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Energy Prediction versus Energy Performance of Green Buildings in Malaysia. Comparison of Predicted and Operational Measurement of GBI Certified Green Office in Kuala Lumpur

Suzaini M. Zaid[1,a] and Amir Kiani[1]

[1]*Department of Building Surveying, Faculty of Built Environment, University of Malaya, Malaysia*

Abstract. Forward from the sustainability agenda of Brundtland in 1987 and the increasing demand for energy efficient buildings, the building industry has taken steps in meeting the challenge of reducing its environmental impact. Initiatives such as 'green' or 'sustainable' design have been at the forefront of architecture, while green assessment tools have been used to predict the energy performance of building during its operational phase. However, there is still a significant hap between predicted or simulated energy measurements compared to actual operational energy consumption, or is more commonly referred as the 'performance gap'. This paper tries to bridge this gap by comparing measured operational energy consumption of a Green Building Index (GBI) certified office building in Kuala Lumpur, with its predicted energy rating qualification.

1 Introduction

Global warming is one of the biggest issues of this century, and according to National Aeronautics and Space Administration (NASA), in the past few years the number of carbon dioxide (CO_2) parts in the atmosphere exceeded an amount that it had never pass in the last 650,000 years [1]. Buildings play a big role in producing CO2 gases; in fact 30% of greenhouse gas emission come from building sector, and between 80-90% of CO2 emissions from the building sector come from the operational phase of already built buildings [2]. Consequently, mitigation of CO2 emissions has affected the building industry in a number of countries in the South East Asian region like Indonesia, Singapore, the Philippines, Thailand and Vietnam are already implementing energy efficiency legislation on newly built buildings [3]. However, it cannot be said the same about the building industry in Malaysia, where such legislation does not exist for both new built and existing buildings.

Other than building energy efficiency legislation, other strategies or approaches however has been done sporadically in the Malaysian building landscape, such as the introduction of Green Building Index (GBI) to rate how 'green' buildings are designed – not operated. The GBI has taken heed from pioneering green building rating tools such as Building Research Establishment Environmental Assessment Method (BREEAM) in The United Kingdom [4] and Leadership in Energy & Environmental Design (LEED) in The United States [5]. These green building rating tools are predicted models of how buildings would perform in operational phase, however it does very little to measure actual performance of the so-called green buildings. Therefore, there is a need to fill in the gap of predicted and operational performance of buildings – known as the 'performance gap' [6] that can truly be a testament of real energy and CO2 reduction.

2 Green Revolution

There has been large body of work that has been done to enhance how a building performs in its operational phase, through simulation and 'green' design or architecture [7]. The term 'green' architecture/building refers to how environmental friendly the building is, in terms of the design, techniques and technology used in the building [8]. The green building revolution is being observed internationally [9], through energy standards such as the European Energy Performance of Building Directive (EBPD), the French Low Energy Building Decree and the Norwegian Standard for Residential Passive House [10] and is even starting to gain awareness locally in Malaysia with the birth of GBI.

The believed benefits of green building practices will possibly provide the triple-bottom-line benefits of sustainable development, in terms of environmental, economic and social [9] [11] Some of the environmental benefits include: biodiversity and ecosystems enhancement; air and water quality improvement; waste reduction; natural resources conservation; and minimizing global warming effects. Other possible economic benefits could include: reduction of operation and maintenance costs; creation of green products and

[a] Corresponding author: suzaini_zaid@um.edu.my

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services; life-cycle economic performance optimization; image improvement; and reduction of cost for civil infrastructure [9]. Meanwhile, perceived social benefit include: occupant productivity improvement; and occupant absenteeism minimization [9].

2.1 Green Rating Tool and Simulation

Many countries have developed their own green rating tool based on one another, mostly adapted from the pioneering BREEAM and LEED rating tools. Examples of green building rating tools available in the South East Asian region are Green Mark from Singapore, Building for Ecologically Responsive Design Excellence (BERDE) from Philippines and the Green Building Index (GBI) from Malaysia [12-14]. Some of the assessment criteria in these green building rating tools are similar, for example energy efficiency (EE), indoor environmental quality (EQ), and water efficiency (WE) [12-14]. However, the assessment measurements and scoring system may differ between these green building rating tools according to local context. Table 1 briefly highlights the assessment criteria for Green Mark, BERDE and GBI for Non-Residential New Construction category, and the maximum scoring points [12-14]. As the focus of this paper is to review the Malaysian building performance, a brief comparison between the energy efficiency criteria of the GBI with its other South East Asian counterpart Green Mark and BERDE is described also in Table 2.

