A comparison of acoustic criteria within green building rating tools, schemes and standards

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ABSTRACT

In Australia the Green Star and NABERS rating tools contain design criteria that are used to evaluate the indoor acoustic environment of buildings. How do these design criteria compare against those of rating tools, schemes and standards used by other countries? In this paper a comparison is provided between the acoustical criteria contained in the latest versions of a number of green rating tools, schemes and standards used across the World with the aim of identifying potential shortcomings, the associated compliance pathways available for a project and the importance of acoustics for each rating scheme.

1. INTRODUCTION

The last two decades has seen a proliferation of green building rating schemes aimed at decreasing the environmental impact of a development while improving the comfort of occupants. There has been a proliferation of internationally recognised building rating schemes such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED), the British Building Research Establishment Environmental Assessment Method (BREEAM) and the Green Building Council of Australia's (GBCA) Green Star that claim to represent best practice in sustainable design and construction.

In terms of acoustics many of these green building rating schemes have focused on the indoor environmental quality (IEQ) with no or minimal consideration of the acoustic emissions from the development, even though pollution and emission comprises one of the assessment elements of many of these schemes (Thahrir et al. 2015). In addition, feedback from post-occupancy surveys has shown that while overall green buildings produce higher ratings of occupant environmental satisfaction, a lower rating is generally achieved for acoustics (Newsham et al. 2013). This result is supported by a review of post-occupancy surveys conducted by Kim et al. (2013), which found that for a sample of over 300 office buildings over 50% of occupants in open office space were dissatisfied with acoustics, with sound privacy achieving the highest level of dissatisfaction. An earlier study of Finish offices also found that around half of open offices and 20% of occupants in private rooms were dissatisfied with acoustics (Haapakangas et al. 2008).

The consistently poor level of occupant satisfaction with regards to the indoor acoustic environment and the absence of the consideration of acoustic emissions from the development indicate that many of the green building rating schemes are not considering acoustic design requirements adequately. To gain an understanding of how the acoustic design requirements are currently addressed the criteria and verification methods used in a number of green building rating schemes have been examined.

2. SCOPE OF COMPARISON

This high level acoustic review has focused on comparing:

1. The acoustic parameters used to evaluate indoor environmental quality (IEQ);
2. Whether the scheme considers acoustic amenity in outdoor recreational areas;
3. Whether acoustic emissions from the development need to be assessed;
4. The pathways available for a project to be certified and obtain recognition; and
5. The importance assigned to acoustics for each rating scheme.

While 21 international rating tools, schemes or standards are considered in this study, it must be noted that this study is not intended to be all-encompassing but rather a snapshot of the current status of acoustical design criteria in green building rating systems.

3. RATING TOOLS, SCHEMES AND STANDARDS OVERVIEW

Table 1 summarises the green rating tools, schemes and standards that were reviewed for this paper. All of the systems presented in this table contain acoustic design requirements. The ratings tools, schemes and standards were selected based upon the availability of information regarding the acoustic criteria and certification/recognition pathways for awarding of a green building rating. In the instance where a country was identified to use a rating scheme that is identical to or based on a scheme from another country, those schemes have been excluded from this analysis. Examples include the application of the LEED scheme in Canada, Mexico and Brazil and Green Star in New Zealand and South Africa.

