can demonstrate compliance with some requirements using these ACP’s when applicable for their region (e.g. Radon zones).

**DGNB** use an international system based on European norms and standards which provide the basis for international assessment that can take two different routes to local conditions. Qualified auditors can choose to recommend adjustments for local conditions, which will undergo conformity assessment by DGNB in Germany, which is the model used in, e.g. Greece, Slovenia, Spain, Turkey and Ukraine. The alternative is a more detailed adaption of the DGNB system where DGNB cooperates with local experts of ‘sustainability building with the DGNB system’ who makes an in-depth adaption to climate, standards, laws, processes and cultural differences, as is the case for Brazil, China and Russia. In some countries, DGNB Systems partners operate independently, make adjustments to national regulation, perform local conformity checks and even use a modified logo. These tailor-made locally adapted systems are operating in Bulgaria, Denmark, Austria, Switzerland and Thailand.

**WELL** v2 differs from v1 in that “This new version of WELL will be regularly and proactively adapted to varying contexts and constructs, making it even more relevant and readily applicable to spaces and places across the globe.” (IWBI, 2019). The standard is the pilot stage but aims for a more nuanced approach to health risks based on building type and region, as well as a localisation strategy that considers regional health concerns, cultural norms and market realities by offering customised scorecards sensitive to regional conditions, regulations and practices.

**LBC** differs from the other certifications, as it deliberately chooses not to have a local adaption strategy. Instead, they argue that the guiding principles and performance metrics of LBC are applicable world-wide due to the performance-

based nature of the assessment: “What changes is the specific mix of strategies and technologies—leaving it up to the genius of the design team to choose the most appropriate design response.” (ILFI, 2016).

## **Adapting to Assessment of Multi-story Dwellings**

This report compares content for assessment of groups of dwellings such as apartment buildings. Some certifications have project type specific standards, which influence content included in the assessment, as well as affecting the weighting and scoring. The certification standards analysed in the report for BREEAM, LEED and DGNB are all designed for (or include adaption rulings for) the assessment of dwellings, meaning that some criteria have been excluded, compared to assessment of other building types within that certification standard. Criteria exclusion can be due to them not being applicable, unimportant, or simply not included as a requirement (e.g. applicable and relevant but too time/cost-consuming for smaller projects). Examples of specific criteria exempted for dwellings in the certification manuals are view out (BREEAM), post construction IAQ measurements (BREEAM), glare (BREEAM and DGNB) and electrical lights (DGNB). For LEED the assessment for dwellings has entirely excluded Thermal IE, Acoustic IE and Visual IE.

The WELL and LBC certifications are for all project types and thus do not consider whether criteria are relevant for dwellings. Some WELL criteria have been excluded by the authors of this report, however, as they are deemed not applicable for the assessment of indoor environment in dwellings for this study. The criteria exempted are concerned with glare, smoking bans, and thermal zoning/control in public and large-scale environments.

# Comparison

This chapter makes a step-by-step presentation of the analyses introduced in the Comparison Procedure chapter above. The analysis is divided into two headlines: 'Assessment Content' and 'Weighting and Scoring'.

## Assessment Content

### Indoor Environmental Content (1a+1b)

Table 2 shows a content overview of the five certifications grouped into five different 'categories': Thermal IE, IAQ, Visual IE, Acoustic IE, and User influence. The content categories of table 2 are based on the combined content of the five certifications by categorising all IE topics for each certification. Note that the categories listed are made for ease of comparison between certifications, and thus the specific parameters are grouped differently from their standard configuration in the individual schemes. Appendix 2 lists the most important category and criterion names contributing to this assessment.

### Content Comparison on IE Main Area Level

Table 2 clearly shows that the certifications differ in their inclusion of IE criteria. The following paragraph will sum up the content findings including overlaps, differences, interesting 'niche'-parameters as well as comments on parameters not covered by any of the five assessments.

**Thermal** content coverage is right for BREEAM, DGNB and WELL (although BREEAM does not include humidity control). Thermal is completely absent in LEED (for Homes). LBC has no thermal standard requirements but does require thermal parameter monitoring, along with WELL that has the only full coverage of thermal content.

**IAQ** content coverage is shared across all certifications for ventilation rates, filtration and emission control. All certifications except DGNB include pollutant monitoring. The rest of the IAQ content differ widely between certifications. Organic gas air quality tests are mandatory for WELL and LBC but are not part of BREEAM and LEED assessments at all. LEED, WELL and LBC include a range of other air quality tests as well, with mandatory thresholds in WELL and LBC (see Table 3). Entryway strategies are part of both LEED, WELL and LBC but not BREEAM and DGNB. Content of note that is only included in a single assessment includes humidity control in bathrooms (LEED), reduced combustion pollution (LEED, mandatory), and reduced construction work pollution (WELL, mandatory).

**Visual** content coverage is right for BREEAM, DGNB and WELL including both daylight quantity, daylight distribution along with other criteria. BREEAM and WELL are the only to include electrical lightning criteria, while DGNB is the only assessment to include access to sunlight. Although DGNB and WELL do take view out access (quantity) into consideration, none of the assessment includes view out content and colour (quality). View out quality is part of LEED for non-dwelling certifications, however, while  $R_a$  values (colour balance distortion) are part of some national DGNB variations for dwellings (e.g. DGNB Systems Denmark). Also, LBC includes view out quality as a positive contribution to the Biophilic Environment imperative, but only as one of many options to fulfil this imperative. No assessment takes exposure to View in (reduced privacy) into account.

