Review Article: Energy & Environmental Rating Systems for Measuring Green Building Performances
บทความปริทรรศน์: เกณฑ์การประเมินพลังงานและสิ่งแวดล้อมเพื่อการวัดประสิทธิภาพอาคารเขียว

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Abstract

Under current energy and environmental concerns, buildings are targeted as problems required immediate solutions. Generally, buildings consume plenty of resources, produce unwanted wastes, and sometimes demote Indoor Environmental Quality (IEQ). Given these negative impacts, Green Building was introduced as an answer to mitigate the current energy and environmental problems. Architects, engineers, and practitioners quickly adopt this green building idea but the direction was both diversified and unclear. At that time, proclaimed green building seems to be just promise lacking of solid evidences. Energy & Environmental rating system was initially proposed as a campaign attempting to quantify green buildings. Different measures were taken and then weighted for scoring purposes. Using these scores, green buildings are possible to be quantified and ranked afterward. In this review article, not only the rating systems, i.e. BREEAM, Green Star, and Green Globe, TEEAM, will be overviewed, but also LEED, the most dominating system in US, will be discussed in detail. The simplicity by having six sustainability measures including sustainable site, water efficiency, energy and atmosphere, material and resources, IEQ, and innovation in design, are the key success of LEED rating system. Moreover, the flexibility of having different compliance methods and scoring options makes many designers are in favor of this approach. By using performance-base compliance method, designers can compare their design against the base case for winning the higher performances such as energy cost. The score will then be interpolated and given by exceeding performances. In order to obtain high scores, practices and technologies that are acknowledged by rating systems, particularly LEED, should be systematically strategized. Xeriscaping, Green Roof, Geothermal Cooling, Displacement Ventilation, and Demand Control Ventilation, are the examples of such technologies that greatly promote the scores across multiple categories. By reviewing compositions, mechanism, practice, and technologies of green building rating systems, this article should be a useful source for practitioners who will or already involve in any green building project and looking forward to quantify their buildings with any rating system in the near future.

บทคัดย่อ

ภายใต้ความวิตกกังวลต่อสถานการณ์ทางด้านพลังงานและสิ่งแวดล้อม อาคารถูกมองว่าเป็นตัวการสำคัญที่ต้องการการแก้ไขปัญหาอย่างเร่งด่วน เนื่องจากโดยทั่วไปแล้วอาคารบริโภคทรัพยากรจำนวนมหาศาล ก่อให้เกิดขยะมากมาย อีกทั้งสภาพแวดล้อมภายในอาคารบางแห่งไม่มีคุณภาพเท่าที่ควร สภาพปัญหาดังกล่าวผลักดันให้เกิดอาคารเขียว (Green Building) ซึ่งเป็นศูนย์รวมของแนวคิดที่อาจเป็นคำตอบและเป็นทางออกของปัญหาพลังงานและสิ่งแวดล้อม แม้ว่าเวลาต่อมาสถาปนิกและวิศวกร รวมถึงผู้ประกอบวิชาชีพที่เกี่ยวข้อง จะตอบรับแนวความคิดของอาคารเขียวเป็นอย่างดี แต่ในความเป็นจริงแนวทางในการออกแบบอาคารเขียวยังคงไร้เอกภาพและขาดความชัดเจน สภาพความเป็นจริงนี้ส่งผลให้อาคารเขียวเป็นเพียงแนวคิดที่ยังขาดข้อมูลที่ชัดเจนมาสนับสนุน เพื่อให้อาคารเขียวเป็นรูปธรรม การวัดประสิทธิภาพของอาคารเขียวอย่างเป็นระบบโดยใช้เกณฑ์การประเมินอาคารทางด้านการอนุรักษ์พลังงานและสิ่งแวดล้อมจึงมีความจำเป็น การประเมินทำโดยการให้คะแนนที่ถูกแบ่งตามลำดับความสำคัญภายใต้หมวดต่าง ๆ ที่ถูกกำหนดขึ้น ซึ่งการใช้ระบบการให้คะแนนในลักษณะนี้ทำให้สามารถกำหนดระดับชั้นเพื่อการวัดประสิทธิภาพของอาคารเขียวอย่างเหมาะสมและชัดเจน บทความนี้ไม่เพียงแต่สรุปภาพรวมของเกณฑ์การประเมินฯ ต่าง ๆ เช่น BREEAM, Green Star, Green Globe และ TEEAM แต่ยังเน้นการอธิบายรายละเอียดของระบบที่มีชื่อเสียงมากที่สุดในสหรัฐอเมริกา คือเกณฑ์การประเมิน LEED สาเหตุสำคัญที่ LEED ประสบความสำเร็จอย่างมากมาจากความเรียบง่ายในการแบ่งหมวด อันประกอบไปด้วย ด้านความยั่งยืนของที่ตั้งโครงการ ประสิทธิภาพการใช้น้ำ พลังงานและชั้นบรรยากาศ วัสดุและทรัพยากร คุณภาพสภาพแวดล้อมในอาคาร และความสร้างสรรค์ในการออกแบบ นอกจากความเรียบง่ายของการจัดแบ่งหมวด LEED ยังเป็นที่นิยมในกลุ่มผู้ออกแบบ เนื่องจากความยืดหยุ่นในการเลือกรูปแบบการประเมินและทางเลือกในการทำคะแนน เช่น ผู้ออกแบบสามารถเปรียบเทียบประสิทธิภาพจากแบบอาคารของตนเองกับแบบมาตรฐาน ซึ่งหากอาคารของตนมีประสิทธิภาพ เช่น ด้านค่าใช้จ่ายทางพลังงานเหนือกว่า คะแนนจะเพิ่มเป็นลำดับขั้นตามประสิทธิภาพที่สูงขึ้น การเพิ่มคะแนนอย่างเป็นรูปธรรมนี้ทำได้โดยการวางแผน การใช้วิธีปฏิบัติและเทคโนโลยีอย่างเป็นระบบ บทความนี้ได้รวบรวมตัวอย่างเทคโนโลยีที่จะช่วยให้ผ่านการประเมิน LEED และเกณฑ์อื่นๆ อันประกอบด้วย การปลูกพืชสวนไร้น้ำ (Xeriscape) หลังคาเขียว (Green Roof) การใช้ความเย็นจากดินเพื่อระบายความร้อนจากระบบปรับอากาศ (Geothermal Cooling) การไหลเวียนอากาศด้วยการแทนที่ (Displacement Ventilation) การควบคุมความต้องการไหลเวียนอากาศ (Demand Control Ventilation) เป็นต้น การรวบรวมองค์ประกอบ กลไก วิธีปฏิบัติ และเทคโนโลยี ของระบบเกณฑ์การประเมินพลังงานและสิ่งแวดล้อมต่างๆ ในบทความนี้สามารถใช้เป็นฐานข้อมูลอ้างอิงสำหรับผู้ที่เกี่ยวข้องหรือกำลังจะเกี่ยวข้องกับโครงการอาคารเขียว รวมไปถึงผู้ที่มีความต้องการเสนออาคารของตนเข้าสู่ระบบประเมินอาคารเพื่อการอนุรักษ์พลังงานและสิ่งแวดล้อมในอนาคตอันใกล้