Table 1: Overview of green building rating schemes

Country	Rating Scheme	Establishment Year	Version Reviewed
Australia	Green Star	2002	Design & As Built v1.1
Australia	NABERS-IE (NABERS Indoor Environment)	2009	NABERS IE v1.0
Australia	EnviroDevelopment	2006	National Technical Standard v2.0
Australia	EarthCheck BPDS (Building Planning and Design Standard)	2014	Version 4.0
USA	LEED (Leadership in Energy and Environmental Design)	1998	LEEDv4
USA	WELL (WELL Building Standard)	2014	v1
USA	ASHRAE - 189.1	2011	2014
USA	Green Globes	2004	1.4 (Oct 2015)
UK	BREEAM (Building Research Establishment Environmental Assessment Method)	1990	V1
Japan	CASBEE (Comprehensive Assessment System for Built Environment Efficiency)	2001	New Construction v2014
Emirates	Estidama - Pearl	2010	v1.0
Hong Kong	BEAM (Building Environmental Assessment Method)	1995	BEAM Plus New Buildings v1.2
Germany	DGNB-Seal	2007	Offices v2014
France	HQE (High Quality Environmental standard)	2009	01.1/01/01/2016
Italy	Protocollo ITACA	2009	Non Residenziale 12/11/2015
China	GBES (Green Building Evaluation Standard)	2006	GB/T 50378-2014
Singapore	Green Mark	2005	Green Mark 2015
Malaysia	Green Building Index	2009	Non Residential v1.05
India	GRIHA (Green Rating for Integrated Habitat Assessment)	2007	V2015
Taiwan	EEWH (Ecology, Energy Saving, Waste Reduction and Health)	1999	2007
Indonesia	Greenship	2009	Feb-12

It is noted that many of the tools presented in Table 1 have different versions of the tool depending upon the type of building being assessed and whether it is a new build or refurbishment. To allow a comparison between tools they have been limited to tools that can be applied to new build non-residential buildings. Due to study constraints, only one rating tool from each organisation that was determined to provide a good representation of

the green rating scheme was selected. Specific details of the documentation that was reviewed for the each tool can be found in the References section at the end of this paper.

4. INDOOR ENVIRONMENTAL QUALITY (IEQ)

Table 2 presents an overview of the parameters that are considered when determining the IEQ performance of a space. It can be seen in the table that eight parameters are covered across the various tools, schemes and standards:

1. Services noise from mechanical services (e.g. air-conditioning), hydraulic services (e.g. noise from waste pipes) and electrical services (e.g. electrical hum);
2. Exterior noise from sources such as mechanical plant, road and rail traffic, aircraft flyovers, entertainment and patrons;
3. Reverberation time;
4. Floor impact isolation;
5. Acoustic separation between adjacent spaces and uses for privacy;
6. Speech transmission index (STI) and speech intelligibility;
7. Sound masking; and
8. Vibration isolation and plant and equipment.

It can be seen in Table 2 that only Green Globes contains criteria across all eight parameters. The Estidama – Pearl scheme addresses six of the parameters for schools only, as the green rating scheme references the U.K. document *Building Bulletin 93 – Acoustic Design of Schools: Performance Standards* (U.K. Department for Education 2015). The rating schemes contain criteria that must be achieved during the design process in order to achieve the rating points on offer. The approach in the schemes is fairly similar with the exception of Green Globes, which has broken the design requirements down in a set of yes/no questions that can be used to quickly determine whether the project contains the required design features for green certification.

Where the tools, schemes and standards include the comparison of services noise and exterior noise against internal design criteria they are usually assessed together, with achieving a specified internal noise level limit being the most common IEQ acoustic requirement. Internal noise level criteria mostly consist of a L_{Aeq} level across time periods varying from 5-minutes to 8-hours, with schemes such as WELL and BEAM referencing noise criteria (NC) curves and Green Globes requiring room criteria (RC) ratings.

For the mitigation of intruding noise from exterior sources, schemes such as HQE, Protocollo ITACA, GBES, and EEWH require the sound insulation of the external walls to meet specified performance levels rather than achieving an internal noise level limit.

Reverberation time is considered in 12 of the rating schemes in Table 2 where it is generally specified as a maximum or a range of times that vary depending upon the use and size of the space. The number of octaves required to be addressed to satisfy the reverberation time criteria varies from considering one or two mid-frequencies only to considering the arithmetic mean of the reverberation times in the 125 Hz to 4 kHz octave bands inclusive for DGNB-Seal. The DGNB-Seal rating scheme presents the most comprehensive criteria for reverberation, as in addition to determining the average reverberation times across several octave bands the shape factor (defined as total absorption/volume) is specified as a criterion where the ratio of the maximum room width/length to height is greater than 5. Minimum noise reduction coefficients (NRC) are specified for ceilings and walls in WELL, while CASBEE specifies the extent and distribution of absorptive materials for the ceiling, floor and walls and HQE has the option of achieving a minimum equivalent absorption area (EAA) for office spaces as an alternative to achieving the specified reverberation times.