Table 1. Assessment criteria of BCA Green Mark, BERDE and GBI. Sources: [12-14].

BCA Green Mark – 120 points	BERDE – 120 points	GBI – 100 points
1.Climatic Responsive Design – 30 2.Building Energy Performance – 30 3.Resource Stewardship – 30 4.Smart & Healthy Building – 30 5.Advanced Green Efforts – 20	1.Management – 14 2.Land Use and Ecology – 20 3.Water – 7 4.Energy – 9 5.Transportation – 18 6.Indoor Environmental Quality – 7 7.Materials – 6 8.Emissions – 4 9.Waste – 11 10. Heritage Conservation – 4 11.Innovation - 20	1.Energy Efficiency (EE) – 35 2.Indoor Environmental Quality (EQ) – 21 3. Sustainable Site Planning & Management (SM) - 16 4.Material & Resources (MR) – 11 5.Water Efficiency (WE) – 10 6.Innovation (IN) - 7

Table 2. Energy Requirements for BCA Green Mark, BERDE and GBI. Sources: [12-14].

BCA Green Mark (Building Energy Performance)	BERDE (Energy)	GBI (Energy Efficiency)
1. Energy Efficiency 2. Air-Conditioning Total System Efficiency 3. Lighting Efficiency 4. Energy Effectiveness 5. Building Energy 6. Car Park Energy 7. Receptacle Energy 8. Renewable Energy 9. Feasibility Study 10. Solar Ready Roof 11. Replacement Energy	1. Energy Sub-Metering 2. Energy Efficient Lighting 3. Natural Ventilation 4. On-Site Renewable Energy Generation 5. Energy Efficiency Improvement 6. Energy Efficiency Building Envelope 7. Energy Efficient Equipment 8. Building Automation Systems	1. Minimum EE Performance 2. Lighting Zoning 3. Electrical Sub-Metering 4. Advanced or Improved EE Performance – BEI 5. Enhanced Commissioning 6. Post Occupancy Commissioning 7. EE Verification 8. Sustainable Maintenance

The GBI Minimum EE Performance is for building envelope and installations like Building Energy Intensity Tool (BEIT) to hoped to minimize the energy consumption, hence reducing CO_2 emission [14]. Lighting Zoning; as the name suggests it is allocated for lighting and zonings of lightings and the flexibility of the system. In this part, GBI's requirements are to install motion sensors to turn off the light in the absence of a user, to install auto-sensors to automatically adjust the level of artificial lighting according the level of natural lighting, and to provide switches for every enclosed area individually to increase the flexibility of the system [14]. Electrical Sub-metering & Tenant Sub-metering is for installing different sub-meters for all energy use more than 100 kilovolt amps (kVa) as well as an individual sub-metering for lighting [14].

Renewable Energy is to promote the use of renewable energies and points are given according the amount of electricity provided by the renewable sources, so the more renewable energy, the more points, and a building can get as high as 5 points [14]. Points are given in Advanced or Improved EE Performance if a building manages to consume less than 150kWh/m^2/year (this number may vary according to the type of building, for more information please refer to GBI) using BEI software or any other software recognized by GBI or to save at least 20% of the normal energy consumption over 3 years using BEI [14]. Enhanced Commissioning is used to ensure that every energy using system is working at its best potential and to ensure the minimal energy used by these systems [14].

Points on On-going Post Occupancy Commissioning will be given for regular Post Occupancy Evaluation (POE) and more points will be given if they are assessed by professional engineers [14]. EE Monitoring & Improvement is for the use of Energy Management System (EMS) to monitor all the energy usage in the building as well as the sub-metering. If a building is not equipped with EMS then they should submit BEI, fuel and water consumption of the building on annual basis to GBI for the 3 years of validity period [14]. Sustainable Maintenance focuses on the maintenance of the energy related systems and points are given is the maintenance is planned properly and at least 75% of maintenance team participate in carrying out of maintenance [14].