Keywords (คำสำคัญ)

Green Building (อาคารเขียว)
Sustainable Design (การออกแบบเพื่อความยั่งยืน)
Energy and Environment (พลังงานและสิ่งแวดล้อม)
Assessment Rating System (ระบบเกณฑ์การประเมิน)
Building Technology (เทคโนโลยีอาคาร)
Indoor Environmental Quality (คุณภาพสภาพแวดล้อมภายในอาคาร)
LEED (ความเป็นผู้นำทางด้านการออกแบบเพื่ออนุรักษ์พลังงานและสิ่งแวดล้อม)

1. Introduction to Green Building and Rating Systems

"There's been this bail out of the financial market. Well I think we need a bail in of renewable energy and green building. I actually do think that the green revolution is the solution to the financial crisis, the national security crisis, the debt crisis, and the climate crisis." (Al Gore presented in West Coast Green 2008 Conference, San Jose, USA, September 27, 2008).

The above quotation from the world famous politician and environmentalist upgrades the status of green building from being a voluntary good will to the policy for strengthening economic. As the importance of green building elevates, the definition of green building itself is being challenged. What is a green building? This simple question has been debated among designers, engineers, and practitioners around the world. In US, residential and commercial sectors consume almost 40% of overall energy as shown in Figure 1. The largest portion of energy in these sectors is spent through buildings. Moreover, buildings consume up to 60-65% of annual electricity (Boyer, 2008). This trend remains the same for major industrial countries in Europe and Asia. In Thailand, buildings in residential and commercial sectors similarly consume a large sum of energy which equates to 46% of our electricity and 20% of overall energy (EPPO/MOE, 2008). See Figure 2. As a result, many practitioners put energy efficiency to be the first task for any building soon to be green. However, many experts argue that the approach of saving energy alone might be too narrow to be the definition of green building. What if an energy efficient building is located in the remote area forcing people to drive and consume more fossil fuel? What if an energy efficient building is harmful to occupants who live and work in so-called green buildings? What if future green building will be built by depleting world precious and non-renewable resources? These questions directly challenge the definition of green building itself.

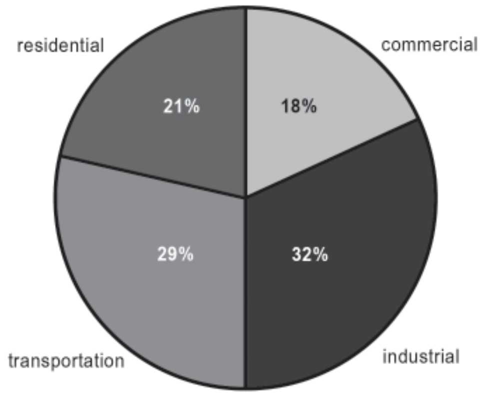

Figure 1. Overall US energy consumption by sectors.

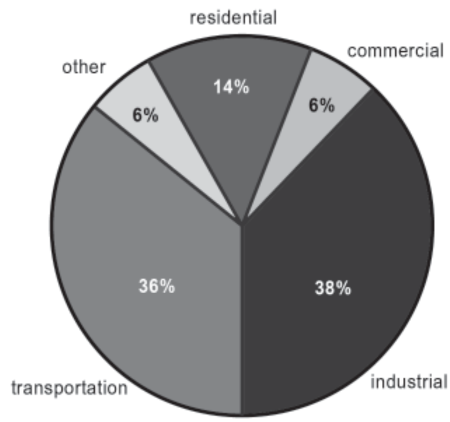

Figure 2. Overall Thailand energy consumption by sectors.

Definition of green building became clearer as the world energy and environmental situations worsen. Fossil fuel dependency, global warming, hazardous environment, and excessive human wastes, shaped the ideas and became parts of green building composition. A book called *Green Office Buildings: A Practical Guide to Development* compressively explained the components for green building with respect to the world current contexts (Frej & Browning, 2005). It summarized the characteristic of green building into three categories including **resources efficiency, occupants' well-**

being, and **environmental waste reduction**. US EPA (Environmental Protection Agency) suggested that the definition should extend toward the design and construction activities. In other words, **buildings must be green from the beginning to the end of the design, construction, and operation process** (EPA, 2008b). By referring to this definition, practitioners began to work under the same framework and toward to the same goal.

