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Association between green building certification level and post-occupancy performance: Database analysis of the National Australian Built Environment Rating System

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ABSTRACT

This study aims to understand the improvement in building performance vis-à-vis a rise in green building certification levels. It investigated the National Australian Built Environment Rating System (NABERS), one of the few government initiatives that rates energy performance, emissions, water consumption, and indoor environment quality (IEQ) separately based on their corresponding post-occupancy data. A set of 2657 certified records of office buildings and their performance data acquired from the NABERS database were analysed. Performance indicators for the analysis were energy use intensity (EUI), emission intensity (EMI), water consumption intensity (WCI), and indoor environment quality score (IEQS). The results revealed a linear relationship between each indicator's performance data and certification level—a one-level rise reduced EUI, EMI, and WCI by 184.45 MJ/m^2, 41.94 kgCO_2-eq/m^2, and 0.24 t/m^2, respectively, per year on average. On the other hand, further rise in the level made the reduction less significant. The reduction also varied from the baseline, which is related to climatic and socioeconomic factors. This study also found that rise in IEQ and energy certification levels correspondingly raised the ratio of IEQS to EUI and EMI, indicating quality/load. Thus, compared with other major green building rating systems, NABERS could differentiate building performance more effectively using different certification levels. This study addresses the baseline issue as well and provides suggestions to improve NABERS and other green building rating systems.

1. Introduction

Buildings not only account for a large amount of energy consumption and carbon emissions [1] but also have specific impacts on the economy and ecology [2]. They consume a lot of natural resources, such as land and water, and also produce harmful substances [3,4]. To address the global challenge brought by energy and environmental issues, the concept of green building has been proposed and has developed rapidly over the past decades [5]. Green buildings are designed, constructed, and operated to improve occupants' satisfaction and well-being, and reduce the utilization of natural resources as well as the adverse impact on environment [6].

Currently, different countries have their own green building rating system, aimed at their respective national conditions as well as the global market [2]. The most representative one is US′ Leadership in Energy and Environmental Design (LEED) [7]. Others include UK's Building Research Establishment Environmental Assessment Method (BREEAM) [8], China's Assessment Standard for Green Building (ASGB) [9], Australia's Green Star [10], Japan's Comprehensive Assessment System for Built Environment Efficiency (CASBEE) [11], and Germany's German Sustainable Building Council (DGNB) [12]. The different systems and their indicators are shown in Table 1—the ratings awarded usually range from 4 to 6.

With more and more projects being certified through these rating systems, studies have been conducted to verify whether the certified green buildings display better operational performance than non-green ones, and how the system of levels differentiates it. The related literature is given in Table 2. These studies have compared the performance of green buildings with that of non-green ones, regional baseline, regional average values, and target values.

In terms of energy use, when compared with the baseline, most green buildings have displayed better energy performance [13,14]; when compared with the regional average value, they have showed lower energy use intensity (EUI) [13,15,16], indicating a greater contribution to local energy saving [17]. However, when compared with non-green

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Abbreviations

ANOVA	Analysis of Variance
BASIX	Building Sustainability Index
BEE	Built Environment Efficiency
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
DGNB	German Sustainable Building Council
DPIE	Department of Planning, Industry and Environment
EEWH	Ecology Energy Saving Waste Reduction Health
EMI	Emission Intensity
ER	Energy Rating
EUI	Energy Use Intensity
GBP	GreenBuilding Programme
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
IEQS	IEQ Score
KGBC	Korean green building certification criteria
LEED	Leadership in Energy and Environmental Design
ASGB	Assessment standard for green building
NABERS	National Australian Built Environment Rating System
NatHERS	Nationwide House Energy Rating Scheme
Tukey	HSD Tukey Honest Significant Differences
WCI	Water Consumption Intensity

Table 1
Comparison between different green building rating systems.

Rating Tools	Country	Level	Indicators
LEED v4	U.S.	Certified; Sliver; Gold; Platinum	Location & Transportation; Sustainable Sites; Water Efficiency; Energy & Atmosphere; Material & Resource; IEQ; Innovation; Regional Priority; Integrative Process
BREEAM	Britain	Acceptable; Pass; Good; Very Good; Excellent; Outstanding (1–6 Stars)	Energy; Health & Well-being; Innovation; Land Use; Material; Management; Pollution; Transport; Waste; Water
ASGB 2014	China	Design One Star; Design Two Stars; Design Three Stars; Operation One Star; Operation Two Star; Operation Three Star;	Land Conservation; Energy Conservation; Water Conservation; Material Conservation; IEQ; Construction Management; Operational Management;
Green Star	Australia	1 Green Stars; 2 Green Stars; 3 Green Stars; 4 Green Stars; 5 Green Stars; 6 Green Stars	Management; IEQ; Energy; Transport; Water; Material; Land Use & Ecology
CASBEE	Japan	Superior (S), Very Good (A), Good (B+), Slightly Poor (B-), Poor (C)	Building Environmental Quality & Performance; Building Environmental Loadings
DGNB	Germany	Bronze; Silver; Gold; Platinum	Environmental Quality; Economic Quality; Sociocultural & Functional Quality; Technical Quality; Process Quality; Site Quality

buildings, the literature is divided—some studies have indicated that green buildings showed a better energy performance [18], while others have suggested that they did not save energy, or even consumed more of it [19,20]. This might be because green buildings have a higher occupancy rate, or more personal computers, making them more energy-intensive [21]. Some researchers have pointed out that proper optimization of air conditioning systems and adoption of passive design could contribute to saving more energy [20]. As for whether a higher certification level could result in better energy performance, there is no consensus yet [15,21]. Some studies have supposed a relationship between the certification level and energy use, while others have not proved that [14,19]. The reason for this might be that these studies have correlated energy use with the overall certification level, while some green buildings with high overall level might gain credits for aspects other than energy [19]. In addition, there also exists a gap between the post-occupancy data and design values of energy use due to personnel behaviour [22]. Therefore, it is more meaningful to conduct a comparison between specific performance data and their dedicated certification level.

In terms of overall satisfaction with indoor environment quality (IEQ), some studies have indicated that it was higher in green buildings than in non-green ones [23–29], while others have said there was no significant difference [30]. With respect to specific IEQ indicators, green buildings have been found to possess better thermal comfort [23,24,28], despite some studies disagreeing with this conclusion [26] and finding green buildings' thermal comfort not up to standard [31]. Most of the studies have found that green buildings had better IAQ than non-green ones [23,24,28], while some scholars have said there was no significant difference [30]. In addition, some studies have found that green buildings had a better lighting environment [23,24], while according to others, it was poorer [30]; the same—that is, contrasting results—has been suggested with respect to the acoustic environment [20,23,26,28]. The reason for this inconsistency could be occupants' high expectation vis-à-vis IEQ in green buildings [32] and some technical deficiency [33]. Noticeably, most studies on IEQ have compared green buildings with their non-green counterparts, while the IEQ performance vis-à-vis the different levels is yet to be evaluated.

In general, previous studies have provided critical evidence that green buildings' post-occupancy performance had important practical implications: to outperform the conventional buildings, or achieve certain performance targets. These studies indeed have certain benefits: some have a large amount of data [15,16,19,21,22,24,30]; some have carried out multiple comparison, such as baseline, regional average values, target values, and so on [13–15,19,21,24,34]; and some have analysed different parameters, such as energy use, emission, water use, and IEQ [13,17,20,21]. However, they have several critical gaps as well, and that is what motivated this study—first, there is little evidence to confirm whether green buildings with higher certification levels give a better performance [14,15,19,21]; second, most of the studies focus on energy performance and IEQ, and only a few involve the other indicators, such as water consumption [13,17]; third, most green building rating systems investigated were originally for optimizing design intent, and hence, the research on verifying the post-occupancy performance may have limited implications for improving these tools in a realistic way; and last but not the least, all of these studies have used the overall certification level instead of a dedicated one to verify its related building performance indicator.

This study, for the first time, examines the National Australian Built Environment Rating System (NABERS) [35], one of the few such in the world assessing the performance indicators building energy, emission, water, and IEQ separately based on their corresponding post-occupancy data. It is hoped that this investigation of NABERS enriches the green building post-occupancy performance research. In particular, this study correlates the certification level with its corresponding building performances, to find out whether and to what extent a higher level can help to improve the overall performance.

This paper is laid out thus: section 2 introduces NABERS, and section 3 the method of data collection and analysis; section 4 discloses the results, and section 5 discusses the results along with domestic and international studies, providing suggestions on green building rating systems, followed by the study's implications and limitations; section 6 presents the conclusion and significance of the research.

2. NABERS

To achieve the target of reducing greenhouse gas emissions by at least 26% from their 2005 level by 2030 [36], the Australian government has introduced several rating tools to evaluate and improve building performance; these are Green Star [10], launched by the Green Building Council; Building Sustainability Index (BAXIS), which is being applied to residential dwellings in New South Wales (NSW) [37]; Nationwide House Energy Rating Scheme (NatHERS), a star-based system that rates a home's energy efficiency [38]; and NABERS, which is a national programme managed by the NSW Department of Planning, Industry and Environment (DPIE) under the guidance of the Federal Government. NABERS provides a set of rating tools that measure the environmental performance of buildings—energy efficiency, carbon emission intensity, water usage, waste management, and IEQ. It is worth reiterating that NABERS measures the actual impact of a building, rather than the design intent [39].

NABERS sets more nuanced levels than other systems, ranging from 0 to 6 stars with 0 indicating the non-certified, and 1 to 6 representing poor, below average, average, good, excellent, and market leading performance. It also has 0.5 star, so there are 12 levels for each performance indicator. At present, most NABERS buildings are office

Table 2
Literature about green building post-occupancy performance.