**Acoustic** content coverage is right for BREEAM, DGNB and WELL for both indoor and outdoor airborne sound, and to some extent for impact sound (BREEAM and DGNB). Curiously, only WELL include reverberation time and background noise as part of their assessment.

**User Influence** content coverage is best for DGNB, only missing requirements for electrical lighting controls. The most common criteria included are operable windows (all except LEED and DGNB) and adjustable temperatures on room level (all except LBC). Curiously, DGNB is the only assessment with criteria for room level ventilation regulation and easily ventilation rate controls, despite LEED and WELL putting so much emphasis on IAQ content.



Thermal		BREEAM	LEED	DGNB	WELL	LBC
Operative temperature	Operative temperature (winter/summer)	x		x	X	
Cooling	Cooling/air conditioning (precautions concerning drafts and humidity)	x		x	x	
Draft	Drafts (winter and summer)	x		x	X	
Radiant temperature	Radiant temperature asymmetry and floor temperatures (winter/summer)	x		x	X	
Monitoring	Monitor thermal parameters (dry-bulb temp, relative humidity, air speed)				X	X
Rel. Humidity	Humidity control (relative humidity within set intervals)			x	x	
IAQ		BREEAM	LEED	DGNB	WELL	LBC
Vent. Rates (quantity)	Ventilation rate (quantity, air distribution strategy, intake/exhaust position)	x	X	x	X	X
Filtration	Air filtration (standards for installed filters, commissioning)	x	X	x	x	
Pollution mapping	Particle pollution maps (and optionally radon concentration maps)			x		
Air quality test: Organic gasses	Threshold levels for VOCs and Formaldehyde			x	X	X
Air quality test: Other	Thresholds for inorganic gasses and particulate matter (and others)		[x]		[X]	[X]
Pollutant monitoring	Monitoring of indoor air pollutants	x	X		X	X
Emission control	Emission control (VOCs, SVOCs, formaldehyde)	x	x	x	x	X
Humidity control/inspection	Humidity controlled vent. (shower), or condensation & mould management		x		x	
Envelope/entryways	Envelope and entryways (walk-off systems, entryway air seals)		x		x	X
Reduce pollution: construction	Pollution from construction work (duct sealing, filter replacing, flushing)				X	
Reduce pollution: combustion	Pollution from combustion-processes (fireplaces, boilers, heaters etc.)		X		x	
Reduced pollution: uncontrolled pathways	Envelope sealing to minimise uncontrolled pathways for pollutants (leakage sealing, blower door test, reducing pollutants from the garage)		X			
Visual		BREEAM	LEED	DGNB	WELL	LBC
Daylight (quantity)	Daylight (quantity)	x		x	X	X
Daylight (distribution)	Daylight (distribution)	x		x	X	
Daylight (quality)	Daylight (color rendering (Ra), or visual balance/brightness management)			x	x	
Sunlight/Daylight exposure	Sunlight/Daylight exposure (quantity - as a positive contribution)			x		*
Electrical light (quantity)	Electrical light (quantity)	x			x	
Electrical light (quality)	Electrical light (quality - colour, flicker, uniformity, circadian rhythm etc.)	x			x	
Electrical light (glare)	Electrical light (glare)	x			x	
View out (quantity, access)	View out (quantity - access to view, view angle)			x	x	*
View out (shading obstruction)	View out (obstruction from solar shading, worst case)			x		
Acoustic		BREEAM	LEED	DGNB	WELL	LBC
Airborne sound	Sound insulation levels (noise from traffic, neighbours, other indoor rooms)	x		x	x	
Impact sound	Impact sound (floors, stairs and balconies)	x		x		
Reverberation time	Reverberation time (inside dwelling)				x	
Background noise	Background noise (HVAC, external noise intrusion)				X	
Privacy and Zoning	Privacy and Zoning (internal walls, bedrooms, loud/quiet/mixed zones)				X	
Noise measurement/mapping	Ambient noise measurements, or the use of existing noise maps			x		
User Influence		BREEAM	LEED	DGNB	WELL	LBC
Ventilation boost	Forced ventilation rate in rooms with dynamic people loads (easy to use)			x		
Ventilation regulation	Regulation of ventilation on room level			x		
Operable windows	Operable windows (manual, or mechanical with override)	x			x	X
Temperature regulation	Adjustable temperatures on room level	x	x	x	x	
Electrical light controls	Controllable electric lights (dampening, extra intensity, color adjustment)	x			x	
Electrical light automation	Automation of electric lights (circadian and visual requirements)				x	
Shading adjust. (view out)	Adjustable external solar shading to accommodate view out			x		

Table 2 Content overview of the five certifications regrouped into five IE categories: Thermal IE, IAQ, Visual IE, Acoustic IE, and User influence.

x = content included

X = content mandatory

[] = expanded in Table 3

\* = indirectly through 'BiophilicEnvironment'

Air quality test: other		BREEAM	LEED	DGNB	WELL	LBC
Inorganic gasses	Inorganic gasses (thresholds for Carbon monoxide and Ozone)		x		X	X
Particulate matter	Particulate matter (thresholds for PM2.5 and PM10)		x		X	X
Radon	Radon (thresholds for Bq/L)				X	
VOCs and formaldehyde	VOCs and formaldehyde (threshold levels, specific targets for individual VOCs)		x			
CO <sub>2</sub>	CO <sub>2</sub>					X
NO <sub>x</sub>	NO <sub>x</sub>					X
Other	4-Phenylcyclohexane					X

Table 3 Expanded content list for air quality tests grouped into seven categories.

x = content included

X = content mandatory

## Well-being Content (1c)

The certifications aiming specifically for creating better conditions for humans also include design qualities that enhance human well-being through aesthetics, integration with nature and various experiences of delight and atmosphere (see Table 4). For WELL this comes from parts of the 'COMMUNITY' (CO2) and 'MIND' concepts (M02, M07 and M09), while for LBC this is covered by the 'Beauty' Petal, and Imperative 09 Biophilic Environment from the 'Health + Happiness' Petal. For DGNB this is not part of the standard certification but comes in the shape of a recently developed DGNB diamond certification option with content selected by local expert panels for each national variation (the content listed here is for Denmark). LEED and BREEAM have very little representation here, as they put less emphasis on the social sustainability aspect (compared to the environmental sustainability aspect). Table 4 lists additional content for human well-being categorised under eight topics.