The E&E (Environmental and Energy) assessment rating system allows practitioners to evaluate green building systematically. The first environmental assessment tool called BREEAM (Building Research Establishment Environmental Assessment Method) was introduced by groups of UK practitioners namely BRE (British Research Establishment) in 1990 (Building Research Establisment [BRE], 2008a, 2008b). Because of this quantifiable approach for scoring green buildings, BREEAM became quickly successful in Great Britain. This initiative raises awareness around the world to see the importance of well-defined rating system. Since then, each country quickly adopted BREEAM approach and created their rating systems based on each individual context. In America, US Green Building Council develops LEED (Leadership in Energy and Environmental Design) rating system (US Green Building Council [USGBC], 2008c), while Canada introduced Green Globe system (Green Building Initiative [GBI], 2008). Australia adopted Green Stars system (Green Building Council of Australia [GBCA], 2008a). In Europe and East Asia, many systems were either already in place or still under development. Analogous to many countries around the world, Thailand also began to create E&E rating systems which one of them is TEEAM—Thailand Energy & Environmental Assessment Method (Chindawanik, 2007a, 2007b).

In this article, the general characteristic of each E&E rating system is reviewed and summarized. Then, one particular rating system called LEED is selected to be a case study for representing E&E general composition. As the readers develop better understanding in green building and E&E systems, the discussion then shifts toward the successful practices and technologies for green buildings to be certified by LEED and other E&E rating systems.

2. Summary of Energy and Environment Rating Systems

In this section, selected E&E rating systems were categorized by responsible organizations, effective countries, available products, scoring categories, and achievable ranks. Major rating systems which are not only adopted in their original country but also accepted internationally are shown in Table 1. Such systems include LEED, BREEAM, Green Star, and Green Globe. Moreover, one newly developed rating system called TEEAM is added to Table 1 to represent a system from Thailand. The components of these rating systems are based on the current available versions which are subjected to change when the updated version is released.

These rating systems share both commonalities and differences. Most of them were operated by the third party organizations that are independent from governments and private organizations. These systems provide the products that fit the different building types, i.e. residence and non-residence. Some rating systems offer products matching the building conditions such as new, renovation and existing. Throughout the design and construction process, all systems are based on the green building principle which covers resources conservation, waste reduction, and occupant's well-being enhancement. The difference is how these principles are grouped or separated for the scoring purposes. For instance, LEED puts the CFC (Chlorofluorocarbon) refrigerants which is the substance that can destroy ozone layer and cause green house effect in Energy and Atmosphere category, while BREEAM puts it in Pollution category (BRE, 2008b; USGBC, 2005). Prior to the scoring tasks, most rating systems require a green building to pass the prerequisites which are scoreless but mandatory. After passing all perquisites, the score from all categories are then added up to be the total score. Based on this score, each E&E rating system can then justify the rank of a green building which typically ranges from 4-6 levels.

Table 1. Comparison of five energy and environmental rating systems.

Rating Systems	Institutes	Products	Categories	Achievable Ranks
U.S. GREEN BUILDING COUNCIL LEED USGBC	**USGBC** **US Green Building Council** Originated in US but effective worldwide	LEED-New Construction LEED-Existing Building: Operation and Maintenance LEED-Commercial Interior LEED-Core and Shell LEED for Homes	Sustainable Sites Water Efficiency Energy & Atmosphere Materials & Resources Indoor Env. Quality Innovation & Design Process (For LEED-NC)	Platinum (>52) Gold (39-51) Silver (33-38) Certified (26-32)
breeam	**BRE** **Building Research Establishment** Originated in UK but effective worldwide	BREEAM Courts BREEAM Ecohomes BREEAM Industrial BREEAM Offices BREEAM Healthcare BREEAM Prisons BREEAM Retail BREEAM Bespoke (Hotels, Laboratories, Leisure complexes, Shared accommodation)	Management Energy use Health and well-being Pollution Transport Land use Ecology Materials Water	Excellent Very good Good Pass
green star	**GBCA** **Green Building Council of Australia** Originated in Australia and effective in New Zealand, and South Africa	Green Star–Education Green Star-Office Design Green Star-Office As Built Green Star-Office Existing Building Green Star-Retail Centre	Energy Management Water Indoor Env. Quality Transport Ecology Land use Emissions, Materials Innovation	1-6 Stars However, GBCA only certifies the following ratings: 4 Star Green Star (score 45-59) 5 Star Green Star (score 60-74) 6 Star Green Star (score 75-100)
GREEN GLOBES	**GBI** **Green Building Initiative** Originated and Canada and effective in US and UK	New Construction or Significant Renovation Management and Operation of Existing Building	Energy Indoor Environment Site Resources Water Emissions& Effluents Project Management	For Canada For US 5 (85-100%) 4 (85-100%) 4 (70-84%) 3 (70-84%) 3 (55-69%) 2 (55-69%) 2 (35-54%) 1 (35-54%) 1 (15-34%)
TEEAM	Minister of Energy, Thailand and Chulalongkorn University Initiated and only effective in Thailand	R-Residential O-Office H-Hospital S-Shopping	Site Landscape Envelope Air-Conditioning Lighting Passive & Renewable Energy Sanitary Material Energy Efficiency Tech.	Environmental Prerequisite + Energy Rating Excellent (>70) Very good (55-69) Good (40-54)

The ranked green building can benefit owners, occupants, and practitioners. Better IEQ attracts more people who want to visit, live, and work in green building. Moreover, green building allows owner to increase the building/property value and boost cooperate image. With the appropriate design strategies, energy and water saving can soon offset the possible higher construction cost. In some counties such as US, certified green buildings by USGBC are promoted through tax exemption and waiver programs (USGBC, 2008d). For the architectural professionals, green building stimulates research and learning activities. Since R&D (Research and Development) is part of green building, it might be possible to increase the design fee following not only project cost alone but also building performances (Sreshthaputra, 2008). Because of all these benefits, practitioners are attracted to obtain the certification for their projects more and more. Understanding the mechanism of E&E system will be greatly helpful for reaching the goal. In this review article, the mechanism and compositions of E&E system is discussed through LEED, the case study of the most successful rating system nowadays.