Reference	Rating Tool	Database	Performance	Comparison	Key results
[13]	LEED	22 LEED buildings	Energy, water use	Baseline, regional average value and target value	EUI 25% better than the baseline, 10% better than regional average value, 13% better than target value; water use 11% better than the baseline.
[18]	LEED	24 LEED buildings	Energy	Non-LEED buildings	EUI 12% better than traditional buildings.
[15]	LEED	121 LEED buildings	Energy	National average value, different rating tiers	EUI 24% better than the national average value for the 121 buildings; EUIs are scattered in the certification levels; there is certain relationship between EUI and certification level.
[19]	LEED	100 LEED buildings	Energy	Non-LEED buildings, rating tiers	EUI 18–39% better than non-LEED buildings; 28–35% of LEED buildings use more energy than non-LEED buildings; EUI of LEED building has little correlation with the certification level.
[21]	LEED	953 office buildings of which 21 are LEED	Energy, emission	Non-LEED buildings, rating tiers	LEED buildings use the same amount of energy and emit the same amount of GHG with non-LEED buildings; there is relationship between EUI and certification level.
[20]	Three Stars	10 green office buildings and 31 non-green office buildings	Energy, IEQ	Non-green buildings	Only mix-mode green buildings have lower EUI compared with non-green buildings; Green buildings have higher occupants' satisfaction, especially thermal comfort, IAQ.
[16]	GBP in Europe	300 green buildings	Energy	Average value	Green buildings saved 304 GWh/year. The energy performance of green buildings outperforms the average value in corresponding countries.
[14]	LEED	21 LEED buildings	Energy	Baseline, rating tiers	The sample saves 27% of the energy compared to the baseline values; the certification level is not correlated with actual energy savings.
[22]	LEED	117 LEED buildings	Energy	Target value	The actual building energy performance could deviate from the intended performance based on the design.
[17]	LEED	2 LEED-v2.2 buildings	Energy, water use	Regional contribution	Both two buildings contributed to local sustainable development goals
[23]	EEWH	5 office buildings in Taiwan of which 3 are green buildings	IEQ and Satisfaction	Non- green buildings	Green buildings have better overall IEQ, acoustics environment, lighting environment, thermal comfort and IAQ.
[24]	Three Star	1892 response from green buildings while 2194 from non-green buildings	IEQ and Satisfaction	Non-green buildings, other rating tools	Three Star building users are more satisfied with IEQ and all IEQ indicators; the effects of LEED or BREEAM on occupants' satisfaction are not as marked as that of Three-Star certification.
[25]	Green Star	2 green campus office buildings	IEQ and Satisfaction	Non-green building	Green building users are more forgiving of the IEQ.
[26]	LEED and ASGB	2 green office buildings and a non-green office building	IEQ and Satisfaction	Non-green building	Green buildings have better satisfaction with overall IEQ. Green buildings have higher satisfaction with thermal comfort in summer while lower satisfaction with thermal comfort in winter. Green buildings have poorer acoustic environment.
[30]	LEED	144 office buildings of which 65 are LEED	IEQ and Satisfaction	Non- LEED building	There is no significant difference of satisfaction with overall IEQ, IAQ between LEED and non-LEED buildings; occupants feel more dissatisfied with the lightning environment.
[28]	ASGB 2014	10 green office buildings and 42 non-green office building	IEQ and Satisfaction	Non-green building	Green buildings possess significantly higher satisfaction than the non-green buildings at the aspect of thermal, visual, acoustic environment, IAQ and the overall environment.
[27]	KGBC	2 green office buildings and 2 non-green office building	IEQ and Satisfaction	Non-green building	Occupants' overall satisfaction is higher in green buildings.
[34]	LEED and ASGB	9 green office buildings and 5 non-green office building	IEQ and Satisfaction	Non-green building, rating tiers	Rating systems do not guarantee an actual comfortable, healthy and productive space for the occupants, especially buildings with a low certification level.
[31]	LEED and ASGB	3 LEED buildings and 9 ASGB buildings	Thermal Comfort and Satisfaction	Target values	Indoor temperature and humidity of most buildings did not meet the standard, while the occupants were generally satisfied with the indoor environment.
[29]	LEED	3 LEED buildings and 3 non-green buildings	IEQ and Satisfaction	Non-green building	The occupants in green buildings had higher satisfaction with IEQ compared with non-green buildings

premises, so this study mainly focuses on the rating rules for those. The system comprises four performance indicators, namely energy, water, waste, and IEQ ratings. Fig. 1 shows these indicators and their measurements.

For the energy rating, the number of stars for offices is calculated based on benchmarking the energy consumption (electricity, gas, and fuel oil) and comparing it with that of other buildings in the same category, using 12 months of post-occupancy data. To be comparable, the consumption data are adjusted for building area (eq. (1)), hours of use (eq. (2)), climate, equipment density (eq. (3)), and greenhouse intensity of the energy source. The benchmarking indicators are calculated by applying correction indicators to the post-occupancy energy use of the rated premises. The certification level for energy is determined in comparison with the correction values of each building.

For the water rating, the number of stars for offices is calculated based on benchmarking the water consumption and comparing it with that of other buildings in the same category, using 12 months of post-occupancy data. To be comparable, the consumption data are adjusted for building area (eq. (1)), hours of use (eq. (2)), and climate [40]. Similar to the energy rating, the benchmarking indicators are calculated by applying correction indicators to the post-occupancy water consumption of the rated premises, and the certification level for water is determined in comparison with the correction values of each building. The equations used for energy and water ratings are given below:

$$A = \sum_{i=1}^{N} o_i a_i \quad .(1)$$

where: A is rated area (m^2); i is each functional space; a_i is floor area of each functional space (m^2); o_i is the proportion of the rated period that the space was occupied.

$$H = \frac{\sum_{i=1}^{N} h_i o_i a_i}{A} \quad (2)$$

where: H is rated hours (hours/week); A is rated area (m^2); i is each functional space; h_i is hours allocated to each functional space (hours/week); a_i is area of each functional space (m^2); o_i is the proportion of the rated period that the space is occupied.

$$s = \sqrt{\frac{\sum_j \left[(x_j - X)^2 a_j \right]}{a - 0.05A}} \quad (3)$$

where: j is the number of spaces surveyed to date; A is the total area subject to the sampling methodology, and $a = \sum_j a_j$.

For the IEQ rating, NABERS measures five key indoor environment parameters—thermal comfort, air quality, acoustic comfort, lighting comfort, and layout. Each parameter is scored separately, to identify the outperforming and underperforming ones [41]. The parameters are weighted differently depending on their impact on occupants. The scores of each are calculated based on the building's performance compared with other offices [41]. The overall IEQS (indoor environment quality score) is calculated by the weight of scores for each parameter. The IEQ certification level is then determined based on the overall IEQS awarded to the building and benchmarked against market performance.

Table 3
Parameters and weights for IEQS.

IEQ parameters	Site visit measurement		Occupants' satisfaction		Total weights
	Parameters	Weights	Survey	Weights	
Thermal comfort	Air temperature Mean radiant temperature Relative humidity Air speed	50%	Perceived thermal comfort	50%	30%
IAQ	Ventilation effectiveness	20%	Perceived comfort in relation to air quality	50%	30%
	PM_{10}	10%			
	Formaldehyde	10%			
	TVOCs	5%			
	CO	5%			
Acoustic comfort	Sound levels in occupied space	50%	Perceived comfort in relation to sound levels	50%	15%
Lighting	Horizontal light levels	50%	Perceived comfort in relation to lighting levels	50%	15%
Office layout	–	–	Perceived satisfaction in relation to the physical layout of the office space	100%	10%

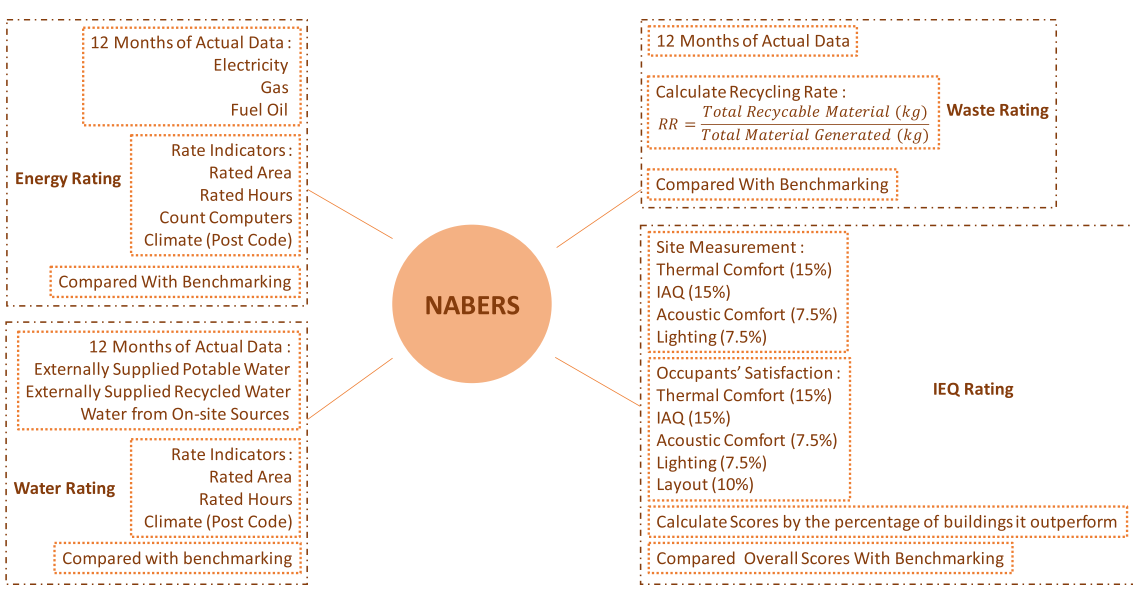


Fig. 1. NABERS performance indicators and measurements.

Table 3 shows the parameters and weights of each measured by the IEQ rating to calculate IEQS.

As for the waste rating, NABERS mainly focuses on the environmental impact of operational waste materials leaving a building [42]. The fundamental calculation is the recycling rate based on 12 months of waste data. This rate measures the extent to which materials leaving the building are diverted from a landfill; it is calculated using the ratio of total recyclable material to total material generated, and is compared with the benchmark to determine the certification level for waste.