2.2 Predicted and Simulated Building Performance

Other than green building rating tools, simulation tools like EnergyPlus and Simplified Building Energy Model (SBEM) are also used as strategies to reduce the building sector's environmental impact and climate change effect. Simulation and modelling tools are used as a design tool to simulate and predict how the said building would perform in its operational phase. An open source software called EnergyPlus was developed under the prevue of the United States Department of Energy Building Technologies Office to simulate energy performance of heating, cooling, ventilation, lighting, plug and process loads and water consumption of buildings [15]. Some of the EnergyPlus features include simulated: thermal zone conditions for heating, ventilation and air-conditioning (HVAC) systems; heat balance-based solution; combined heat and mass transfer; luminance and glare, and built-in HVAC and lighting control strategies [15].

The Simplified Building Energy Model (SBEM) is a software developed by the Building Research Establishment (BRE) to model building's CO2 emission and energy consumption rates for new buildings, in compliance with United Kingdom Building Regulations [16]. SBEM predicts monthly energy use and CO2 emissions of a building, using variables such as building geometry, construction, function and usage, HVAC systems and lighting [16]. The SBEM uses a steady-state model for its building energy calculation, which is highly simplified and highly computational – as it largely ignores any dynamic characteristic [17], and is mainly intended as a CO2 emissions compliance tool [18] rather than energy simulation software.

However, these simulation tools are not able to predict the biggest variable in the calculations, as user behaviour, presence and activities can differ considerably to personal and group preference [6,7]. Building occupants can considerably effect energy consumption by influencing internal conditions, such as individual controls on air-conditioning and heat, window openings - passive ventilation and cooling methods, and shading mechanisms [6]. Furthermore, building occupants also have personal control over various electrical equipment and appliances – or known as 'unregulated loads', such as computers, laptops, printers, and so forth [6].

Conversely during the operational stage of a building, energy and facility management can significantly effect how energy is consumed in a building. Good management and control can enhance operational efficiency of building services while the opposite reaction can occur through inappropriate strategies that result in unnecessary energy wastage [19]. Other significant parameters to evaluate operational energy performance of buildings include energy efficiency services and fittings, thermal performance of materials and material efficiency [20]. A study done in New York City found that one forth of the LEED Energy Star buildings actually consume more energy than predicted, and some was even consuming more than the national baseline (Refer Figure 1) [21]. The discrepancy is likely due to differences in operational practices and schedules, equipment, construction changes and other issues not predicted in the energy modelling process [21].

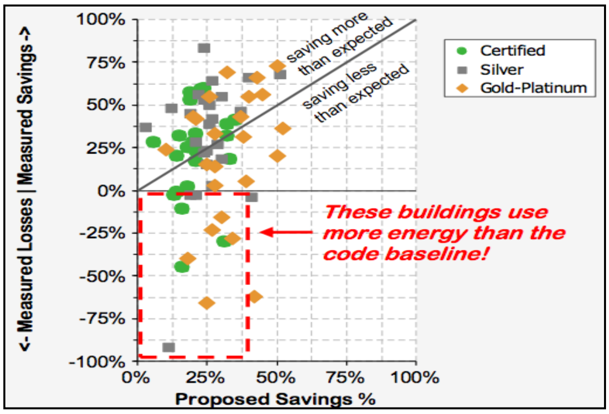

Figure 1: Predicted Energy Savings Versus Actual Performance. Source: [21].

Similar results were found in United Kingdom, through a free online energy data-sharing platform called CarbonBuzz (refer Figure 2). CarbonBuzz was launched in 2008 by the Royal Institute of British Architects (RIBA) and the Chartered Institution of Building Services Engineers (CISBE) in United Kingdom, published its analysis of shared energy consumption data in three building sectors, i.e. schools, general offices and university buildings [6] [22].

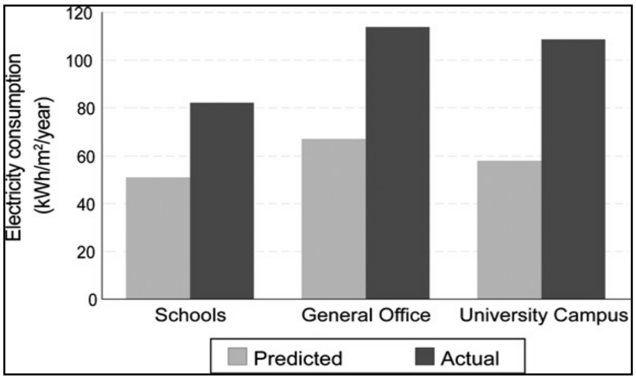

Figure 2: CarbonBuzz median electricity consumption per-sector – predicted vs. actual. Source: [22].