3. Case Study of E&E Rating System: LEED

In early 90's after BREEAM movement in UK, USGBC, which is a group of building professional in US, introduced the green building assessment system called LEED. US and international practitioners across the various disciplines related to building industry form this consensus-base system which addresses the issues defined as green buildings. Since 2000, LEED has been successfully adopted by many practitioners in more than 2,000 certified projects and 17,000 registered projects around the world (USGBC, 2008a). It opens a new gateway for many architects, engineers, contractors, and other professions to join the green building industry as one of 70,000+ LEED AP (LEED Accredited Professionals) worldwide. Current US policy of newly elected Barack Obama just announces new aggressive policy on promote green buildings and green jobs. He aims to implement LEED to new and existing government building which should increase energy efficiency 40% and 25%, respectively. Five millions new jobs related to green industry will be supported by more than 150 billion US dollars which will be spent on promoting renewable energy, energy efficiency, newly advanced fuels, and smart electricity infrastructures (USGBC, 2008b). Not just in US, LEED began to influence several new construction projects in many countries including Thailand. After a carpet factory called InterfaceFLOR became the first approval of LEED-certified ranking, many upcoming projects possibly select USGBC to certify their green buildings. By understanding LEED categories and characteristics, it might benefit both readers who just want to understand E&E system in general and readers who desire to adopt LEED in their future projects.

3.1 LEED Categories

Though LEED has various products as shown in Table 1, the main focus of this section is LEED-New Construction and Major Renovation or LEED-NC. LEED divided green building into six categories including Sustainable Sites (SS), Water Efficiency (WE), Energy & Atmosphere (EA), Materials & Resources (MR), Indoor Environmental Quality (IE), and Innovation & Design Process (ID). The proportion of available points in each category is demonstrated in Figure3. Total score of LEED is 69 points with 6 prerequisites and the highest portion is dedicated for EA category with 17 points. Projects that pass all prerequisites will be ranked as Certified with 26-32 points, Silver with 33-38 points, Gold with 39-51 points, and Platinum with more than 52 points (USGBC, 2005). The detailed components of LEED-NC and associated credits (within the parentheses) are demonstrated as follows:

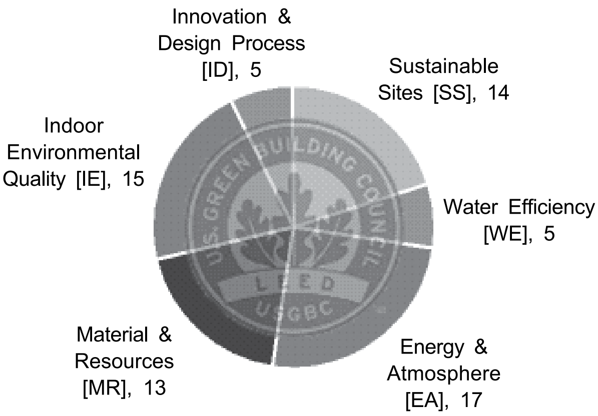

Figure 3. LEED-NC V2.2 points by categories.

3.1.1 Sustainable Sites [SS]

This category covers the impact of green building before construction and during operation. A single perquisite (SS P1) forces the builders to prevent the pollution for construction activities which might disturb soil, water, and air of site and surroundings. Then, the site should not be located in the restricted area (SS1) but rather located in previously developed area (SS2) or brownfield (SS3). The location of the site should be easy to access by mass-transit which will reduce the use of personal automobile (SS4). For the site planning, the building should have small footprint but maximizes open space with local vegetation for people and wildlife habitat (SS5). Combining vegetation and pervious and reflective pavement, building should reduce storm water run-off (SS6) and heat island effect (SS7). Outdoor and indoor lighting systems should not pollute the surroundings (SS8).

3.1.2 Water Efficiency [WE]

Preservation of portable water is the main concern of this category. Landscape irrigation should be almost free from portable water demand (WE1). Water closet and urinals should either use less water or black water from these equipments should be treated to match the tertiary standard (WE2). For the indoor plumbing system, the portable water of the project excluding landscape should be reduced by 20-30% (WE3).

3.1.3 Energy & Atmosphere [EA]

This category aims at reducing the energy consumption and atmosphere disturbance from design to operation phrases. To qualify for this category, building must at least match the energy standard (EA P1), use non-CFC refrigerants (EA P2), and perform standard commissioning (EA P3). By exceeding energy standard (EA1), utilizing renewable energy (EA2), and selecting least harmful refrigerants (EA4), a green building is estimated to score many credits in the design phase. Once the construction is complete, a green building should be employed full-scale commissioning by the third party (EA3) and it should be measured and verified to confirm the estimated performances (EA5). Owners should consider purchasing the green power from the certified providers (EA6).