Currently, NABERS has given out over 2600 ratings for around 1300 office buildings. Approximately 70% of offices in Australia are using NABERS energy rating to measure and promote their energy and carbon efficiency. Since 2010, NABERS-rated buildings have reduced carbon emissions by more than 380,000 tonnes and saved 1.6 million litres of water [39]. Although several studies have introduced NABERS [43,44], a detailed analysis of its performance is missing.

3. Methodology

3.1. Data sources

The NABERS database comes from its website, which comprises more than 2600 rating records of office buildings—1742 energy, 750 water, 27 waste, and 98 IEQ (Table 4). The database also includes the exact locations and sizes for all the records. The main performance indicators related to the energy rating are EUI and EMI—the former is the annual electricity, gas, and fuel oil consumption per square metre, and the latter is the equivalent annual carbon emissions from lighting (interior, exterior, and signage), air conditioning and ventilation (office and car park), power for equipment, generator fuel, lift and escalator, and so on per square metre. The main performance indicator related to the water rating is water consumption intensity (WCI), the annual quantity of externally supplied potable water, externally supplied water, and water from on-site sources per square metre. The detailed calculation methods can be found in Ref. [45]. The main performance indicator related to the waste rating is the recycling rate, while that related to the IEQ rating is IEQS, which is the overall score of thermal comfort, acoustic comfort, lighting, and layout scores (as shown in Fig. 1). Past year's data on these indicators for each rating record are in the database—considering the small amount of data related to waste rating, we have excluded it and only analysed energy, water, and IEQ ratings. Besides the rating record and related indicators, basic information, such as location, has also been acquired from the database.

3.2. Analysis techniques

To better understand the differences in EUI, EMI, WCI, and IEQS amongst the different certification levels, a series of analyses was carried out as shown in Fig. 2.

First, analysis of variance (ANOVA) and the Kruskal-Wallis test were carried out by using Rstudio. ANOVA, also known as 'variance analysis' or 'F test', is used to test the significance of the differences between two or more variables [46]. The Kruskal-Wallis test works better when the data are less and not distributed normally [47]. If the results of ANOVA and the Kruskal-Wallis test are significant, it is an indication of significant differences in EUI, EMI, WCI, and IEQS amongst the different levels.

Table 4
Statistics of NABERS rating database.

Performance rating	Energy Rating (0–6)	Water Rating (0–6)	Waste Rating (0–6)	IEQ Rating (0–6)
Performance data	EUI & EMI	WCI	Recycle Rate	IEQS
Number of Buildings	1740	750	27	98

To define the range of the levels, this study adopted the Tukey Honest Significant Differences (Tukey HSD) by using Rstudio to determine the differences scale. It is used to create a set of confidence intervals on the differences between the means of the levels of an indicator with the specified family-wise probability of coverage [48].

To verify the variation law of EUI, EMI, WCI, and IEQS with the variation of different levels, linear regression models were adopted. For the regression models, the independent variable was the certification level of a performance indicator (energy, water, and IEQ), and the dependent variable was average values of the corresponding post-occupancy performance data (EUI, EMI, WCI, and IEQS) at this level. Considering the wide range of data of the 0 rating, the regression models did not take this level into account. The regression models can be written as [49]:

$$y = \beta_0 + \beta_1 x + \varepsilon \quad .(4)$$

where y is EUI, EMI, WCI, and IEQS, respectively, and x the corresponding rating.

The output parameters were 'Estimate', 'Intercept', 'R^2', 'Adjusted R^2', and 'Standard Error'. In the above equation, 'Estimate' is 'β_1', which means improvement in EUI, EMI, WCI, or IEQS with a one-level rise in certification, and 'Intercept' is 'β_0', which indicates EUI, EMI, WCI, and IEQS, respectively, when the rating is 0. 'Standard Error' describes the degree of dispersion of the mean sampling distribution and measures the size of the mean sampling error. Both 'R^2' and 'Adjusted R^2' present the significance of the regression models. The results of the linear regression models can be used to predict the post-occupancy performance of NABERS buildings.

3.3. Analysis strategies

3.3.1. Cities

Australia is a large territory with complex climates—the eastern part has a humid subtropical climate, the western has Mediterranean, the northern has a tropical savanna one, while the southern usually sees oceanic climate [50]. In addition, every city has its own population structure and financial situation, which may result in different EUI, EMI, and WCI [51,52]. Therefore, it is necessary to analyse NABER buildings according to the different cities. In this study, based on the demographic [53], climate [54], and the number of samples, six major cities were selected—Sydney, Melbourne, Brisbane, Perth, Adelaide, and Canberra. Because the number of those that have obtained IEQS was not high enough, the number of IEQ ratings in different cities was too small to be representative. Therefore, in this study, we only analysed EUI, EMI, and WCI for the selected cities. The basic information of the sample buildings and the climatic characteristics of each city are shown in Table 5. The number of rating records of each level and city are shown in Table 6. Considering the climatic characteristics of each city, the highest to the lowest, rank-wise, of the energy rating benchmark were Melbourne, Canberra, Sydney, Adelaide, Brisbane, and Perth, and the detailed benchmark can be found in Ref. [52]. In terms of the water rating benchmark, the highest to the lowest, rank-wise, were Brisbane, Sydney, Perth, Adelaide, Melbourne, and Canberra, and the specific benchmark can be found in Ref. [51].

To analyse the differences in EUI, EMI, and WCI in different cities, ANOVA, the Kruskal-Wallis test, and Tukey HSD were carried out through Rstudio, and the analysis processes are shown in Fig. 3. Next, linear regression models were adopted to establish the relationship between EUI, EMI, WCI, and their corresponding certification levels in different cities. The results reveal the impact of the certification level on EUI, EMI, and WCI in different cities.

3.3.2. Built Environment Efficiency

To better establish the relationship between energy and IEQ, Built Environment Efficiency (BEE) was adopted. This concept was first

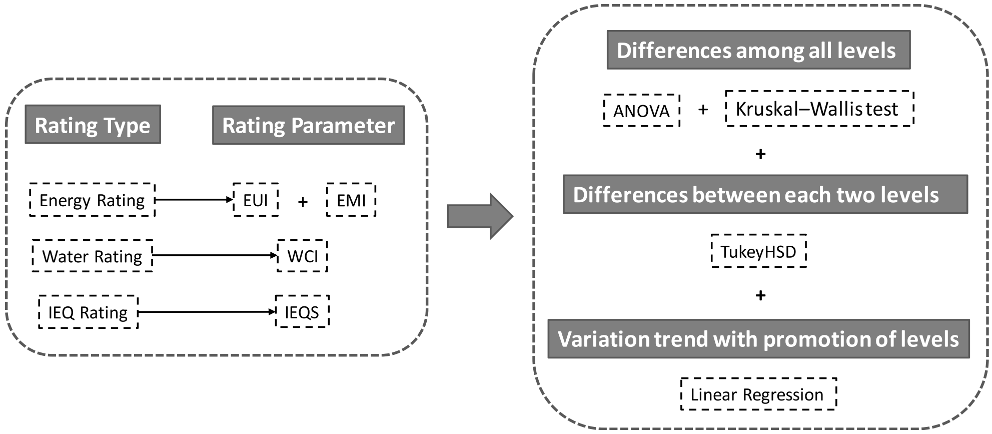


Fig. 2. Analysis methods of rating parameters among different certified levels.

Table 5
Information of sample buildings and the climate characteristics of each city.

Cities	Number of Rating		Building Area (m^2)				Climate	Degree Days (°C·d)		Temperature (°C)	
	Energy	Water	Max	Avg.	Min	Std.		HDD	CDD	Average High	Average Low
Sydney	502	262	10,252,267	45,271	61	499,160	Humid Subtropical Climate	1000	500	26.5	8.7
Melbourne	306	116	173,183	15,448	177	21,214	Oceanic Climate	1500	250	26.6	7.1
Brisbane	229	94	118,346	11,508	345	15,332	Humid Subtropical Climate	250	1000	29.1	8.2
Perth	219	135	74,907	7795	111	9888	Hot-Summer Mediterranean Climate	500	500	31.2	7.8
Adelaide	103	19	34,478	7961	72	7334	Hot-Summer Mediterranean Climate	1000	250	29.6	7.6
Canberra	119	48	44,568	11,519	210	11,118	Oceanic Climate	1500	250	28.7	0.2

Table 6
The number of rating records of each level for each city.

Rating		Sydney	Melbourne	Brisbane	Perth	Adelaide	Canberra
Energy Rating	0 Stars	15	7	14	16	2	3
	1 Star	8	3	6	3	2	2
	1.5 Stars	3	4	3	1	NA	1
	2 Stars	10	9	6	11	2	3
	2.5 Stars	17	13	9	7	2	5
	3 Stars	24	32	15	13	11	3
	3.5 Stars	29	32	19	29	10	6
	4 Stars	61	54	29	29	16	20
	4.5 Stars	100	55	40	43	27	23
	5 Stars	143	54	55	52	18	36
	5.5 Stars	75	30	27	15	11	12
	6 Stars	17	13	6	NA	2	5
Water Rating	0 Stars	5	3	1	6	1	5
	1 Star	2	NA	NA	1	NA	3
	1.5 Stars	2	NA	1	4	1	NA
	2 Stars	11	4	1	1	1	4
	2.5 Stars	21	11	NA	10	2	2
	3 Stars	46	23	6	11	1	3
	3.5 Stars	68	20	16	27	5	7
	4 Stars	67	19	47	31	3	9
	4.5 Stars	27	16	15	28	4	7
	5 Stars	6	14	3	13	1	5
	5.5 Stars	4	3	3	3	NA	2
	6 Stars	3	3	1	NA	NA	1

introduced in Japan's CASBEE [11]. BEE is calculated based on two indicators: built environmental quality (Q) and built environmental loads (L) (eq. (5)).

$$BEE = \frac{Q(Built\ Environmental\ Quality)}{L(Built\ Environmental\ Load)} \tag{5}$$

In this study, IEQS was regarded as Q, and EUI and EMI as L; so the equation can be written as:

$$BEE_{EUI} = \frac{Q(IEQS)}{L(EUI)} \quad .(6)$$

$$BEE_{EMI} = \frac{Q(IEQS)}{L(EMI)} \quad .(7)$$

In this study, 98 IEQS records and 98 corresponding EUI and EMI records were used to calculated BEE_{EUI} and BEE_{EMI}. These records were from NABERS office buildings all over Australia, mainly concentrated in major cities such as Sydney, Melbourne, Brisbane, Perth, and Adelaide.