As a side note, the LBC Imperative 16 Universal Access to Nature and Place of the Equity Petal, demands that the project does not 'block access to, nor diminish the quality of' fresh air, sunlight and natural waterways. Also, the DGNB criteria Immissions Control (TEC1.7) rewards measures that reduce noise pollution and light pollution of the local environment. For these two initiatives, the aspirations for better human (and wildlife) conditions also goes for the occupants in neighbouring buildings, which is a quite amiable notion.

Human Well-being		BREEAM	LEED	DGNB	WELL	LBC
Interiors	Visual and spatial qualities, light, surface materials, textures, details			x	x	x
Exteriors	Facade materials, construction, finish			x		x
Appearance	Proportion, rhythm, scale, composition			x		
Contextual integration	Place, climate, outdoor spaces			x	x	x
Social qualities	Culture, community, neighbourhood, urban integration			x	x	x
Art	Local artists, public art				x	x
Nature, interiors	Nature views, natural materials, plants/light/water			x	x	x
Nature, exteriors	Green roofs, landscaping, green or blue spaces, inside-outside connection	x		x	x	x

Table 4 Content overview by certification for topics related to human well-being (not already covered by the IE content in Table 2 above).

x = content included

## Interaction Effect Content (1d)

Although several certifications consider all four main IE categories in their assessment of the IEQ performance, they all treat the categories separately, despite research indicating that "Building occupants balance the good features against the bad to reach their overall assessment." (Humphreys, 2005). Several papers have attempted to create an overview of how IE categories relate to one another or how single parameters are influenced by other IE parameters or even non-IE parameters (C. J. Weschler, 2004; van Hoof, 2008; Frontczak and Wargocki, 2011; Frontczak *et al.*, 2012; Kim and De Dear, 2012).

The literature points to interaction effects between IE categories (or sub-category parameters) as summarised in an ASHRAE guideline that gathers information on how to improve the acceptability of indoor environments (ASHRAE Guideline 10, 2016). The foreword of the ASHRAE guideline 10 reads: "Meeting the requirements of standards for various aspects of indoor environments, such as air quality, thermal conditions, acoustics, or illumination, is not always sufficient to ensure the acceptability of the environment to all relevant parties." None of the certifications considers how certain IE parameters interact with other parameters, i.e. by capping a certain parameter score based

on the results of another parameter - or by awarding bonus points in one parameter based on performance in another parameter. Examples of synergistic interactions from the ASHRAE guideline include the risk of lung cancer being a factor 5 greater by combining exposure to tobacco and asbestos (rather than merely the sum of the two), and subjective warmth is increasing more by a combined temperature and humidity increase than a sum of their separate contributions.

While none of the standards has included interaction effects documented in the literature, LBC does treat the holistic nature of a combined IE performance on a more general level as all parameters are mandatory in this certification. Thus, all IE categories included in the assessment will have to live up to the requirements dictated. Some hesitancy towards including interactions effects in certifications is to be expected as the literature on interaction effects is a complex and relatively unexplored area (in particular within acoustic and visual IE). Until the field is sufficiently explored, certifications could take on a conservative 'robustness-approach' to the topic, to increase the lower performing parameters to decrease the risk of overall IEQ acceptability being far lower than the sum of the individual contributions. For instance, the overall DGNB certification is not only awarded based on the average percentile performance across all criteria but includes a minimum threshold for each of the five overall topics or 'Qualities' (see the Weighting and Scoring chapter below), so that one cannot ignore, e.g. economic sustainability. A similar approach could be implemented for the Indoor environmental topics so that a high score within Social Quality depends on a decent performance on all IE related topics.

## Weighting and Scoring

### Certification Structure (2a)

Since all rating systems use different aggregation and scoring systems, comparisons between scores and values require some interpretation and alignment of content categories. Brief paragraphs below introduce the structure of each certification, while Table 5 gives an overview of the aggregation levels for the five systems, including information on topics, weighting factors, point ranges and certification levels. The highlighted numbers at the bottom of some cells in table 5 show data specifically concerning IE assessment topics relevant for this report. For additional information on the certification structure of each certification, please refer to Appendix 3.

Note that since LEED and BREEAM work with degrees of fulfilment of a category (points scored/points available when the number of points available change (i.e. credit is not relevant for the given building type or context) the number of points required for fulfilment changes automatically. The same is true for DGNB as it works with a fixed 100-point scale for a category, so if content is removed or added, the contributions of criteria change to add up to 100. This is not the case for WELL since it works with final points. A set amount of points is required for each level of certification, meaning that it is harder to certify dwellings since there are fewer points available. Since LBC works only with requirements if fewer criteria are relevant for the assessment in question the results are slightly lowered requirements to achieve certification.