3.1.4 Materials and Resources [MR]

The objective of this category is to preserve the world resources. Green building must establish the waste management program (MR P1). For existing building, maintaining the majority of non toxic structure, envelope and interior materials (MR1) are highly recommended. During and after construction, waste should be diverged away from landfill (MR2). Building material and furniture should be the combinations of reuse (MR3), recycle (MR4), regional (MR5), and rapid-growth (MR6). Additional score can be obtained if wood in the project is certified (MR6).

3.1.5 Indoor Environmental Quality [IE]

Occupants' well-being should be enhanced in any green building. The prerequisites for green building include meeting the ventilation design standard (IE P1) and controlling or prohibiting smoking (IE P2). To enhance Indoor Air Quality

(IAQ), green building should increase ventilation rate (IE1), monitor outdoor air (IE2), install low emitting materials (IE4), and control the sources of pollutants (IE5). IAQ should be the priority not only for the occupants but also for the workers during the construction (IE3). Occupants should be allowed to control their lighting and comfort preferences (IE6). HVAC should be designed and verified to pass the thermal comfort need and standard (IE7). Regularly occupied space should utilize daylight and provide outdoor view access for the majority of occupants (IE8).

3.1.6 Innovation & Design Process [ID]

Green building should not be limited to LEED requirements but rather it should perform to exceed expectation. Additional scores can be archived if any green building reach exemplary performances or demonstrate the sustainable policy beyond the scope of LEED (ID1). To ensure that all the requirements are conformed and, to promote the green building participation, at least one LEED AP (Accredited Professionals) should be included in the design team (ID2).

3.2 LEED Compliance Methods and Scoring Options

In addition to the LEED components that are quite straightforward, key successful characteristic of LEED is the flexibility of the compliance methods and scoring options. Four types of compliance methods including standard, prescriptive, trade-off, and performance-base are designed to fit the characteristic of each point. In some LEED credits, multiple compliance methods are available for practitioners to select the most effective and convenient scoring options. The complete list of LEED-NC re-quirement, points, required standards, and com-pliance methods are in Table 2 located in Appendix section. Details of four compliance methods are discussed as follows:

3.2.1 Standard Compliance

LEED occasionally requires green building to pass some specific standards without any additional requirement. For instance, US EPA (EPA, 1992) must be complied for credit SSP1 (Construction Activity Pollution Prevention).

3.2.2 Prescriptive Compliance

LEED adds extra or specific requirements for any particular standard or reference. Usually, the requirement is numerical base. For instances, in credit SS5.2 (Site Development: Open Space), the first option is to provide additional 25% of open space from requirement. In credit IE2 (Increased Ventilation), the breathing zone outdoor air must be higher than the requirement in ASHRAE Standard 62.1, 2004 by 30% (ASHRAE, 2004c).

3.2.3 Trade-off Compliance

To accommodate the designers, LEED allows the designers to trade-off their design to surpass the benchmark. In credit SS7 (heat island), designers have choices to trade-off tree-shaded, open grid pavement, or highly reflected roof cover areas (ASTM, 1998) but the combined area must not be higher than 50% of site hardscape area. Another good example is credit IE4 (Low-Emitting Materials). In credit IE4.2 (paints and coatings), flat and non-flat paints should not have VOC (Volatile Organic Compound) exceeding 50 g/L and 150 g/L, respectively (GreenSeal, 2008). If the over-limited paints were already used, designers can use the low VOC paints for compensation in the area that is yet painted. However, the total amount of VOC must be at least equal and not over the limits for both cases. This method is called VOC budget method.

3.2.4 Performance-Base

This method has the highest flexibility for the designers though it occasionally depends on computer simulation which demands expertise.

LEED uses baseline model to be the benchmark for measuring the performance of proposed design. Baseline model strictly follows required standard and proposed model is the actual design. The score will be given accumulatively if the proposed model performs exceed the baseline model over a desirable range. Credit EA1 option 1 (Optimize Energy Performance) requires both baseline and proposed models to comply with ASHRAE 90.1 2004 appendix G (ASHRAE, 2004d). Proposed model must compete against baseline model which adopts good energy efficient practices such as good building envelope, appropriate glass area, efficient HVAC system, etc. The highest expectation of LEED for new building is reduction of energy cost up to 42% (10 points) and the minimum is 14% (2 points).

The first two compliance methods are traditional and frequently used by typically E&E rating systems. In TEEAM credit 4 (air-conditioning), green building can comply with prescriptive requirement by using efficient air-conditioning system to reach higher score. Also, prescriptive requirement in credit 3.2 (heat transfers of building envelope) rewards the building with WWR (Window to Wall Ratio) less than 30% (Chindawanik, 2007a). Prescriptive compliance might be simple and easy to comply but it can be resisted by the designers who dislike forced restriction. As a result, LEED provides the new compliance options to overcome this inflexibility. The performance-base compliance in credit EA1 permits designers to compare their proposed design against the qualified baseline model. In other words, it is possible to have 100% glazing WWR but the annual energy cost must be less than that of the baseline model.

4. Practices and Technologies for Green Buildings

To certify a green building is sometimes analogous to the construction permission process. There are rules and regulations that practitioners must follow. Rules and regulations are set to be overcome by using correct day-to-day practices and applicable technologies. Such practices and technologies must be proven and referable to well-known standards. In reverse, many new and unproven practices/technologies are yet accepted. In this section, selected practices and technologies that are potentially help the E&E qualification will be overviewed. These practices and technologies will support but not limit to just any project aiming for LEED certification. Extra and more tips/details can also be found in ASHRAE Green Guide (ASHRAE, 2003).

4.1 Appropriate Common Practices

Site planning, building design, materials choices, systems selection, sustainable activities are the category that practitioners must keep in mind when designing a green building.