In an energy audit done by CarbonBuzz in 2013, it was largely found that the actual energy performance of all the building sectors was higher than its predicted performance, approximately about 70% to 89% higher than the predicted energy performance, or a Factor of Change (from Design to Actual) – Performance Gap between 1.71 to 1.90 (refer Table 3) [23]. The typical variable that affects operational energy performance of a building largely lies in the underestimating the 'unregulated' energy use from occupant-related usage, such as personalized computer/laptop, electronic plug-in appliances, heating and cooling, operating time, number of occupant and so forth [23].

Table 3. CarbonBuzz median electricity consumption per-sector – predicted vs. actual. Source: [23].

Building Sector	Median Electricity Consumption (kWh/m2/year)		Factor Change Design to Actual – 'Performance Gap'	Differen -ce (%)
	Predict-ed	Actual		
Schools	71	121	1.71	70%
General Office	56	106	1.90	89%

The 'performance gap' discrepancy can also be attributed to the lack of feedback to building designers after handover to enhance building performance [6] and therefore the inability to ensure the building performs as predicted. Other factors that could contribute to such discrepancies insufficient data and assumptions during the design stage, where the building function, use and future tenant are largely unknown or uncertain, which could lead to oversimplified and unrealistic performance [6]. Additionally, the modelling and simulation software used can contain fundamental errors in its calculation if the tools have not been extensively validates and do not consider the specific typology of buildings being modelled [6]. Consequently, this paper helps to bridge the gap by collecting real operational energy consumption data of a GBI rated building, and comparing it with a conventional non-GBI rated building to develop a baseline study.

3 Methodology

The methodology used in this study is comparative case study. This method is used when two or more similar case studies are subjected and in depth comparison is required between them [24]. Case studies for this research have been chosen firstly from GBI Non-Residential New Construction (NRNC) list of certified buildings, the second conventional baseline building is chosen carefully from the commercial buildings, which have the similar number of floors and floor area for a fair and valid comparison. There are total number of 116 NRNC buildings in Malaysia which have been awarded by GBI certification, 54 of which have been awarded by GBI Certified certification, 18 have been awarded GBI Silver certification, 39 have been awarded Gold and only 5 are awarded GBI Platinum certification [25].

Consequently, electricity bills were collected from the case studies and the data are quantitative and the monthly average electricity consumption is calculated for each building. The selected GBI certified building is categorized under the Non-Residential New Construction category. The data is then categorized in Building Energy Index (BEI), in terms of kWh/m2/year. The findings are then compared to see how better (or worse) GBI certified buildings perform, in comparison to a baseline conventional non-GBI certified building.

4 Case Study and Findings

The selected GBI certified building was designed to perform at 150 kWh/m2/year and has a total floor area of 43,943 m2, while the baseline building with 41,249 m2. Both buildings used double-glazed glass for its windows, and the GBI certified building has a total of 15 lifts, while the baseline building had 11 lifts. A brief description of the building characteristics of the selected case studies is presented in Table 4.

Table 4: Building Characteristics of Selected Case Studies

Item	Non-Residential	
	Baseline Building	GBI Certified Building
Number of Floors	36	35
Total Floor Area (m2)	41,249	43,943
Building Façade	Double-glazed low E insulated glass	Tempered Double-Glazed tinted glass

Lifts	4 high-speed lifts for low zone, 4 high-speed lifts for high zone, 2 carpark lifts and 1 VIP lift. Total of 11 lifts	6 high-speed lifts for low zone, 6 high-speed lifts for high zone and 3 car park lifts. Total of 15 lifts
Air-Conditioning System	Variable Refrigerant Volume (VRV) system.	Central water chilled air-conditioning system supported by high energy-efficient ‘green’ chiller and complemented by individual air handling unit (AHU) installed at every floor.
Lighting System	28 Watt T5 tubes; 18 Watt T8 LED tubes; 9 Watt Plasma Lighting System (PLS); 18 and 36 Watt Fluorescent lights; 8, 15 and 20 Watt LED	T5 Fluorescent tube equipped with high frequency electronic ballast.