Aggregation levels	BREEAM	LEED	DGNB	WELL	LBC
Topic Groups	<b>9 Environmental Categories</b> (+ Innovation Category)	<b>6 Categories</b> (+ Innovation and Regional Priority Categories)	<b>6 Qualities</b>	<b>10 Concepts</b> (+ Innovations)	<b>7 Petals</b>
Main Topics	<b>1 Category</b> <b>57 Issues</b>	<b>1 Category</b> <b>40 Credits</b>	<b>1 Quality</b> <b>37 Criteria</b>	<b>4 Concepts</b> <b>112 Features</b> (89 Optimizations + 23 Preconditions)	<b>1 Petal</b> <b>20 Imperatives</b>
Weighting Factors	<b>4 Issues</b> <b>Category weight factors</b> (in %, varies) (14.4%)	<b>7 Credits</b> <b>Credit point caps</b> (varying credit point caps) (varying credit point caps: range 1-3)	<b>6 Criteria</b> <b>Criteria weight factors</b> (rank 1-7) (rank 2-5)	<b>(24 Optimizations + 7 Preconditions)</b>	<b>2 Imperatives</b>
Sub Topics (with points)	<b>Criteria</b> (varying amount of credits) (varying amount of credits: range 1-4)	<b>Options</b> (varying amount of points) (varying amount of points: range ½-2)	<b>Criteria Indicators</b> (0-100 pts for all criteria) (0-100 pts)	<b>Optimisation Parts</b> (varying amount of points, range 1-3) (varying points: 1-3)	
Sum of Points	<b>Overall score</b> (sum of: % achieved vs available credits for each Category multiplied by Category weight factors)	<b>Total points from Categories</b> (sum of: points from Options)	<b>Total performance index</b> (sum of: % of achieved vs available Criteria Indicator points multiplied by Criteria weight factors)	<b>Total points from Concepts</b> (sum of: points, from Optimizations - min 2 / max 12 for each Concept)	
Certification	<b>Certification</b> (Pass ≥ 30, Good ≥ 45, Very Good ≥ 55, Excellent ≥ 70, Outstanding ≥ 85)	<b>Certification</b> (Certification ≥ 40, Silver ≥ 50, Gold ≥ 60, Platinum ≥ 80)	<b>Certification</b> (Silver ≥ 50%, Gold ≥ 65%, Platinum ≥ 80%)	<b>Certification</b> (Silver ≥ 50, Gold ≥ 65, Platinum ≥ 80)	<b>Certification</b> (yes / no)
Additional requirements	Minimum standards for some Criteria must be fulfilled  <b>1 Criteria with Minimum standards</b>	All 18 Prerequisites must be fulfilled  <b>7 Prerequisites</b>	No Qualities can score lower than a threshold below a given certification level. E.g. for Platinum all Qualities (except SITE must be ≥ 65%)	All 23 Preconditions must be fulfilled  <b>7 Preconditions</b>  WELL Core Certification option: Certification requires 40+ points (min 1 per Optimization)	All 20 Imperatives must be fulfilled  <b>2 Imperatives</b>  Petal Certification option: Certification requires fulfilling 3+ Petals, one of which must be Water, Energy or Materials

Table 4 Overview of Content structure, Levels of aggregation and Indication of IE content amount for the five analysed certifications. Text with a grey highlight shows key numbers for IEQ.

## Overall IE Weights (2b)

Table 6 below lists how much of the total assessment of each certification is attributed to indoor environmental contributions, after the application of varying scores, points and weightings. Since the certifications group IE content in different ways, it can be challenging to determine which certification gives IE content the highest priority. Table 6 includes the name of the main category or categories with IE content as well as the weight of that category (if any), which is the 'first impression' combined IE priority for each certification. Such first impressions can be misleading, however, due to; inclusion of non-IE content in the IE category, IE-relevant content placed in other categories, or differences in available points for each category. Instead, the far right column shows the actual combined IE priority given to IE topics as defined in this report. This comparison indicates the actual impact of IE topics for each of the five

certifications. Note that mandatory criteria without allocated pts are not represented in the calculated weights. See Appendix 4 for supplementary notes on mandatory criteria and the calculation of content percentages for WELL.

Certification	Indoor Environmental content: Category Names	Indoor Environmental content: Category Weights	Indoor Environmental content: Contribution to the overall assessment (as defined in this report)
BREEAM	Health and Wellbeing	14.4%	9.8%
LEED	Indoor Environmental Quality	16.3%	15.3%
DGNB	Sociocultural and Functional Quality	22.5%	16.0%
WELL	Thermal, Air, Light and Sound	30.9%	27.5%
LBC	Health + Happiness	10%	10%

Table 5 IE-related categories and their weights for each certification, as well as a calculated 'actual IE contribution' in % of the overall assessment.

The weights listed in Table 6, have been calculated differently for each certification. For BREEAM and DGNB the IE category weights have been listed in column three and adjusted to a relative IE weight that only includes IE content in table 4. For BREEAM this means excluding topics with content related to accessibility, natural hazards, water quality, outdoor spaces and laboratory safety, resulting in a much lower actual contribution weight. Similarly, DGNB topics excluded are related to accessibility, spacial qualities and safety – but some topics outside the 'Sociocultural and Functional Quality' category are also added, such as sound insulation and selected local environmental conditions.

LEED and WELL do not use category weights, but the points assigned for each topic has been used to calculate relative weights. For LEED the 16 points assigned to the Indoor Environmental Category make up approx. 16.3% of the total 98 topic-related points (Innovation, Regional Priority and Integrative Process are ignored here), adjusted to 15.3% after removing a single credit related to tobacco smoke. For WELL the 55 points from the four IE-related, categories add up to approx. 30.9% of the total of 178 points available. Although some topics are excluded as being un-related to dwellings such as glare and tobacco smoke, some emission topics of the Materials category are added to the count.