4.1.1 Site Planning

The first step is to select the appropriate location for the site. The location should not be harmful to the nature such as farmland, potential flood plane, undeveloped land near water, site near wetland, and public park (US Code of Federal Regulations [USCFR], 2008a, 2008b). The site that becomes positive for green development should be previously developed with adequate population or services. Selected site should be accessible by various means of transportation such as bicycles, trains, and buses. The good site planning should allow the occupants to easily access these means of transportation as much as possible (Chartier & Hollingworth, 2004). For instance, there should be bicycle trail on-site leading to adequate parking spots near the building entrances and shower rooms. In United States, since up to 30% energy is spent on traveling to workplace (Wilson, 2007), green building should discourage personal fossil fuel-base vehicle. With mass transit systems, individual car parking area should be minimized (Shoup, 1999) but rather provide preferred parking area for low-emitting vehicles such as NGV (Natural Gas Vehicle) or hybrid cars. Tuck-under and shared parking lots are highly preferred for a green building because they allow the site open space to be enlarged (VanGeem, 2006). For the same reason, the size of building footprint should be also small as much as possible (Thompson et al., 2007). Large open space should be managed to be green area, leisure space, and storm water retention. By following LID (Low-Impact Development) guide (EPA, 1999), open space should be pervious to minimize water run-off and it should be planted with large tree for shading purposes. Selected tree and vegetation should demand less portable water and irrigated by collected rain or grey water. Hardscape pavement should be pervious, shaded, and reflective to reduce UHI (Urban Heat Island) effect. Past study indicates that UHI can cause the peak temperature of metropolitan such as Bangkok can be higher than the surroundings by 3.5°C (Boonjawat et al., 2000). To solve UHI and other problems, the good site planning practices have been demonstrated in the green hospital project called Metropolitan Hospital in Wyoming, Michigan (McCawley & Maine, 2007). See Figure 4. Green open space with storm water collection features and on-site bicycle system help this project archive LEED certified ranking.

Figure 4. Metropolitan Hospital in Wyoming, Michigan, designed by HDR Inc.

4.1.2 Building Design

Different climatic condition such as solar geometry, predominant wind, temperature profile, and humidity level are the factors impacting the building design (Olgyay, V. & Olgyay, A., 1963). Orientation and form of a green building can significantly impact building energy demand (Stein et al., 1992). In general cases including Thailand, building should be laid along East and West axis; thus, majority of the building façade should face North and South (Nittaya, 2002; Buranasomphob, 1996). Narrow part of the building facing East and West can avoid facing direct sun which can increase air-conditioning demand and glare problem. Opaque or small window area with shading services is highly recommended for these directions. North is the best direction where daylighting is most desirable and irradiance is least disturbing. North glazing area should be maximized and sun control devices should be provided. South facing f̃aade has the most uniform and intensive solar radiation which comes high altitude. Accordingly, glazing area should be optimized and shading devices are mandatory. Long south facing orientation is suitable for cross natural ventilation which is most beneficial to a passive design building. In order to use natural ventilation, green building must pass the criteria such as low cooling load and pollution (Chartered Institution of Building Services Engineers [CIBSE], 2005). When passing these criteria, natural ventilation may be used to increase period of thermal comfort, e.g., increase thermal comfort 20% annually in suburban of Bangkok (Tantasavasdi et al., 2001). Choice of having natural ventilation through operable window for individual comfort is desirable for occupants who live or work in a green building (Huizenga et al., 2006). However, the building must be able to be sealed and air-tighten when air-conditioning is operated (ASHRAE, 2004d). Building designed with a streamline form can reduce pressure difference which can increase infiltration and exfiltraiton (Boonyatikarn, 2002d). Energy efficient glass with optimum WWR can significantly reduce the building energy consumption. In Thailand, depending on glass types, recommended WWR ranges from 25%-40%, while skylight should not go beyond 2-5% of roof area (Chindawanik, 2007a, 2007b; ASHRAE, 2004d). Form of air-conditioned building should be compact to reduce the heat-transferable area but majority of occupied space should be accessed to view and daylight. Using narrow room depth (less than 12 m), room daylight access through single corridor, and daylit atrium/core can help reducing demand for electric lighting (Baker & Steemers, 2002; Saihong & Srisutapan, 2007). Locating open offices in the parameter zones and using interior glazing can help occupants having outdoor view access. A BREEAM bespoke excellent award winner 2008 (BRE, 2008c), Matthew Hay building at University of Aberdeen is the good example of compact design, appropriate WWR, and shading devices utilization. See Figure 5.

4.1.3 Materials Choices

A green building should be built with high performance, sustainable, and healthy materials. Building envelopes should be highly insulated

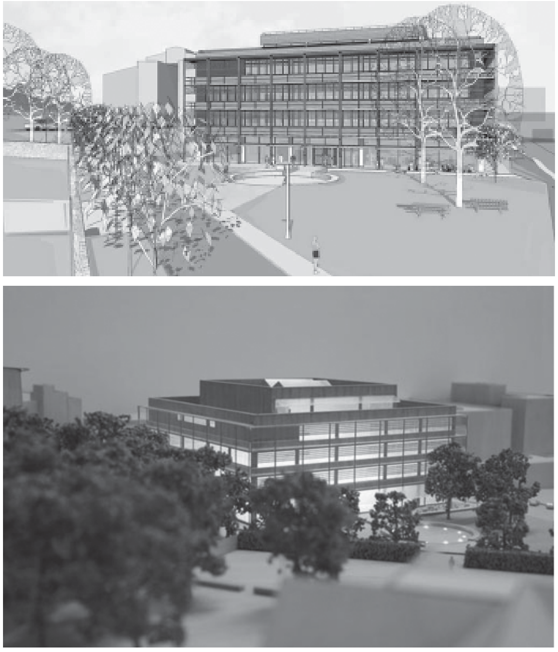

Figure 5. Matthew Hay building in Aberdeen, UK, designed by Bennetts Associates.