Floor impact isolation is considered by around half of the rating schemes in Table 2. With the exception of CASBEE the tools requiring the consideration of floor impact isolation require the evaluation of the impact isolation class (IIC), weighted standardised sound pressure level ($L'_{nT,w}$) or weighted normalised sound pressure level ($L'_{n,w}$). Due to the proliferation of lightweight building structures in Japan, CASBEE uses the sound insulation grade L_r that is determined by applying data to the classification curves contained in standard JIS A 1419.2 (2000) across the 63 Hz

to 4 kHz octave bands. None of the rating schemes contain criteria specific to impact generated noise from sources such as free-weights area in a gym or a bowling alley.

Table 2: Summary of IEQ acoustic requirements

Rating Scheme	Services Noise	Exterior Noise	Reverb Time	Floor Impact Isolation	Acoustic Separation	STI/Speech Intelligibility	Sound Masking	Vibration
Green Star	Yes	Yes	Yes	No	Yes	No	No	No
NABERS-IE	Yes	Yes	No	No	No	No	No	No
EnviroDevelopment	No	No	No	No	No	No	No	No
EarthCheck BPDS	No	Yes	No	No	No	No	No	No
LEED	Yes	No	Yes	No	Yes	Yes (sound systems)	Yes	No
WELL	Yes	Yes	Yes	No	Yes	No	Yes	No
ASHRAE - 189.1	No	Yes	No	No	Yes	No	No	No
Green Globes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
BREEAM	Yes	Yes	Yes	No	Yes	No	No	No
CASBEE	Yes	Yes	Yes	Yes	Yes	No	No	No
Estidama - Pearl	Yes	Yes	Schools only	Schools only	Schools only	Schools only	No	No
BEAM	Yes	Yes	Yes	Yes	Yes	No	No	Yes
DGNB-Seal	No	No	Yes	No	No	No	No	No
HQE	Yes	Yes	Yes	Yes	Yes	No	No	No
Protocollo ITACA	Yes	Yes	No	Yes	Yes	No	No	No
GBES	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Green Mark	Yes	Yes	Yes	No	Yes	No	No	No
Green Building Index	Yes	Yes	No	No	No	No	No	No
GRIHA	Yes	Yes	No	No	No	No	No	No
EEWH	No	Yes	No	Yes	Yes	No	No	No
Greenship	Yes	Yes	No	No	No	No	No	No

Acoustic separation is the next most common acoustic IEQ parameter after the internal noise level due to service noise and exterior noise. Green Star and BREAM specify a minimum privacy index (PI) defined by:

$$D_w + L_{Aeq,T} \geq PI \quad (1)$$

where D_w is the weighted sound level difference and $L_{Aeq,T}$ the measured ambient indoor noise level in the acoustically sensitive room. In Green Star PI equals 75 while in BREAM PI equals 85 or 75 depending upon whether privacy is viewed to be critical or not. The other rating schemes that address acoustic separation specify partition performances in terms of the composite sound transmission class (STCC), sound transmission class (STC), noise isolation class (NIC), inter-room sound pressure level grade (D_r), weighted standardised level difference ($D_{nT,w}$), the apparent weighted sound reduction index (R'_w) and the weighted sound reduction index (R_w). It is interesting that the rating schemes use a variety of laboratory/theoretical parameters as well as in-situ parameters for acoustic

separation. The use of laboratory/theoretical parameters such as STC and R_w makes in-situ compliance testing impossible unless the acoustic consultant is allowed to make an adjustment to account for field conditions. Finally, EEWH is the only rating scheme that provides the option of "deemed to comply" external wall and window constructions as an alternative to achieving the specified R_w.