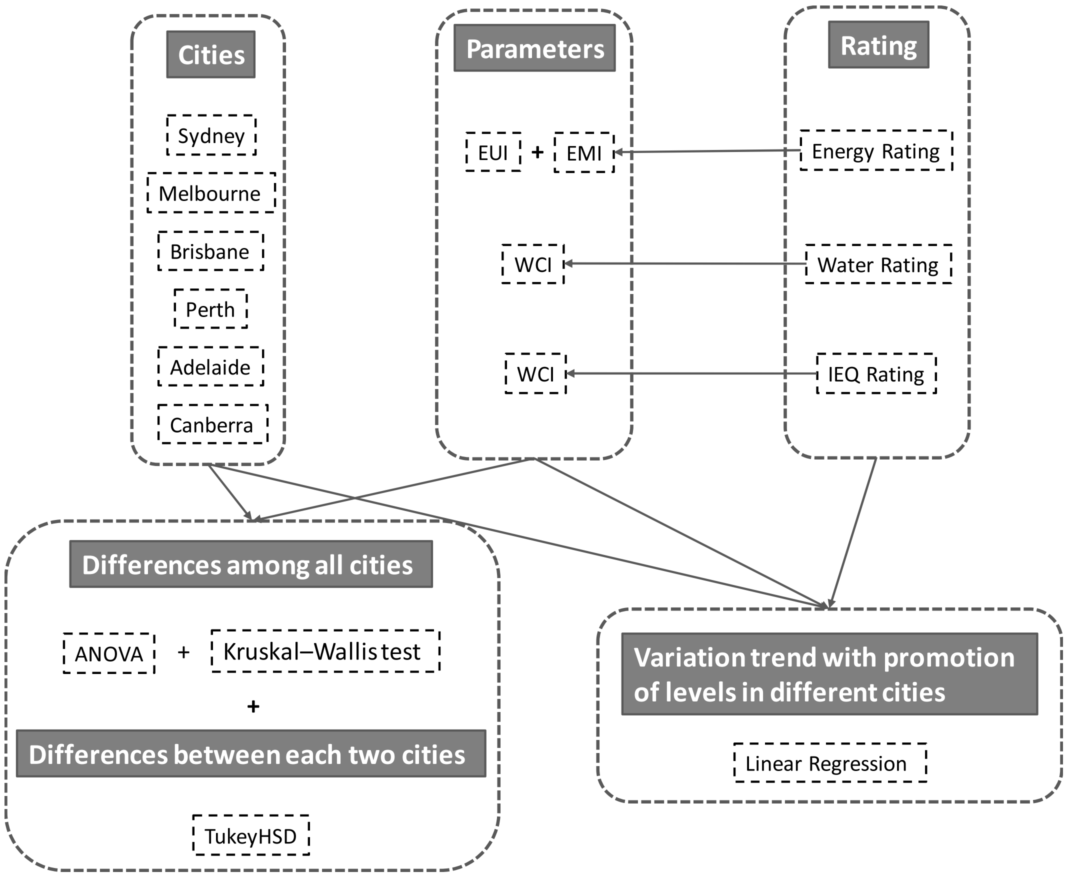


Fig. 3. Analysis methods of rating parameters among different cities.

This study establishes the relationship between BEE and certification level through linear regression models to understand whether higher levels can contribute to a better BEE—if they can, NABERS can be considered as a feasible and effective tool to evaluate and enhance energy and IEQ performance of office buildings in Australia; in other words, it stays true to the concept of green building: low energy use while ensuring a high-quality environment.

4. Results

4.1. Data overview

The basic statistics, including maximum, median, minimum, and mean values, and standard deviation of EUI, EMI, WCI, and IEQS of different types of buildings are given in Table 7. There are some offices with rather low EUI, possibly because of their low occupancy rate.

The 95% confidence intervals of different ratings are presented in Fig. 4. In general, the relationships between the energy certification and EUI, energy certification and EMI, and water certification and WCI are quite the same: as the level goes up, the consumption decreases.

Table 7
Basic statistics of data.

Parameters	Maximum	Median	Minimum	Mean	Standard Deviation
EUI (MJ/m^2 per year)	5742	404	52	518.9	191.75
EMI (kgCO$_2$-eq/m^2 per year)	1617	88.81	5.95	114.8	429.48
WCI (t/m^2 per year)	3.99	0.66	0.07	0.77	0.56
IEQS	72.5	60.96	25.6	59.2	9.08

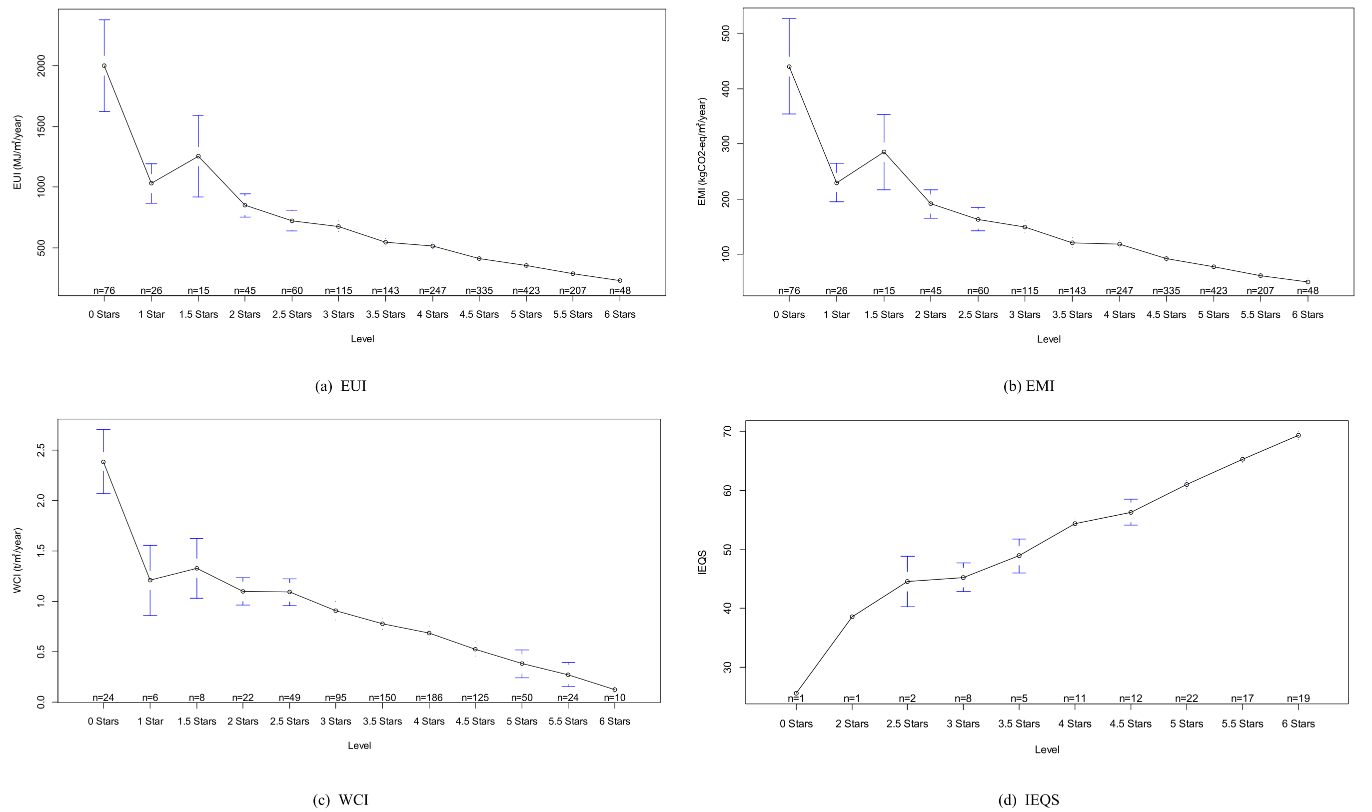
However, EUI, EMI, and WCI of 1.5 stars are slightly higher than those of 1 star. This is because different regions have different baselines for each level, and the baseline of 1 star in some regions is even lower than that of 1.5 in other regions [51,52], which also proves that analysis for different cities is necessary. In terms of IEQS, it increases as the IEQ certification level goes up.

The Tukey HSD results of different levels are shown in Fig. 5. In terms of energy performance, as the energy certification level goes up, differences in EUI and EMI become less significant. The same trend can be observed for water; IEQSs of different IEQ certification levels, on the other hand, are significantly different.

The results of regression models (Table 8) reveal that the models are acceptable with statistical significance. When the energy certification goes up one level, EUI decreases by 184.45 MJ/m^2 and EMI by 41.94 kgCO$_2$-eq/m^2, per year; when the water certification goes up one level, WCI decreases by 0.24 t/m^2 per year; when the IEQ certification goes up one level, IEQS increases by 7.49. The weighted estimate has been calculated by modifying the values of EUI, EMI, WCI, and IEQS to a certain range and establishing the regression between the modified values and certification levels. Based on this estimate, promotion of the water certification has the most favourable impact on WCI, while that of the IEQ certification has the least favourable impact on IEQS. The results in the table can also be used for EUI, EMI, WCI, and IEQS prediction by adopting equation (1) in section 3.2—for example, the prediction equation for EUI can be written as: $y = 1270.5\text{–}184.45x$, where y represents EUI and x the corresponding rating.