beyond recommendation of referred standards. ASHRAE 90.1 2004 recommends buildings in Thailand (climate zone 1) to have wall U-Value of 0.5-0.642 W/m^2 ^{o}C (insulation of R-13 (I-P)) and roof U-value of 0.193-0.358 W/m^2 ^{o}C (insulation of R-15 to 30 (I-P)). U-value for window with frame should be less than 6.92-7.21 W/m^2 ^{o}C (1.22-1.27 Btu/h ft^2 ^{o}F) with WWR not exceeding 40% where SHCG (Solar Heat Gain Coefficient) of less than 0.33 for north facade and 0.19 for other directions. At 5%, glazed skylight on frame should have U-value of less than 11.24 W/m^2 ^{o}C (1.98 Btu/h ft^2 ^{o}F) and SHGC of less than 0.19 (ASHRAE, 2004d). It was found that this recommendation is very close to what was proposed in TEEAM, particular the opaque wall portion (Chindawanik, 2007a, 2007b). In contrast, glazing U-value proposed by ASHRAE is much higher than what was recommended for air-conditioned building in Thailand. Glazing U-value with low-e coating can go lower to 1.64 W/m^2 ^{o}C (0.29 Btu/h ft^2 ^{o}F) (Boonyatikarn, 2002b). In a major renovation project, it is best to preserve new unexcavated materials (McDonough & Braungart,

2002) by maintaining most building envelopes and structures. Only hazardous materials should be removed, while the performance of usable envelope should be strengthened to meet the required standards. The preserved structure and envelope can conserve construction energy which takes into account of 11.14% of US energy annually (Stein et al., 1980) and they can significantly reduce the construction waste going to landfill. If it is a new construction project, considering reuse, recycle, regional, and rapid renewable materials for building, interior, and furniture. Reuse materials are preserved from demolished buildings such as doors, windows, exterior walls, and interior panels. Similar to reuse, recycle is very effective for conserving resources. In Japan, past study demonstrated that it is possible to build a building with recycled materials and, in turn, conserve unexcavated resources up to 50% (Gao et al., 2001). Recycled material can be categorized as pre and post-consumer content. Pre-consumer is the materials left over from the manufacturing process such as sawdust, chips, sunflower seed hulls, etc. Post-consumer is the material from consumers or households such as demolition debris, materials collected through curbside, etc. Regional material must be extracted, processed, and manufactured near the construction site, e.g., 800 km (USGBC, 2005). Rapid renewable materials such as bamboo and cotton should have less than 10 years to grow. Besides the sustainability concerns, material should enhance occupants' IAQ. Sealants, adhesives, and paints with VOC should be avoided (Baechler, 1991) and pass necessary standards (GreenSeal, 1997, 2000, 2008). Carpets should be certified by approved institute/program, while composite wood and agrifiber products should not contain Urea-formaldehyde resins (USGBC, 2005).

The extreme case study of material choice is Proximity Hotel, a first LEED Platinum hotel in Greensboro, NC. See Figure 6 and Figure 7. This hotel recycled 87% of the construction debris (1,535

Figure 6. Proximity Hotel in Greensboro, NC, designed by Centrepoint Architecture (perspective).

tons), applied over 40% of the building materials locally, and used over 20% recycled content. High performance building skins help dropping energy cost up to 41% above ASHRAE standard (ASHRAE, 200d). For the interior spaces, low-emitting VOC paints, adhesives, carpets, etc., reduce indoor air contamination (File, 2008).

4.1.4 Systems Selection

Building systems including water, HVAC, and lighting are the mechanism driving a green building. In a major city such as Bangkok, portable water is consumed up to 1,200 billion cubic meters each year (Metropolitan Waterworks Authority [MWA], 2008). The majority of portable water is spent toward buildings through site irrigation and sanitary systems. Both systems of a green building should demand less portable water (including on-site well) by storing rain water, using grey water, and applying water-conserving technologies. Coming from showers, bathroom wash basins, clothes-washer, and laundry tubs, grey water is suitable for irrigation and flushing systems such as urinals and water closets. These functions can be also supported by run-off rain water which can be applied to the process water systems such as chilled water and cooling tower. A green building should apply advanced irrigation technologies such as drip and micro-mister and water-conserving technologies, i.e. low-flow water closets and waterless urinals. For HVAC system which consumed the