The electricity data collected for both the case study buildings were for a total duration of 12 months between 2013 and 2014. Table 5 represents the collated electricity data and energy performance of the baseline building and the GBI certified building. It was found that the energy performance of the baseline building was lower than the GBI certified building, at 69 kWh/m2/year and 111 kWh/m2/year, respectively. As presented in Table 5, there is a stark difference in total electricity consumed by both buildings, where the annual electricity consumption by the baseline was at 236,984 kWh and the GBI building was at 407,131 kWh.

Table 5: Electricity Consumption and Energy Performance of Case Studies

Month	Baseline Building		GBI Building	
	Floor Area: 41249 m2		Floor Area: 43943 m2	
	kWh	kWh/m2	kWh	kWh/m2
1	281,333	7	212,551	5
2	251,001	6	212,201	5
3	225,765	5	235,059	5
4	200,778	5	418,868	10
5	213,104	5	427,861	10
6	263,810	6	478,788	11
7	231,928	6	469,016	11
8	225,961	5	479,199	11
9	252,135	6	524,961	12
10	243,920	6	482,067	11
11	232,277	6	483,446	11
12	221,791	5	461,555	11
	kWh/ year	kWh/m2/ year	kWh/year	kWh/m2/ year
Total	2,843,803	69	4,885,572	111
Aver-age	236,984	6	407,131	9

In comparison to the intended energy performance designated for the selected GBI building case study at 150 kWh/m2/year, it would seem that the GBI case study building was performing better than the intended or simulated with a lower energy performance of 111 kWh/m2/year. However, this does not negate from the significantly higher electricity consumption of the GBI certified building to the baseline non-GBI certified building. Further research needs to be done to investigate the factors of electricity consumption in non-residential building to understand why conventional non-GBI certified building consume lower electricity than the supposedly ‘green’ buildings that are GBI certified.

5 Discussion

This paper has highlighted the need to bridge the ‘performance gap’ between simulated and operational measured energy performance of buildings. Through the case studies selected and the data collected, it was found that the selected non-residential GBI certified building was performing better than the simulated or intended energy performance. However, through the comparative case study between a conventional non-GBI certified building and a GBI certified building, it was found that the conventional building was performing better than the GBI rated building over time. Identifying the factors that affect how energy is consumed in buildings will enable researched to bridge this performance gap to potentially predict energy performance and design building more accurately through simulated.

Researching how user behaviour affects energy performance of buildings is essential to bridging the performance gap, and can be done through Post-Occupancy Evaluation (POE) and sensor monitoring. POE is a common method to measure actual building performance, and now can be used to address to bridge the gap between simulated and operational building performance (Menezes et al., 2011). Green building rating tools like the GBI is an effective tool to reduce electricity consumption, but using this tool alone and certification does not guarantee energy saving. From the research it is understood that a well-managed and efficient building operations of a conventional non-GBI certified building can perform as well as or even better than a green building.