Since the LBC certification does not work with points or scores, the 10% contribution is listed as 10% of the total content of LBC, as two out of 20 Imperatives fit the definition of IE for this paper, namely 07 Civilized Environment and 08 Healthy Interior.

## Mandatory Criteria (2c)

The bottom row of Table 5 above ('Additional Requirements') and the criteria listed in **bold** in Table 2 above, shows the mandatory criteria for each certification. Detailed information is provided in Appendix 5.

## Relative Weights for IE Main Areas (2d)

Comparisons of inter-area prioritisation are illustrated through pie charts of relative IE topic contributions, shown for all five certifications in Figure 1. The figure shows how the different certifications prioritise IE content by IE area. All the four main areas are represented for four of the five certifications (LEED only addresses IAQ), but the contributions vary up to a factor five. Note that the diagrams only map topics awarding points (except for the LBC chart which does not work with scores and thus is based solely on the requirements counts for the given topic) and thus does not represent the number of mandatory criteria. For WELL this means, that the seven topics are not included in the pie chart data, but as the distribution of these matches the amount of potential points for each topic well, this does not affect the results much. For LEED this means that six topics are not shown in the chart, but as they are all IAQ parameters, this is of no influence. The number of mandatory criteria not included in the pie charts are listed next to the relevant category for each certification in Figure 1.

While WELL, BREAM and LBC give more or less equal consideration to Thermal, DGNB puts a very high emphasis on the topic (high weighting factor). LEED for Homes only considers IAQ and is thus not suited for an inter-area comparison. LBC and WELL also put a very high emphasis on IAQ with strict requirements including extensive air quality tests and pollutant monitoring that are mandatory. Visual is well represented in both DGNB, WELL and in particular BREEAM where it is the biggest contributor. Curiously, Acoustics is not part of the LBC assessment at all, but is represented in both DGNB and WELL – and is very well represented in BREEAM.

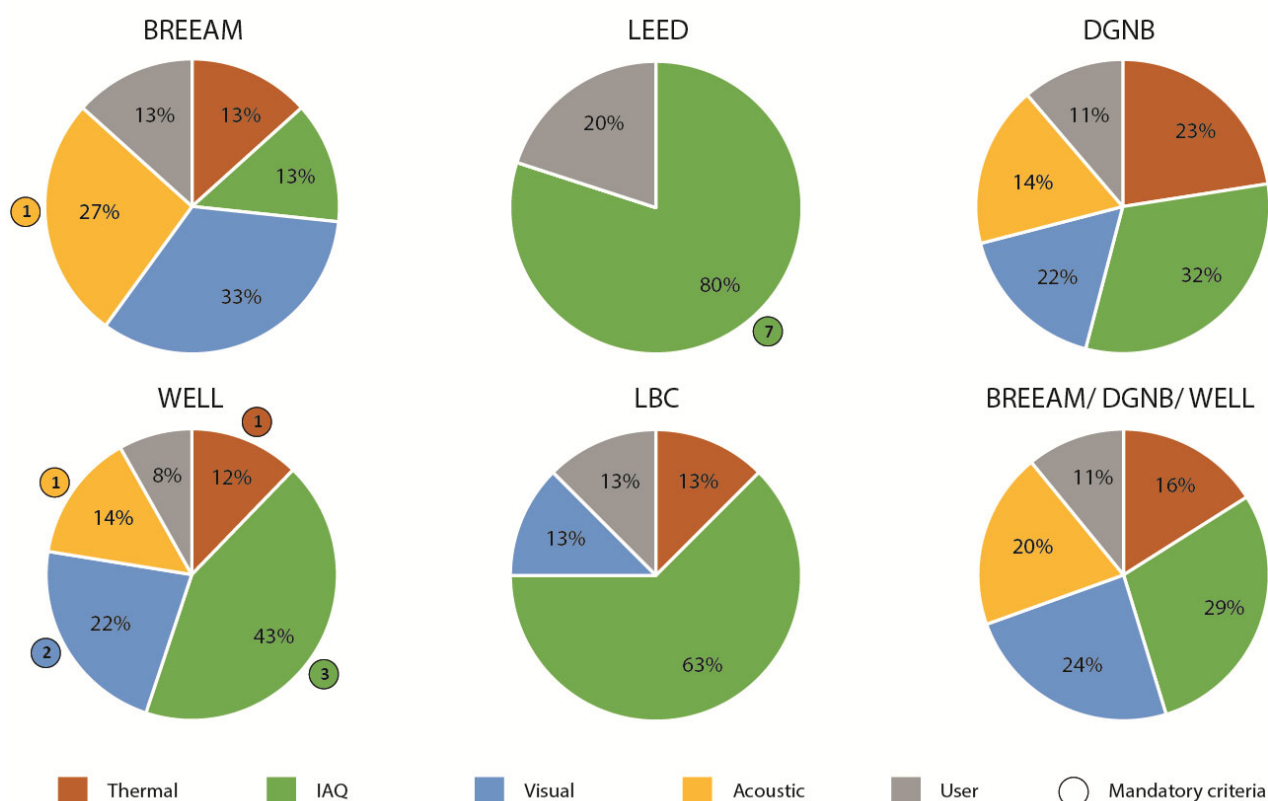


Figure 1 Pie charts of relative IE topic contributions for five certifications, as well as an averaged contribution chart for the three certifications that include all four main IE areas (BREEAM, DGNB and WELL). The number of mandatory topics that do not award points are not included in this comparison but are indicated by the small circles next to each pie chart.