4.2. Major cities

Sydney, Melbourne, Brisbane, Perth, Adelaide, and Canberra were selected for the comparative analysis. The ANOVA results with respect



(a) EUI

(b) EMI

(c) WCI

(d) IEQS

Fig. 4. The 95% Confidence Interval of different performance ratings.

to EUI, EMI, and WCI of all six cities are shown in Table 9—considering the data may not be normally distributed, there are significant differences in the values for all three for the cities.

The 95% confidence intervals of EUI, EMI, and WCI of the cities are shown in Fig. 6. In terms of EUI, NABERS buildings in Melbourne consume more energy per square metre, around 525 MJ/m^2 per year. It is the second-largest city in Australia with high-density structures and population; its office buildings need cooling in summer and heating in winter, which may result in high EUI. In terms of EMI, it is higher in Brisbane and Melbourne, above 120 $kgCO_2$-eq/m^2 per year, and the lowest in Adelaide, around 60 $kgCO_2$-eq/m^2 per year. In terms of water, WCI of buildings in Brisbane and Sydney is higher than that in other cities, which may be due to the dry climate and water scarcity in the two cities.

The Tukey HSD results of different cities are shown in Fig. 7. In terms of EUI, the differences between Melbourne and Adelaide, Melbourne and Perth, and Melbourne and Sydney are more significant compared with that between other cities. Buildings in Melbourne consume more heating energy in winter, hence the higher EUI. In terms of EMI, there exists significant difference between Adelaide and the other cities. This may be because Adelaide is the smallest amongst all six, and thus, its sample size is limited. There are also some differences between Perth, Brisbane and other cities. Furthermore, in terms of WCI, the differences between Sydney and Melbourne are significant.

The regression results for energy certification with EUI and EMI, and water certification with WCI are shown in Table 10 and Fig. 8. From the results of R^2 and Adjusted R^2, it can be concluded that the regression models are valid. The results show that rise in the energy certification level decreases both EUI and EMI of NABERS buildings in Canberra the most, by 292.77 MJ/m^2 and 45.81 $kgCO_2$-eq/m^2, respectively, and in Perth the least, by 131.58 MJ/m^2 and 22.76 $kgCO_2$-eq/m^2, respectively, per year for one level. Furthermore, rise in the water certification level decreases WCI in Brisbane the most and Canberra the least, by 0.47 t/m^2 and 0.15 t/m^2, respectively, per year for one level. Thus, NABERS energy rating shows a more effective reduction in energy consumption and emissions in Canberra, while its water rating shows a more effective reduction in water consumption in Brisbane.

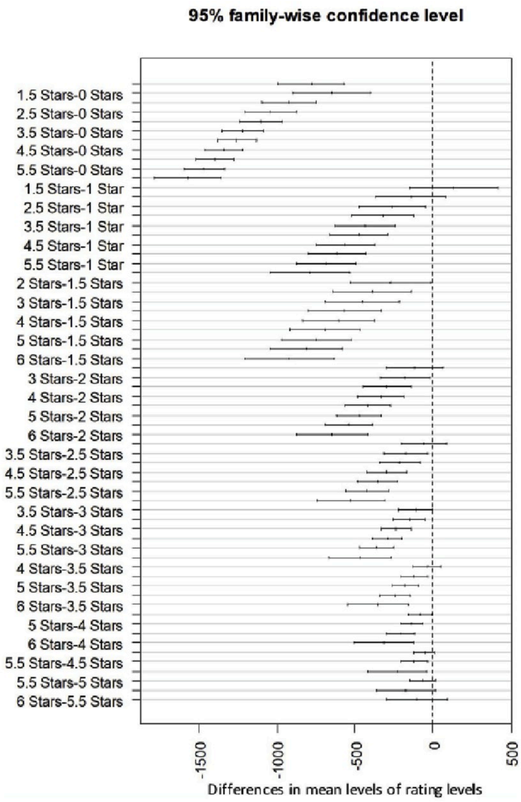
4.3. Built Environment Efficiency

Fig. 9 shows the relationships between the BEE value and energy certification as well as IEQ certification. In general, rise in these certification levels raises the BEE values correspondingly, indicating that NABERS buildings with higher energy and IEQ certification levels have better IEQS and lower EMI and EUI. Such improvement in BEE based on EMI is more significant than that based on EUI. This may be because the values of EMI are concentrated in a lower range than those of EUI, which result in higher BEE. Besides, EMI takes more factors into consideration, and the calculation methods for different energy types are different, which causes the disparity between EUI and EMI.

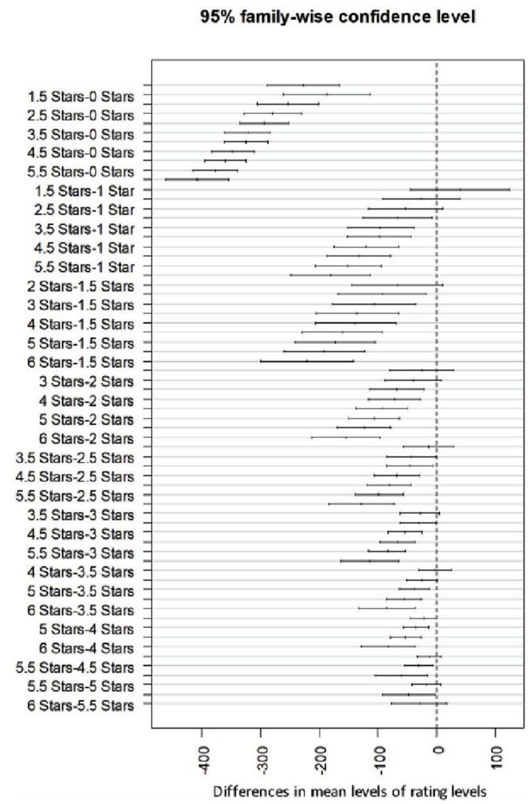
5. Discussion

5.1. Major findings

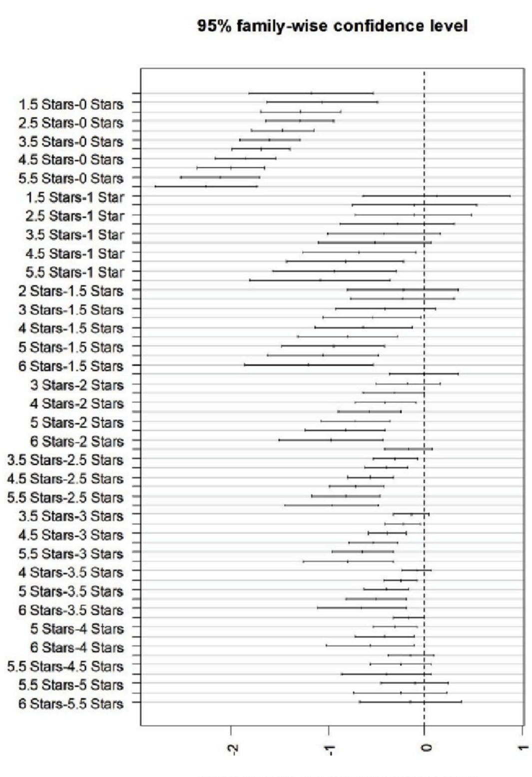
There are significant differences in EUI, EMI, WCI, and IEQS amongst the certification levels, and the relationships between them can be regarded as linear: when the level rises, EUI, EMI, and WCI decrease, while IEQS increases. In general, EUI of NABERS office buildings which is 518.9 MJ/m^2 per year, is less than the average EUI of commercial buildings in Australia, 971 MJ/m^2 per year [55]. NABERS buildings in Melbourne have the highest EUI and EMI, which is reflected in the benchmark of NABERS energy rating [52] and is consistent with the building energy use report [56]. Melbourne is Australia's second-largest city [53], and its energy use for HVAC has been found to be the largest in the country [56]; its commercial buildings need cooling in summer as well as heating in winter [57]. Melbourne's cooling and heating degree hours are the longest amongst those of Australia's top three biggest cities



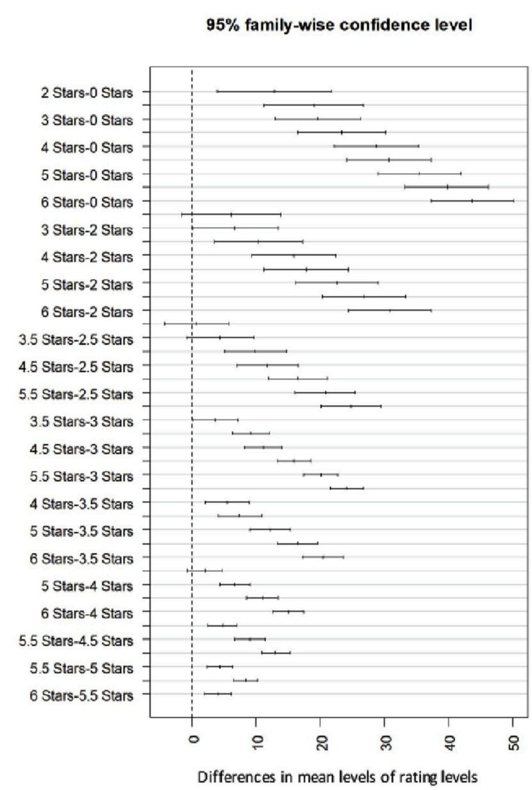
(a) EUI



(b) EMI



(c) WCI



(d) IEQS

Fig. 5. Multiple comparison of different ratings.

Table 8
Regression results of different ratings.

	Intercept	Estimate	Weighted Estimate	R^2	Adjusted R^2	Standard Error	Sig.
EUI	1270.5	−184.45	−178.96	0.908	0.898	102.558	<0.01
EMI	286.98	−41.94	−182.33	0.903	0.892	24.033	<0.01
WCI	1.599	−0.24	−197.52	0.973	0.969	0.070	<0.01
IEQS	23.776	7.49	107.97	0.990	0.988	1.124	<0.01

Table 9
ANOVA results of different cities (EUI, EMI and WCI).