STI and speech intelligibility was not considered in most of the rating tools considered in this paper. Given that several of the tools apply across multiple types of buildings including educational facilities, churches, auditoriums and hospitals the absence of criteria for STI and speech intelligibility could be considered to be a major oversight. The tools appear to rely on reverberation control with the assumption that controlling reverberation will automatically result in high levels of STI and speech intelligibility.

Sound masking is only considered by three of the rating schemes. LEED and WELL consider sound masking in the context of design levels for speaker coverage and loudness, while Green Globes considers sound masking in open office areas with respect to spatial uniformity, temporal uniformity, spectrum shape and sound level.

Vibration is not considered by most of the tools. However it could be argued that structure-borne noise re-radiated as airborne noise is addressed by the services noise design criteria.

In addition to the acoustic requirements summarised in Table 2 it is important to note that in tools such as LEED which can be applied to healthcare developments the acoustic finishes to different spaces also need to be tabled. WELL also contains a measure titled Adaptable Spaces that requires the application of acoustic design principles to create a productive work environment that is free of distracting stimuli, allows for focused work and encourages short naps.

5. EXTERNAL SPACES

The assessment of noise intrusion into external recreation spaces is ignored by most of the rating schemes, with only the EnviroDevelopment and EarthCheck BPDS schemes making any reference to outdoor areas. Neither of these schemes present design criteria or design approaches for these areas but rather include general statements of intent as described in Table 3. In addition, EnviroDevelopment only requires retail and health care uses to be considered, while EarthCheck BPDS is specific to tourist accommodation.

Table 3: Rating schemes where the assessment of external spaces is required

Rating Scheme	Description
EnviroDevelopment	Have at least two designated places within centre that are located to avoid noise pollution (retail and health care only)
EarthCheck BPDS	Reduce noise pollution from building facilities that may affect guests, the community and the environment

It is noted that even though most of the green rating schemes do not consider external spaces, this does open up the possibility of obtaining additional credit points in the area of acoustics by providing an outdoor area that is "soundscaped" to provide a relaxing environment to be enjoyed by building occupants and visitors.

6. ACOUSTIC EMISSIONS

Acoustic emissions have the potential to significantly impact upon the amenity of the local environment surrounding a green rated building. For example, a typical commercial building has a variety of continuous, quasi-continuous and transient noise emission sources such as mechanical plant and equipment, carpark activities, loading dock activities, entertainment and patrons. Given that many of the green rating schemes require the assessment of air and light emissions it is reasonable to expect that noise emissions would also need to be assessed.

Table 4 shows that the assessment of acoustic emissions is required by five of the green rating schemes. Of these five schemes, only BREEAM, CASBEE and GRIHA make direct reference to an emission standard or regulation.

The absence of requirements to assess the noise emissions across most of the green rating schemes is a surprising result and might be due to:

- An assumption that local laws and regulations are adequate to ensure that noise emissions do not cause annoyance; and/or

- The difficulty in obtaining a consensus amongst rating scheme developers regarding the best way to assess noise emissions from a development.

While the IEQ of the subject building might be assured through the application of the green rating scheme, ignoring a development's potential adverse impact upon the acoustic environment due to noise emissions is considered to be a major oversight in many of the green rating schemes.

Table 4: Assessment of acoustic emissions

Rating Scheme	Assessment Required?	Description
Green Star	No	
NABERS-IE	N/A	Tool is specific to IEQ.
EnviroDevelopment	Yes	Minimise noise pollution during and post construction via use of a Construction Management Plan
EarthCheck BPDS	Yes	Reduce noise pollution from building facilities that may affect guests, the community and the environment
LEED	No	
WELL	No	
ASHRAE - 189.1	No	
Green Globes	No	
BREEAM	Yes	Noise pollution to be considered in noise-sensitive areas, noise impact assessment to be completed using ISO 1996 series.
CASBEE	Yes	Noise emission levels are assessed against the Noise Regulation Law, with a different green rating given depending whether the noise emission level is above, at or below the current regulation standard
Estidama - Pearl	No	
BEAM	Yes	Minimise nuisance to the immediate neighbourhood caused by noise during the construction of buildings and the infrastructure serving buildings.
DGNB-Seal	No	
HQE	No	
Protocollo ITACA	No	
GBES	No	
Green Mark	No	
Green Building Index	No	
GRIHA	Yes	Outdoor noise levels must conform to the CPCB (Central Pollution Control Board) – *Environmental Standards-Noise (ambient standards)*.
EEWH	No	
Greenship	No	