Although max. and min. category weights within certifications vary approximately by a factor 2 to 3.5 (for BREEAM, DGNB and WELL), the categories are relatively equal if you create average weightings across certifications (approx. factor 1.8). Figure 1f plots the average weight per IE area for the three certifications that include all four IE categories (BREEAM, DGNB and WELL), showing a reasonably even distribution among the areas ranging from approx. 16% (Thermal) to 29% (IAQ), and about half as much for Users at approx. 11%. Another indication of this approximation of equality importance of the categories is seen from the differences in the top priority categories of each assessment with, DGNB favouring IAQ (31.54%) and Thermal (22.53%), WELL favouring IAQ (42.86%) and Visual (22.45%), and BREEAM favouring Visual (33.33%) and Acoustic (26.67%).

#### NOTES:

##### LEED

Note that all Credits in the Category of Indoor Environmental Quality has been assigned to the Atmospheric IE topic. However, the Credit Balancing Heating and Cooling Distribution Systems (registered as a User parameter) have implications for both IAQ and thermal comfort in the dwelling.

Curiously, despite the overwhelming focus on IAQ, LEED for Homes has no User content related to IAQ. Those listed primarily apply to Thermal.

##### LBC

Relative comparisons of IE topic content are difficult to make for an assessment without scores and with overlapping topics. To give some sort of impression of the relative weights, simple IE topic counts has been made, and distributed to the various areas (Thermal - Temperature and humidity monitoring; IAQ - Ventilation - IAQ tests - Pollutant monitoring - Emission control - Entryways; Visual - Daylight quantity; Acoustic - none; User - Operable windows).

# Discussion of findings

This chapter summarises some of the most important findings from the analysis and comparison of the investigated certifications, with reflections on how to assess IE in future sustainable building certifications.

## What content should be included for 'full coverage'?

Based on the IE content investigation LEED and LBC are inappropriate for assessment of overall IEQ in dwellings, as they have significant content shortcomings. LEED has excluded the three categories of Thermal, Visual and Acoustic (despite it being part of all other LEED project types), while LBC lacks Acoustics and only requires monitoring for Thermal. BREEAM, DGNB and WELL have good coverage of the four main areas although with some inadequacies for BREEAM including air quality tests (organic gasses), daylight quality, view out (access), and initiatives to avoid humidity issues.

Some IE aspects are only assessed in one of the certifications. **IAQ** - Pollution mapping (DGNB), Reduced pollution: Construction (WELL), and Reduced pollution: Uncontrolled pathways (LEED). **VISUAL** – Sunlight/Daylight exposure (DGNB), and View out: shading obstruction (DGNB). **ACOUSTIC** - Reverberation time (WELL), Background noise (WELL), Privacy and Zoning (WELL), and Noise measurements/mapping (DGNB).

A few IE aspects that are expected to affect occupants in dwellings are absent across all five certifications, such as: View out quality (positive view content, and absence of colour balance distortion), and View in (risk of annoyance and reduced privacy from exposure to view from the outside).

## Which certification is best for IE in dwellings?

The gradual shift in focus from environmental to social sustainability mentioned in the certification presentation is well reflected in the IE category weights as presented in Table 6 above. Moving from BREEAM, over LEED to DGNB and WELL the focus on social sustainability increases, which positively influences the IE content impact. The most noticeable difference is that BREEAM only attributes 9.8% of the total influence to IE compared to 15.3% and 16.0% for LEED and DGNB. As an occupant-centred certification WELL gives higher priority to IE aspects by definition.

Combined with the findings on content above, it seems that WELL and DGNB are the certifications best fit to assess holistic IE. DGNB is the certification with the best IE coverage, which manages to address all of the three pillars of sustainability. WELL prioritises IE even more than DGNB but is not a typical stand-alone sustainable building certification. Instead WELL can be used as a supplementary 'seal of approval for IE performance' (along with other occupant benefits) other sustainable building certifications.

## What should future IE assessments look like?

The content comparison of this paper shows that some topics are mandatory in one certification and completely absent in others. This investigation shows significant inadequacies in visual and acoustic IE assessment. The next generation of sustainable building certifications or IE assessment tools should work to provide comprehensive coverage of IE criteria, possibly by getting inspiration from the content of other IE certifications. Future certifications should be open to all new IE parameters, possibly inspired by field study findings from measurements and surveys to cover the complexity of indoor environmental influences on occupants. In the long term, this may (or may not) include adopting topics from the 'Human Wellbeing' list in Table 4.

Future IE assessments should be very aware of the balance between the four main IE categories. This report shows that these differ widely both within a single certification and between certifications. For instance, IAQ is weighted 3.5

times as high as Thermal in WELL and five times as high in LBC, but the two have equal weights in BREEAM. Also, IAQ is weighted five times as high as Visual in LBC and approx. twice as high in DGNB and WELL, but for BREEAM Visual is 2.5 times as important as IAQ. The individual certifications seem confident in prioritising between IE categories, but there is no consensus across certifications. It is crucial that we search for unambiguous evidence on which main categories (and sub-categories) influence occupants most. Until we have that evidence, we should take care not skew the IE weight balance by merely counting the number of sub-categories into which a topic is divided. Once we begin to solve the puzzle on interaction effects, we could include this to minimise the gap between the assessed and the actual occupant influence from indoor environmental conditions.