References

1. NASA. (2013). Climate change: How do we know? The National Aeronautics and Space Administration (NASA). Retrieved from http://climate.nasa.gov/evidence
2. UNEP-SBCI. (2010). Common Carbon Metric. United Nations Environmental Programme-Sustinable Building Climate Initiative. Retrieved from http://www.unep.org/sbci/pdfs/UNEPSBCICarbonMetric.pdf
3. Zaid, S., & Graham, P. (2015a). The Need for Energy Efficiency Legislation in Malaysian Building Sector. A Comparative Study of South East Asian Policies. Conference Proceedings of RICS COBRA Legal Research Symposium 2012.
4. BREEAM. (2013). What is BREEAM? Building Research Establishment (BRE) Ltd. Retrieved from: http://www.breeam.org/about.jsp?id=66
5. U.S. Green Building Council. (2013). Leadership in Energy and Environmental Design (LEED). Retrieved from: http://www.usgbc.org/leed
6. Menezes, A. C., Cripps, A., Bouchlaghem, D., & Buswell, R. (2012). Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. Applied Energy, 97, 355-364
7. GhaffarianHoseini, A., Dahlan, N. D., Berardi, U., GhaffarianHoseini, A., Makaremi, N., & GhaffarianHoseini, M. (2013). Sustainable energy performances of green buildings: A review of current theories, implementations and challenges. Renewable and Sustainable Energy Reviews, 25, 1-17.
8. Love, P. E., Niedzweicki, M., Bullen, P. A., & Edwards, D. J. (2011). Achieving the green building council of Australia's world leadership rating in an office building in Perth. Journal of Construction Engineering and Management, **138**(5), 652-660.
9. Nilashi, M., Zakaria, R., Ibrahim, O., Majid, M. Z. A., Zin, R. M., Chugtai, M. W., ... & Yakubu, D. A. (2015). A knowledge-based expert system for assessing the performance level of green buildings. Knowledge-Based Systems, **86**, 194-209.
10. Zaid, S. M., Myeda, N. E., Mahyuddin, N., & Sulaiman, R. (2015b). Malaysia's Rising GHG Emissions and Carbon 'Lock-In'Risk: A Review of Malaysian Building Sector Legislation and Policy. *Journal of Surveying, Construction and Property*, ***6***(1).
11. Ahn, Y. H. (2010). The development of models to identify relationships between first costs of green building strategies and technologies and life cycle costs for public green facilities (Doctoral dissertation, Virginia Polytechnic Institute and State University).
12. BCA Green Mark. (2015). BCA Green Mark for New Buildings (Non-Residential). Building and Construction Authority (BCA). Retrieved from http://www.bca.gov.sg/GreenMark/others/GM2015_NewBuildings_NRB_Pilot.pdf
13. BERDE. (2013). BERDE for New Construction Commercial Buildings. Phillippine Green Building Council. Retrieved from http://philgbc.net/berde/berde-nc/1.1.0/BERDE-NC-COM-v110.pdf
14. GBI. (2009). GBI Assessment Criteria for Non-Residential New Construction (NRNC). GreenBuildingIndex Sdn Bhd. Retrieved from http://new.greenbuildingindex.org/Files/Resources/GBI%20Tools/GBI%20NRNC%20Non-Residential%20Tool%20V1.0.pdf
15. U.S Department of Energy, 2015. EnergyPlus Energy Simulation Software. Retrieved from http://apps1.eere.energy.gov/buildings/energyplus/
16. BRE. (2016). Simplified Building Energy Model (SBEM). Building Research Establishment Ltd. Retrieved from https://www.bre.co.uk/page.jsp?id=706; http://www.uk-ncm.org.uk/
17. Wang, S., Yan, C., & Xiao, F. (2012). Quantitative energy performance assessment methods for existing buildings. *Energy and Buildings*, *55*, 873-888.
18. Lee, W. L., & Burnett, J. (2008). Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED. *Building and Environment*, ***43***(11), 1882-1891.
19. Bordass B, Cohen R, Standeven M, Leaman A. Assessing building performance in use 3: energy performance of probe buildings. Build Res Inform 2001;**29**(2):114–28.
20. Mwasha A,Williams R G, Iwaro J. Modeling the performance of residential building envelope: The role of sustainable energy performance indicators. Energy and Buildings 2011;**43** (9):2108–17.
21. Turner, C., & Mark, F. (2008). Energy Performance of LEED for New Construction Buildings. Vancouver, WA: New Buildings Institute, 2008.
22. Hamilton I, Steadman P, Bruhns H. CarbonBuzz – Energy Data Audit. UCL Energy Institute, July; 2011.
23. CarbonBuzz. (2013). Summary of Audits Performed on CarbonBuzz by the UCL Energy Insitute. CarbonBuzz Performance Gap. Retrieved from http://www.carbonbuzz.org/index.jsp#performancegap; http://www.carbonbuzz.org/downloads/PerformanceGap.pdf
24. Mills, A. J., Durepos, G., & Wiebe, E. (Eds.). (2009). Encyclopedia of case study research (Vol. **2**). Sage Publications.
25. Greenbuildingindex Sdn Bhd. (2014). GBI Certified Buildings. Retrieved from greenbuildingindex: http://www.greenbuildingindex.org/organisation-certified-buildings-NRNC-01.html