Analysis	Parameters	EUI	EMI	WCI
ANOVA	Df	5	5	5
	SS	839,000	515,241	3.26
	MS	167,803	103,048	0.652
	F value	1.248	15.11	2.231
	p-value	0.284	<0.01***	0.050*
Kruskal-Wallis test	Chi-squared	24.706	191.96	68.599
	DF	5	5	5
	p-value	<0.01***	<0.01***	<0.01***

(***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$).

[58]. In Canberra, however, the promotion of energy rating has resulted in greater energy and emission reduction. As shown in Table 5, it has the same cooling and heating degree hours as Melbourne, and higher average highest temperature and lower average lowest temperature, which may result in more energy consumption and significant differences in it amongst the different levels. Brisbane has the highest WCI, which may be related to the climate and water scarcity in Queensland [59]. NABERS WCI benchmark for Brisbane is the highest [51]. Meanwhile, the water certification has the most significant impact on WCI in Brisbane. In terms of BEE, it is higher in buildings with a higher certification level, indicating that NABERS can embody the concept of green building: lower energy use while ensuring better IEQ.

5.2. International comparison

To further understand the results, this study selected two other major rating tools—US′ LEED and China's ASGB—on which similar studies can be found. In general, EUI of LEED office buildings is more than 750 MJ/m^2 per year, which is close to that of NABERS 3-star buildings [19], while EMI of LEED buildings is almost the same as that of NABERS 6-star ones, around 25 $kgCO_2$-eq/m^2 [60]. According to the Tukey HSD results of EUI in different cities, three major cities were selected for the international comparison (Table 11). EUI of NABERS's low certification level is higher than that of LEED's low certification level, while EUI of NABERS's high certification level is lower than that of LEED's high certification level. This may be because NABERS has a wider rating scale with 12 levels that certifies buildings with a larger EUI range. Moreover, the significant differences in EUIs between different certification levels also imply the effectiveness of NABERS. Compared with China's Three-Star buildings, EUI of most NABERS buildings is slightly higher. In general, rise in the certification level decreases EUI of NABERS and LEED buildings accordingly, but not of Three-Star buildings. According to the Tukey HSD results of EMI in different cities, three major cities were selected for the international comparison (Table 12). The results are similar to those of EUI: EMI of NABERS's low certification level is higher than that of LEED's low certification level, while EMI of NABERS's high certification level is lower than that of LEED's high certification level. Admittedly, the absolute figures of EUI and EMI may not be comparable because the sample buildings in each system come from different climatic and socioeconomic contexts, and the emission factor for calculating EMI could be different; however, the trend of a higher certification level having a lower EUI and EMI is more pronounced in NABERS than the other two rating systems. This finding reinforces the conclusion that NABERS is effective in differentiating and improving building performance using certification levels.

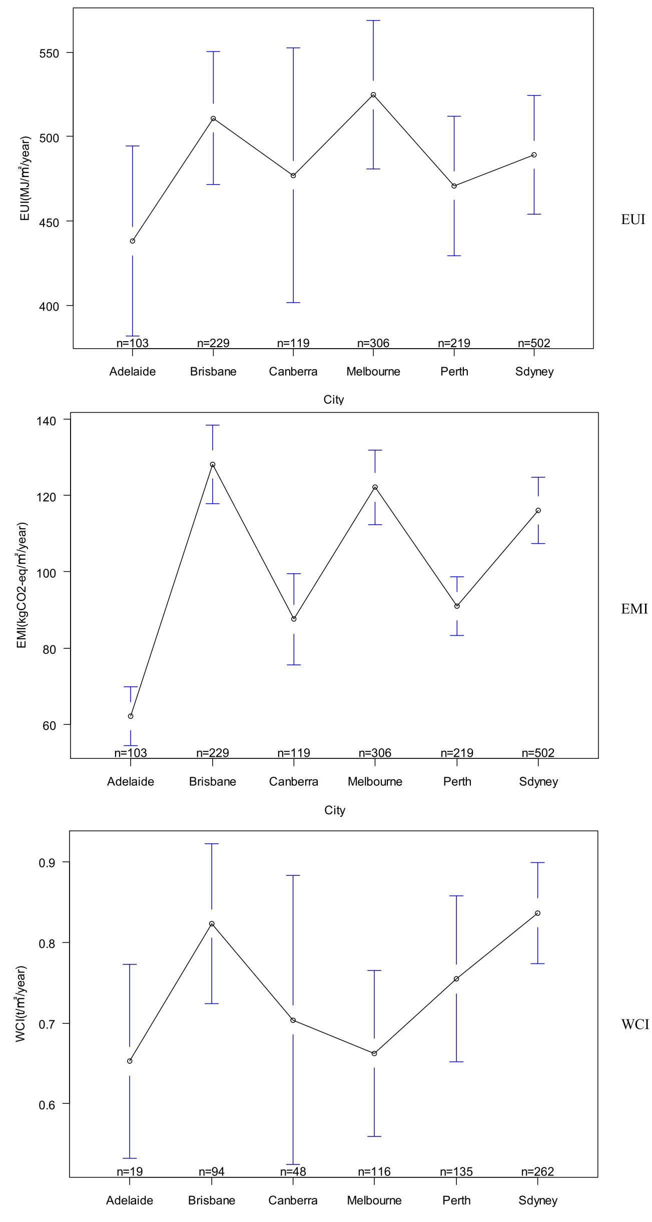


Fig. 6. The 95% CI of different Cities (EUI, EMI, WCI).

5.3. Implications and limitations

This study introduces NABERS, which is relatively unfamiliar in green building research, as only a few papers on it were found. In this respect, this study indeed enriches the literature on green building rating systems by disclosing EUI, EMI, WCI, and IEQS data of NABERS office buildings. The data and related analysis not only represent the

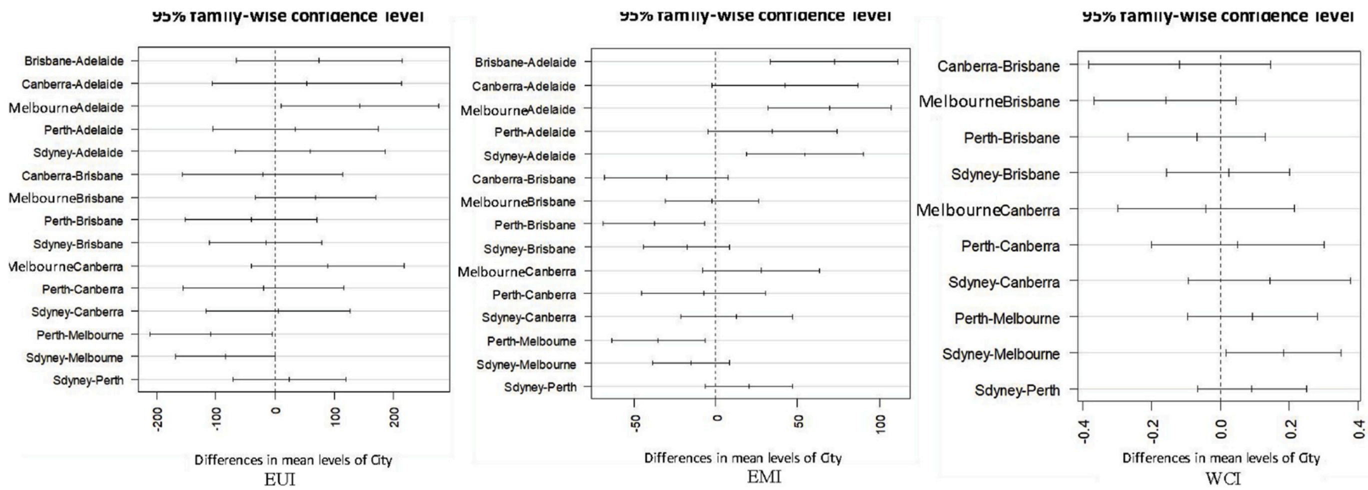


Fig. 7. Multiple comparison of different cities.

Table 10
Regression results of different cities (EUI, EMI and WCI).

	City	Intercept	Estimate	R^2	Adjusted R^2	Standard Error
EUI	Sydney	1200	−167.37	0.901	0.900	97.205
	Melbourne	1398.7	−210.29	0.862	0.847	146.822
	Brisbane	1132.6	−155.73	0.955	0.950	58.966
	Perth	955.67	−131.58	0.834	0.814	94.143
	Adelaide	1313.3	−210.9	0.914	0.903	109.941
	Canberra	1790.4	−292.77	0.850	0.831	217.37
EMI	Sydney	306.4	−44.41	0.886	0.873	27.884
	Melbourne	306.54	−45.63	0.945	0.938	18.678
	Brisbane	294.77	−41.9	0.965	0.962	13.912
	Perth	173.73	−22.76	0.864	0.844	14.194
	Adelaide	174.55	−27.47	0.937	0.929	12.072
	Canberra	289.88	−45.81	0.813	0.792	38.416
WCI	Sydney	1.878	−0.30	0.994	0.993	0.041
	Melbourne	1.282	−0.19	0.919	0.908	0.080
	Brisbane	2.750	−0.47	0.975	0.971	0.124
	Perth	1.594	−0.24	0.909	0.898	0.124
	Canberra	1.064	−0.15	0.994	0.994	0.019

best EUI, EMI, and WCI in Australia but also provide the comparison sample for green office buildings in other countries.

For green building design and management, this study provides some suggestions—with respect to the design stage, as every city has its own climate as well as economic situation, which may lead to different building operational performance, the designers should take the local conditions (climate and economy) into account for the targeted performance; as for the operational stage, this research provides prediction models for facility managers to compare the energy and resource consumption with the national and local benchmarks. If the consumption is higher, the facility manager can modify the building operational model, such as adjusting occupancy rate, usage hours, and plug load, to help save energy and resources.