The overall sustainable building certificate of a building says little about the IE performance as the IE content influence is low (9.8%-16%). Even on IE topic level comparisons between certifications are of little value as the discrepancies between IE content and the weights of IE categories makes it difficult to compare across certifications, and thus also between projects. Next generation IE assessments should address this through systematic IE content coverage and transparency in applied weights on both category and sub-category levels.



# Appendix 1

## Assumptions for Comparisons

**BREEAM** criteria weights are compared relatively based on the achievement of maximum points for each criterion. BREEAM Innovation credits are excluded from the comparison as they do not represent 'content' in the same way as the other categories.

**LEED** prerequisites are not part of the relative influence comparisons (2b and 2d) as they are not awarded any points in the certification. Instead, they are highlighted in the content overview in table 1 and treated in the text under headline 2c in the Comparison chapter. LEED Innovation, Regional Priority and Integrative Process credits are excluded from the comparison as they do not represent 'content' in the same way as the other categories.

**DGNB** criteria weights are compared relatively based on the achievement of maximum points for each criterion. Similarly, sub-criteria are weighted based on their contribution to the maximum number of points for each criterion (100 points) without taking special bonus points into account (Innovation bonus or Agenda 2030 bonus).

**WELL** prerequisites are not part of the relative influence comparisons (2b and 2d) as they are not awarded any points in the certification. Instead, they are highlighted in the content overview in table 1 and treated in the text under headline 2c in the Comparison chapter. WELL innovation credits are excluded from the comparison as they do not represent 'content' in the same way as the other categories.

**LBC** does not use points or weights for their criteria but is given equal weights as they are all prerequisites.

# Appendix 2

## Assessment Content - Contributions

For **BREEAM** the main contributions come from the Category 'Health and Wellbeing' (Hea 01-05, except Hea 03 Safe containment in laboratories - not relevant for dwellings).

For **LEED** the main contributions come from the Category 'Indoor Environmental Quality' (EQ). The LEED for Homes (or Multifamily Midrise) rating system is (surprisingly) limited to IAQ only, unlike most other LEED rating systems including Retail, Hospitality, Schools, Healthcare, Warehouse and Distribution Centers, Data Centers and New Construction. The 'Balancing of heating and cooling distribution systems'-credit concerning air systems does, however, mention thermostats, radiative systems and supply air flow rates meeting heating/cooling designed airflow for each room. Besides, LEED for Homes has added 'Acoustics' to the list of Pilot Credits (a beta testing group of 16 very different test-stage credits).

For **DGNB** the main contributions come from 'Sociocultural and Functional Quality' (SOC 1.1, 1.2, 1.4, 1.5), but also includes acoustics from 'Technical Quality' (TEC 1.2). Also, some content from 'Site quality' (SITE 1.1) is included in both content overview and the weighting and scoring analysis below. The three contributions from Site Quality are attributed to IE main categories as follows: (outdoor) Air Quality - IAQ, Outdoor Noise – Acoustics, and Radon – IAQ.

For **WELL** the main contributions come from the Concepts of 'AIR' (A01-A14, except A02 Smoke-Free environment – not relevant for dwellings), 'LIGHT' (L01-L08), 'THERMAL COMFORT' (T01-T07, except T03 Thermal Zoning – not relevant for dwellings), 'SOUND' (S01-S04, as S05 – Sound Masking is not relevant for dwellings), and 'MATERIALS' (X11 and X12 on emission control, which in this assessment is attributed to IAQ).

For **LBC** the main contributions come from the Petals of 'Health + Happiness' (Imperative 07 and 08). Parameters marked with \* are indirect contributions from Biophilic Environment (Imperative 09) demanding integration of human/nature connection – for IE this is through working with of sunlight and views.

# Appendix 3

## Certification Structure – Additional notes

**BREEAM** has 9 Environmental Categories (plus 1 Innovation Category), with 57 individual assessment Issues across the 9 Categories. Each Issue addresses a specific building environmental impact or issue and has a number of credits assigned to it. For the Category of 'Health & wellbeing', BREEAM credits are awarded where a building demonstrates that it addressed a specific building occupant-related issue, such as thermal comfort. The four 'Health & wellbeing' Issues relevant for dwellings each consist of 2-3 parts worth 1-4 credits each. The percentage of credits achieved for 'Health & wellbeing' (compared to the number of credits available for the certification in total) is multiplied by a Category weighting to give a Category score. Scores from all 9 Categories are then added to get the overall BREEAM score (plus +1% for each 'innovation credit'). Note that the Category weightings ('Environmental Category Weightings') provide weightings adapted for local conditions. This report uses the certification standard for a 'fully-fitted single residential building' using the UK weightings from the Approved Weightings New Construction 2016 List (version 31.1).

**LEED** is made up of 8 Categories, of which the six largest accounts for 98 out of the total 110 possible points. The remaining 12 points are divided between Innovation (6), regional priority (4) + the 'no-Category Credit' Integrative Process (2). LEED has 40 Credits in total, each with different Options that award points. Points awarded vary from the most commonly occurring 3 points (x10) and 2 points Credits (x14) to as high as 12, 15 and 29 for the top 3 Credits ('Total water use', 'LEED for Neighborhood Development', and 'Annual energy use' are all combination credits replacing a series of separate alternative Credits). For IEQ all Credits score 1, 2 or 3 points depending on the relative influence on the overall certification goal, with each underlying Credit Option being worth either ½, 1 or 2 points. The LEED certification has 18 Prerequisites (mandatory), of which 7 are related to IEQ.