7. CERTIFICATION AND RECOGNITION OF A PROJECT

The documentation requirements vary significantly between the standards including the detail and stringency of the documentation required and the testing requirements as well as who performs the test (consultant test or third party tested). Regardless of on-site testing requirements, almost all of the rating systems

require some form of initial design documentation submittal. This is typically provided by the Acoustic Consultant and includes design details of how the criteria will be achieved. While some standards clearly define what a qualified acoustic consultant is, many of the standards do not have a description of who would be the responsible party.

Table 5: Pathways for certification and recognition

Rating Scheme	Design	Acoustic Testing at Completion while Unoccupied	Acoustic Testing at Completion while Occupied	Post Completion Occupancy Survey
Green Star	Yes	Optional	No	Potential
NABERS-IE	No	Yes	Yes	Yes
EnviroDevelopment	Yes	No	No	No
EarthCheck BPDS	Yes	No	No	No
LEED	Yes	No	No	Potential
WELL	Yes	Yes	Yes	Yes
ASHRAE - 189.1	Yes	No	No	No
Green Globes	Yes	Optional	Optional	Potential
BREEAM	Yes	Yes	Yes	Potential
CASBEE	Yes	Yes	Yes	No
Estidama - Pearl	Yes	Yes	No	Potential
BEAM	Yes	Yes	Yes	No
DGNB-Seal	Yes	Yes	Yes	No
HQE	Yes	No	No	No
Protocollo ITACA	Yes	No	No	No
GBES	Yes	No	No	Potential
Green Mark	Yes	No	No	No
Green Building Index	Yes	Yes	Yes	Yes
GRIHA	No	Yes	Yes	No
EEWH	Yes	No	No	No
Greenship	No	Yes	Yes	Yes

Acoustic testing may be required with or without occupancy depending on the project circumstances as well as the particular rating that is being pursued. For example, within the WELL Building Standard acoustic testing is done without occupancy for a Core and Shell Building but requires at least one (1) month of occupancy for an Interiors Certification. Some of the rating tools provide an option to pursue testing, for example Green Star will require a commissioning report which includes the measured noise levels in the space.

Post-occupancy surveys including qualitative acoustic comfort feedback in many cases are used as “innovation” points in a separate category of the rating tools. The certification systems where a post-occupancy survey can be included as an additional point are listed as “potential” in Table 5. The strictest criteria in this regard are from NABERS-IE and WELL which both require a compulsory post-occupancy survey administered by a recognised third party provider such as the University of California (CBE) or University of Sydney (BOSSA).

8. IMPORTANCE OF ACOUSTICS IN THE GREEN RATING SCHEMES

Table 6 provides an indication of the importance of acoustics in each of the green rating schemes. The table identifies whether there are minimum acoustic requirements, the number of points assigned to acoustics and the overall number of points available across all variables along with the weighted value in the rating system used by each scheme. Points related to post-occupancy surveys are not included in Table 6 even if they include an acoustic component, as those surveys are not specific to acoustics.

It can be seen in Table 6 that for over half of the schemes there are no minimum requirements for acoustics. On a project where the required number of points can be achieved without considering acoustics, value management can be used to remove acoustic treatments to the detriment of the overall quality of the building.