This study has some practical implications for green building rating systems. NABERS shows that the rating based on post-occupancy data can effectively stratify the certification vis-à-vis the actual performance. It is worth mentioning that the performance baseline varies amongst regions; therefore, green building rating systems should propose different benchmarks and principles according to the cities, considering the climate, population, economy, emission factor, and so on. There are also some outstanding issues in NABERS that need to be addressed. With respect to the water rating, only when WCI is in the middle range, the trend of it decreasing with rise in the certification level is observed; beyond that range, that is, either high or low WCI, the trend disappears. Furthermore, most NABERS office buildings obtain just the energy

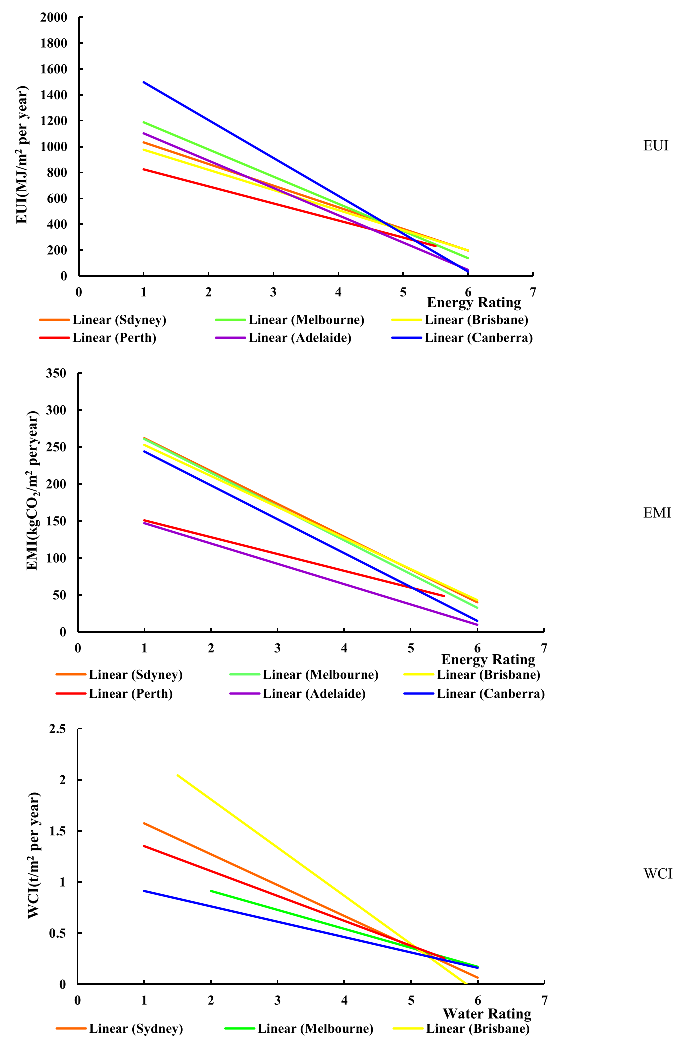


Fig. 8. EUI, EMI and WCI variation trends with their corresponding ratings in different cities.

certification; only a few acquire the IEQ certification. In terms of the parameters related to the IEQ certification, the lighting and layout scores are almost 0, so it is necessary to encourage more buildings to

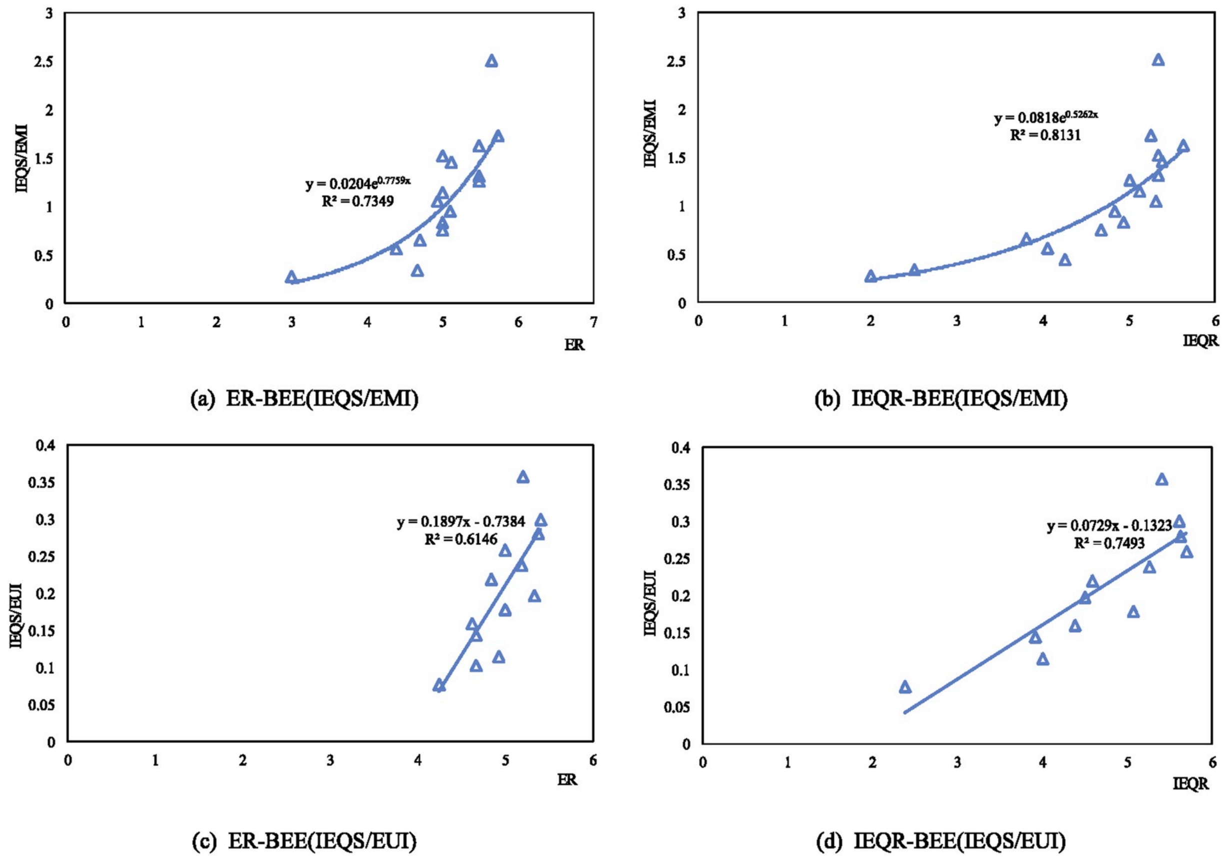


Fig. 9. Relationships between BEE values and ERs, IEQRs.

Table 11
International comparison of EUI (MJ/m^2/year).

Tiers	LEED		NABERS			ASGB [61]
	New York [21]	Chicago [62]	Perth	Sydney	Melbourne	
Platinum/6/ Three Star	No data	790	No data	235	273	282
Gold/5–4/ Two Star	930	810	341	388	389	275
Silver/2–3/ One Star	1135	890	554	676	674	117
Certified/ 0–1/N/A	1470	1010	1433	1562	1707	No data

Table 12
International comparison of EMI (kgCO$_2$-eq/m^2/year).

Tiers	LEED [21]	NABERS		
		Adelaide	Perth	Melbourne
Platinum/6	No data	12	No data	54
Gold/5-4	76	48	66	92
Silver/2-3	95	84	112	158
Certified/0-1	116	185	271	382

pursue this certification, especially by improving the lighting environment and layout for better IEQ. In terms of the waste certification, even fewer buildings have been certified, which leaves this study lacking in the relevant analysis; therefore, it is imperative to popularize the waste rating. Besides this missing data, the amount of data on some ratings and cities is small, which may introduce bias in the results.

6. Conclusion

This study correlates NABERS certification with office buildings' actual performance. The main conclusions are as follows:

1. There are significant differences in EUI, EMI, WCI, and IEQS and their corresponding certification levels, and the relationship between them can be regarded as linear: rise in the certification level decreases EUI, EMI, and WCI and increases IEQS—a one-level rise in the certification reduced EUI, EMI, and WCI by 184.45 MJ/m^2, 41.95 kgCO$_2$-eq/m^2, and 0.24 t/m^2, respectively, per year, and improved IEQS by 7.49 on average. In terms of the variation of different certification levels, rise in the level made the performance difference less significant;
2. There are noticeable differences in EUI, EMI, and WCI amongst the major Australian cities. NABERS office buildings in Melbourne have the highest EUI (525 MJ/m^2) and EMI (120 kgCO$_2$-eq/m^2) due to its climate and socioeconomic status. On the other hand, reduction in EUI and EMI with rise in the energy certification level in Canberra is also more significant compared with that of the others—a one-level rise resulted in a reduction of 292.77 MJ/m^2 and 45.81 kgCO$_2$-eq/m^2, respectively, per year. NABERS office buildings in Brisbane have the highest WCI compared with other cities per year on average—and reduction in it is most significant with rise in the water certification level—0.47 t/m^2 per year for one level.
3. BEE has been proved as an appropriate index for combining energy and IEQ for NABERS—rise in the certification level raises BEE accordingly, indicating embodiment of the green building concept of lower energy use with better IEQ. The results of the comparison with other international green building rating systems also imply the effectiveness of NABERS in improving building performance in accordance with the certification system.