**DGNB** evaluates a building's overall score in a percentage of the maximum obtainable points. The overall score is split into 6 Qualities; Environmental, Economic, Sociocultural & Functional (22.5% each), Technical (15%), Process (12.5%) and Site (5%). Each Quality includes 1-2 Criteria groups (10 in total), consisting of between 1 and 8 Criteria (37 in total). Each criterion is awarded 0-100 points based on point contributions from a range of Indicators within that Criterion. A weighting factor between 1 and 8 is applied depending on the relative importance of that Criterion (e.g. Thermal Comfort weighting 4 is equal to 3.6% of the overall DGNB evaluation). Note that IEQ also includes a few criteria and parameters from Technical quality (Acoustics) and Site quality directly related to IEQ as defined in this report.

**WELL** evaluates a building's overall score as the sum of accumulated points from Optimizations (2-12 per concept) for each of the 10 Concepts. Optimisations are worth 1-3 pts each (except for AIR - Enhanced Air Quality for 4 pts & the Innovate Well features for 10 pts). For certifications, each Concept has to score at least 2 points worth of Optimizations (although min 1 point for WELL Core Certification), and each Concept is capped at 12 points. Thus, Concepts are principally equal but vary in the number of available Optimizations. The Optimizations/ points distribution is as follows (#Optimizations/ #Max Points): Air 10/ 18, Light 6/ 14, Thermal 6/ 12, Sound 4/ 11. The WELL certification has 23 Preconditions (mandatory criteria), of which 7 are related to IEQ.

**LBC** consists of 7 Petals with one to five Imperatives that have to be fulfilled to receive certification. There are no points to be earned, no score to be gained and no variation in certification rank to achieve. Thus, LBC is poorly fit for the percentage-wise comparisons of this chapter. Only the Petal 'Health + Happiness' includes IEQ content.

# Appendix 4

## Overall IE Weights – Additional notes

### **Mandatory**

Table 6 only map topics awarding points and thus does not represent the number of mandatory criteria of each scheme if they do not have points allocated to them. For WELL this has little influence as the 7 IE topics (reduced from 8) that are not represented in the 27.5% listed, matches the IE contributions score very well (IE topics cover 7 out of the total 23 mandatory criteria – 30.4%). For LEED this difference is much more apparent as the 6 mandatory IE topics (reduced from 7) out of 18 topics in total makes up 33.3% of the total mandatory topics, compared to the modest 15.3% IE contribution listed in Table 6. Thus, one can argue that IEQ has a higher priority in LEED than the IE contribution number of Table 6 indicates.

### **WELL**

Note that while IE content for WELL is listed as approx. 27.5% of the total content of the WELL standard (based on point accumulation from Optimizations), the standard has a cap of 100 points (out of the 178 points available) and each Concept is capped at 12 points. This cap results in the maximum possible points scored from IE aspects as defined in this report adds up to 39 points (8 thermal, 12 IAQ, 12 visual, 7 acoustic) out of 100 points maximum score. These points alone will be enough for Silver certification (at 50 pts), as long as the remaining six (non-IE) concepts of the standard score the minimum of 2 points required for certification.

# Appendix 5

## Mandatory Criteria – Additional notes

This section lists a few notes about mandatory IE criteria for each certification.

For **BREEAM** Acoustic performance ‘appoint qualified acoustician’ is the only criteria relevant for dwellings with a predefined mandatory nature (Visual comfort: ‘frequency ballasts for fluorescent lights’ and Indoor air quality: ‘no asbestos’ are both not applicable). Note also that mechanical ventilation is required for Gold certification unless the pollution levels for surroundings meet rigorous demands (thresholds for PM<sub>2.5</sub>, PM<sub>10</sub>, CO, and O<sub>3</sub> for at least 95% of the hours in a year within a 4 km radius of the site).

While the **LEED** Indoor Environmental Quality Category has no less than 6 Prerequisites (‘Environmental Tobacco Smoke’ is not applicable), they are all within the topic of Atmospheric IE in the LEED for Homes rating system.

Although the new international **DGNB** system analysed do not include mandatory criteria, previous national adoptions of DGNB systems had a few so-called Knock-out criteria (typically within IAQ), which may be included again in national adoptions of the new certification standard.

In **WELL** all four IE areas are conceptually equal as all Concepts have a score cap of 12 points. However, they vary in the number of Preconditions (mandatory Features that unlike Optimizations do not award points): with 3 for ‘AIR’, 2 for ‘LIGHT’ and only 1 for ‘THERMAL’ and ‘SOUND’. Note also that Hea 08 Private Space, concerning private outdoor spaces for dwellings, is required to achieve Outstanding overall rating.

As all **LBC** Imperatives are mandatory, and some Imperatives include several IE main areas (07 Civilized Environment: Air and Light, 08 Healthy Interior: Thermal and Air), the only conclusion is that all IE main areas are mandatory, except for acoustics which is not part of LBC certification.

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This report analyses and compares five leading building sustainability certifications on their assessment of indoor environmental quality. While all of the five certifications include indoor environmental aspects in their certification, the differences in topics, content and weighting differ significantly.

For each of the five certifications analysed the report address topics such as:

- How important is the indoor environment compared to the overall certification?
- Which indoor environment topics are covered in the different certifications?
- What are the relative weights of the respective indoor environment topics?

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Readers of this report will get an overview of how the five selected certifications treat indoor environmental assessment. Furthermore, the content analysis gives an indication of what indoor environmental topics to include for a holistic IEQ assessment.

This report acts a supplement to the journal paper *“How should assessment methods for Indoor Environment be designed to facilitate decision support?”* which includes a qualitative analysis of the potential design stage influence of the five certifications investigated in this report.