Table 6: Importance of acoustics in rating scheme

Rating Scheme	Is there a min. requirement?	Number of Points for Acoustics	Total Number of Points Possible	Weighted Value in System (%)
Green Star	No	3	110	2.72
NABERS-IE	Yes	1	5	20.00
EnviroDevelopment	No	1	123	0.81
EarthCheck BPDS	No	1	80	1.25
LEED	No	1	110	0.91
WELL	Yes	6	102	5.88
ASHRAE - 189.1	There are no points			
Green Globes	No	29	1000	2.90
BREEAM	No	4	110	3.63
CASBEE	Yes	0.086	2	4.30
Estidama - Pearl	No	2	177	1.13
BEAM	No	5	128	3.91
DGNB-Seal	No	1	111	0.90
HQE France	Yes	6	442	1.35
Protocollo ITACA	No	1	33	3.00
GBES	No	3.3	110	3.00
Green Mark	No	2	140	1.42
Green Building Index	No	1	100	1.00
GRIHA	No	2	104	1.92
EEWH	No	3	100	3.00
Greenship	No	1	101	0.99

The sustainability ratings studied consider acoustics on average to be 1 % to 4 % of the total value of the rating system. The exceptions are rating systems that are not based on sustainability as a whole but focus on IEQ. The rating scheme that places the highest emphasis on acoustics is NABERS-IE with a weighted value of 20%, while the second highest emphasis is applied by WELL at 5.88%. Both of these rating schemes are geared towards IEQ which accounts for the higher importance assigned to acoustics.

It is surprising that LEED which is one of the biggest and most highly regarded green rating schemes only applies a weighting of 0.91% to acoustics. This low weighting and the absence of the assessment of intruding noise (refer Table 2) indicates that the acoustic design requirements outlined in LEED are inadequate.

Table 6 excludes any points related to a post-occupancy survey which would have an acoustic component. In

some rating systems such as Green Star and LEED this is a credit that would be included within the Innovation Category. Since it is not a direct requirement for acoustics, it has been excluded. Table 6 accounts for all possible or potential points in the rating system, including in the total any "innovation" or "bonus" points possible.

9. CONCLUSIONS

Based upon the comparison presented in this paper it is clear that none of the green rating schemes address all potential acoustic design requirements associated with green buildings. The Green Globes scheme currently provides the most comprehensive assessment of IEQ with respect to acoustics. The "yes/no" question approach used by that scheme is unique amongst the schemes reviewed in this paper and allows design professionals to easily identify ways the acoustic design can be enhanced while achieving a higher green rating.

Many of the schemes provide an inconsistent evaluation of the acoustic IEQ whereby important parameters that contribute towards acoustic quality are ignored. This inconsistent approach, coupled with the use of criteria specified in terms of laboratory/theoretical parameters rather than in-situ parameters, may allow potential acoustic design requirements to be avoided and results manipulated to obtain the green rating points on offer for each scheme.

To ensure that the acoustic design has been properly implemented acoustic testing at completion is preferred over a design report. As acoustics is guided by empirical evidence due to the complexity of the interactions that occur in reality only in-situ testing can provide a definitive confirmation that the design criteria have been achieved. There are difficulties in conducting acoustic testing at completion – if the testing is completed while unoccupied, the test conditions may not match those of the occupied building in terms of the furnishings and finishes that contribute to the acoustic environment. If testing is conducted post-occupation, the use of L_{eq} and L_{max} parameters creates difficulties as they can be influenced by occupant activities such as the use of telephones, loud conversations, playing of music etc. A post-occupancy survey in addition to the post-construction in-situ acoustic testing is a valuable tool to help refine the design criteria and acoustic standards to meet the expectations of the building stakeholders.

Given that acoustics is one of the factors by which occupants rate the quality of a building and is critical to ensuring occupant comfort and productivity, the absence of a minimum acoustic design requirement in many of the schemes helps to explain why a lower rating is generally achieved for acoustics in green buildings as reported by Newsham et al. (2013). In addition, with the exception of NABERS-IE and WELL it can be argued that acoustics is under-represented in terms of its environmental impact, as the weighted values in the rating tools, schemes and systems are below the importance occupants and the general public place on acoustic amenity.

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