In general, although this study has some limitations, mainly due to data missing for some performance ratings and cities, it enriches the research on green buildings' rating systems and post-occupancy performance of green office buildings. Furthermore, it provides some practical implications and suggestions for improving green building rating tools, and can be regarded as a reference for developing new ones that are based on post-occupancy data. As part of our future work, the specific relationships between building performance data and climatic and economic conditions for different certification levels and regions will be established, based on which the prediction models will be proposed.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] J. Zuo, Z.-Y. Zhao, Green building research–current status and future agenda: a review, Renew. Sustain. Energy Rev. 30 (2014) 271–281.
[2] B. Mattoni, C. Guattari, L. Evangelisti, F. Bisegna, P. Gori, F. Asdrubali, Critical review and methodological approach to evaluate the differences among international green building rating tools, Renew. Sustain. Energy Rev. 82 (2018) 950–960.
[3] L.-Y. Shen, J.L. Hao, V.W.-Y. Tam, H. Yao, A checklist for assessing sustainability performance of construction projects, J. Civ. Eng. Manag. XIII (4) (2007) 273–281.
[4] W. Lu, H. Yuan, A framework for understanding waste management studies in construction, Waste Manag. 31 (6) (2011) 1252–1260.
[5] J. Zuo, S. Pullen, R. Rameezdeen, H. Bennetts, Y. Wang, G. Mao, Z. Zhou, H. Du, H. Duan, Green building evaluation from a life-cycle perspective in Australia: a critical review, Renew. Sustain. Energy Rev. 70 (2017) 358–368.
[6] EPAGB. https://archive.epa.gov/greenbuilding/web/html/index.html, 2016. Accessed 6th Dec 2018.
[7] U.S green building Council, Available online, www.usgbc.org. Accessed 19th Jan 2020.
[8] BREEAM international new construction, Available online, http://www.breeam.com. Accessed 19th Jan 2020.
[9] Ministry of Housing and Urban-Rural Development of the People's Republic of China, Inspection and Quarantine of the People's Republic of China, GB/T 50378-2014 Assessment Standard for Green Building, China Architecture & Building Press, Beijing, 2014.
[10] Green building Council Australia, Available online, https://new.gbca.org.au/green-star/. Accessed 19th Jan 2020.
[11] CASBEE, Available online, http://www.ibec.or.jp/CASBEE/english/. Accessed 19th Jan 2020.
[12] DGNB, Available online, http://www.dgnb.de/en/. Accessed 19th Jan 2020.
[13] K. Fowler, E. Rauch, J. Henderson, A. Kora, Re-Assessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings, U.S. Department of Energy, 2011.
[14] R. Diamond, M. Opitz, T. Hicks, B.V. Neida, S. Herrera, Evaluating the energy performance of the first generation of LEED-certified commercial buildings, ACEEE Summer Study Energy Effic. Build. 3 (2006) 41–50, 2006.
[15] C. Turner, M. Frankel, Energy Performance of LEED for New Construction Buildings, New Building Institute, 2008.
[16] M. Valentová, P. Bertoldi, Evaluation of the GreenBuilding programme, Energy Build. 43 (8) (2011) 1875–1883.
[17] R. Alawneh, F.E. Mohamed Ghazali, H. Ali, M. Asif, Assessing the contribution of water and energy efficiency in green buildings to achieve United Nations Sustainable Development Goals in Jordan, Build. Environ. 146 (2018) 119–132.
[18] D. Baylon, P. Storm, Comparison of commercial LEED buildings and non-LEED buildings within the 2002-2004 pacific Northwest commercial building stock, ACEEE Summer Study Energy Effic. Build. 4 (2008) 1–12, 2008.
[19] G.R. Newsham, S. Mancini, B.J. Birt, Do LEED-certified buildings save energy? Yes, but, Energy Build. 41 (8) (2009) 897–905.
[20] B. Lin, Y. Liu, Z. Wang, Z. Pei, M. Davies, Measured energy use and indoor environment quality in green office buildings in China, Energy Build. 129 (2016) 9–18.
[21] J.H. Scofield, Efficacy of LEED-certification in reducing energy consumption and greenhouse gas emission for large New York City office buildings, Energy Build. 67 (2013) 517–524.
[22] J. Liang, Y. Qiu, M. Hu, Mind the energy performance gap: evidence from green commercial buildings, Resour. Conserv. Recycl. 141 (2019) 364–377.
[23] H.-H. Liang, C.-P. Chen, R.-L. Hwang, W.-M. Shih, S.-C. Lo, H.-Y. Liao, Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan, Build. Environ. 72 (2014) 232–242.
[24] Y. Liu, Z. Wang, B. Lin, J. Hong, Y. Zhu, Occupant satisfaction in Three-Star-certified office buildings based on comparative study using LEED and BREEAM, Build. Environ. 132 (2018) 1–10.
[25] M.P. Deuble, R.J. de Dear, Green occupants for green buildings: the missing link? Build. Environ. 56 (2012) 21–27.
[26] Z. Gou, S.S.-Y. Lau, Z. Zhang, A comparison of indoor environmental satisfaction between two green buildings and a conventional building in China, J. Green Build. 7 (2) (2012) 89–104.
[27] B.G. Sediso, M.S. Lee, Indoor environmental quality in Korean green building certification criteria—certified office buildings—occupant satisfaction and performance, Sci. Technol. Build. Environ. 22 (5) (2016) 606–618.
[28] Z. Pei, B. Lin, Y. Liu, Y. Zhu, Comparative study on the indoor environment quality of green office buildings in China with a long-term field measurement and investigation, Build. Environ. 84 (2015) 80–88.
[29] D.O. Sant'Anna, P.H. Dos Santos, N.S. Vianna, M.A. Romero, Indoor environmental quality perception and users' satisfaction of conventional and green buildings in Brazil, Sustain. Cities Soc. 43 (2018) 95–110.
[30] S. Altomonte, S. Schiavon, Occupant satisfaction in LEED and non-LEED certified buildings, Build. Environ. 68 (2013) 66–76.
[31] S. Lu, Y. Liu, Y. Sun, S. Yin, X. Jiang, Indoor thermal environmental evaluation of Chinese green building based on new index OTCP and subjective satisfaction, J. Clean. Prod. 240 (2019).
[32] M.H. Issa, J.H. Rankin, M. Attalla, A.J. Christian, Absenteeism, performance and occupant satisfaction with the indoor environment of green toronto schools, Indoor Built Environ. 20 (5) (2011) 511–523.
[33] B.J. Birt, G.R. Newsham, Post-occupancy Evaluation of Energy and Indoor Environment Quality in Green Buildings: a Review, National Research Council Canada, 2009.
[34] Z. Gou, D. Prasad, S.S.-Y. Lau, Impacts of green certifications, ventilation and office types on occupant satisfaction with indoor environmental quality, Architect. Sci. Rev. 57 (3) (2014) 196–206.
[35] NABERS, Available online, https://www.nabers.gov.au/. Accessed 19th Jan 2020.
[36] Australian Government, Australia's 2030 Climate Change Target, 2015.
[37] NSW Government, Available online, https://www.planningportal.nsw.gov.au/planning-tools/basix. Accessed 19th Jan 2020.
[38] National House energy rating Scheme, Available online, https://www.nathers.gov.au/. Accessed 19th Jan 2020.
[39] NABERS, The Key Principles and Defining Features of NABERS (VERSION 1.0), 2014.
[40] NABERS, NABERS Energy and Water for Offices the Rules (Version 3.2), 2018.
[41] NABERS, NABERS Indoor Environment for the Next Generation of Sustainability Leaders, 2015.
[42] NABERS, NABERS Waste the Rules (Version 1.2), 2019.
[43] C. Residovic, The new NABERS indoor environment tool – the Next frontier for Australian buildings, Procedia Eng. 180 (2017) 303–310.
[44] D. Lee, I. Dixon, T. Dunn, C. Donovan, Life cycle cost comparison of a high NABERS performing commercial building, Procedia Eng. 180 (2017) 311–319.
[45] NABERS, Ruling: Calculating a NABERS Portfolio Rating, 2019.
[46] Academy of Mathematics and System Science Chinese Academy of Sciences, Analysis of Variance, Science Press, Beijing, 1977.
[47] S. Guo, S. Zhong, A. Zhang, Privacy-preserving kruskal-wallis test, Comput. Methods Progr. Biomed. 112 (1) (2013) 135–145.
[48] R.G. Miller, Simultaneous Statistical Inference, Springer, 1981.
[49] R.B. Darlington, A.F. Hayes, Regression Analysis and Linear Models: Concepts, Applications, and Implementation, Guilford Publications, 2016.
[50] G. Cary, S. Dovers, Australia Burning: Fire Ecology, Policy and Management Issues, CSIRO, 2003.
[51] HFM Asset Management, Water Efficiency Benchmarks Commercial Buildings - Perth & West Perth CBD Western Australia, 2017.
[52] NABERS, NABERS Energy for Offices Benchmarking Factors, 2011.
[53] Australia Bureau of Statistics, Regional population growth, Australia, 2017-18; Available online, https://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/3218.0Main+Features12017-18?OpenDocument, 2019. Accessed 27th Mar 2019.
[54] Australia Government, Climate statistics for Australian locations, Available online, http://www.bom.gov.au/climate/averages/tables/cw_040764.shtml, 2017. Accessed 26th Dec 2019.
[55] D. Daly, P. Cooper, Z. Ma, Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings, Energy Build. 75 (2014) 382–393.
[56] Australian Government, Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia, 2012.
[57] Global sea temperature, Available online, https://www.seatemperature.org/australia-pacific/australia/port-melbourne.htm. Accessed 26 Dec 2019.
[58] M. Robati, G. Kokogiannakis, T.J. McCarthy, Impact of structural design solutions on the energy and thermal performance of an Australian office building, Build. Environ. 124 (2017) 258–282.
[59] E. Linacre, B. Geerts, Climates and Weather Explained, Routledge, London, 1997.

[60] J. Jeong, T. Hong, C. Ji, J. Kim, M. Lee, K. Jeong, Development of an evaluation process for green and non-green buildings focused on energy performance of G-SEED and LEED, Build. Environ. 105 (2016) 172–184.
[61] Y. Geng, W. Ji, Z. Wang, B. Lin, Y. Zhu, A review of operating performance in green buildings: energy use, indoor environmental quality and occupant satisfaction, Energy Build. 183 (2019) 500–514.
[62] J.H. Scofield, J. Doane, Energy performance of LEED-certified buildings from 2015 Chicago benchmarking data, Energy Build. 174 (2018) 402–413.