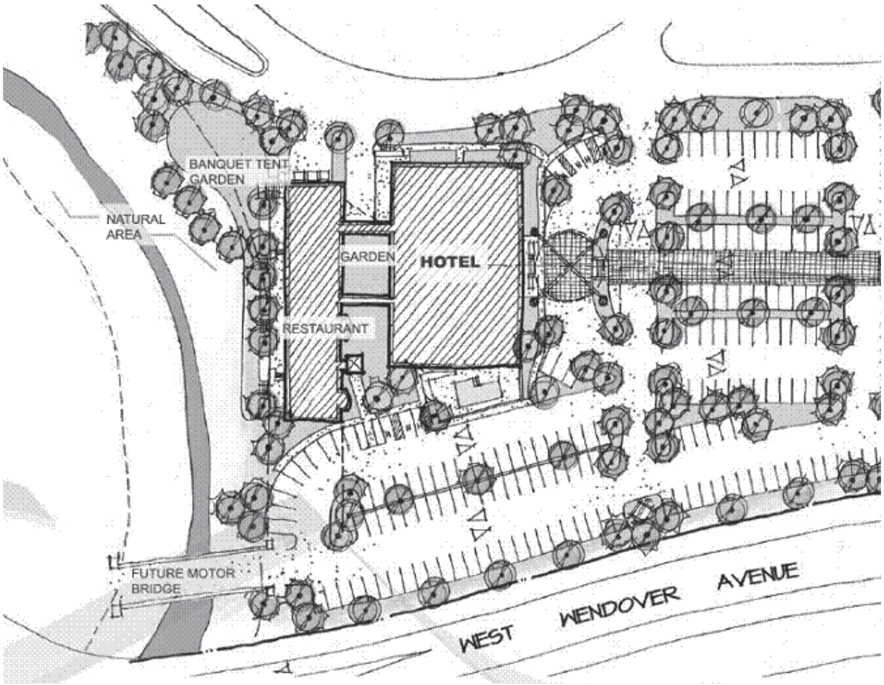

Figure 7. Proximity Hotel in Greensboro, NC, designed by Centrepoint Architecture (layout).

majority of building energy (Stein, 1992), the rule of thump is simple. HVAC must be most efficient as long as remains environmental friendly. So, it is best to avoid inefficient systems such as DX (direct exchange), reheat fan, multi-zone, and dual duct. In stead, practical systems such as fan coil, Variable Air Volume (VAV) and feasible technologies such as variable speed fan/pumps, energy recovery, high efficiency chiller, etc., should be the first choices. Such HVAC equipments should be practical and proven by trusted organizations such as ASHRAE and ARI (Air-Conditioning and Refrigeration Institute). Outdoor air monitoring system can help improving IAQ, while refrigerants used in HVAC equipments should not disturb ozone layer and cause global warming. Similar to HVAC system, lighting system should be efficient without causing lighting pollution. High efficiency of lighting system can come from daylight integration and energy efficient light sources/fixtures. Both strategies can reduce period of electric lighting and LPD (Lighting Power Density) (ASHRAE, 2004d; Rea, 2000). Interior lighting should avoid spill-over to outdoor through windows. Lighting distribution of landscape, parking, and fã̃ade should remain only within site boundary. Also, light fixtures in these areas should avoid illuminating the sky without necessity. For individual comfort, both lighting and HVAC should be adjustable and match users' preferences. Task and ambient light allow users to have individual lighting demand, while VAV (Variable Air Volume) system provides a good balance between personal comfort and energy saving (Bobenhausen, 1994). Located in Sydney, Hume city council, five Green Star rating project under office design category, is a good model for systems selection and design. See Figure 8. High efficiency HVAC system with UFAD (Under Floor Air Distribution) (Bauman & Webster, 2007) and CO_2 monitoring system helps this project archiving high energy and IEQ scores. For water and lighting systems, this project utilizes both grey water for irrigation and high performance T-5 fluorescent lamp for electric lighting system (GBCA, 2008b).

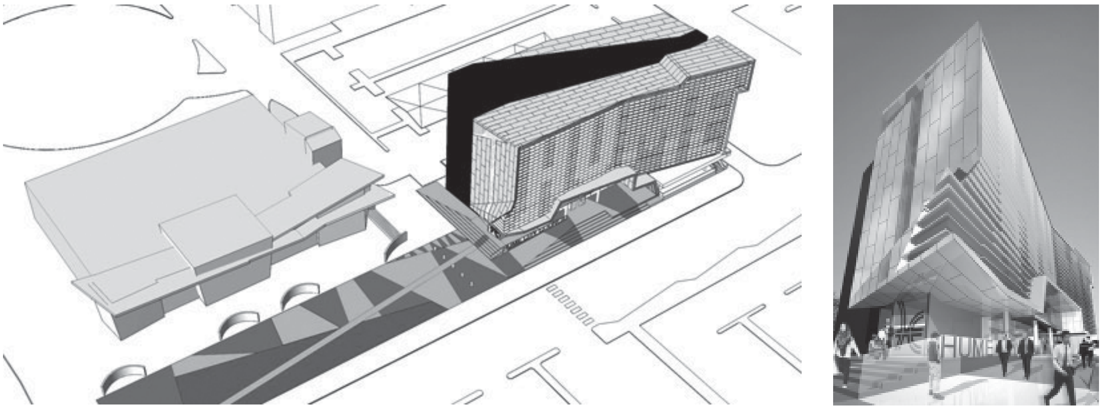

Figure 8. Hume City Council, Sydney, designed by Lyons.

4.1.5 Sustainable Activities

Building should be green from the beginning till the end of its life. Various activities such as green construction, measurement and commissioning, smoking & pollution control, green energy, car pooling, and recycle programs should be promoted in any green building. Knowledgeable contractors are the key person who must understand the green construction process. The process of constructing a green building should be least harmful to the environment and follow stringent standards such as EPA (EPA, 1992). Dust, top soil, and erosion are the main concerns. The construction wastes and debris must be managed for recycling or reuse process. On the site with rich nature, the construction activities must be scoped not too far beyond development area. During the design process, commissioning authority should be assigned to perform the commissioning task such as specification verification, producing commissioning report, writing an operation manual, etc. Additional task should include the verification of energy performance after the building is stabilized (International Performace Measurement & Verification Protocal [IPMVP], 2003). Building allowing smoking and having pollutant sources must be zoned. Such areas must be confined and performed pressurization test (ASTM, 2003). Air exhausted from these zones shall not be recirculated back to return air stream (ASHRAE, 2004c). For a green building owners, purchasing green energy which renewable energy is the primary source can be the strong message to public at large (Green-e, 2008). To reduce individual cars, a green building owner should provide shuttle buses routed for mass transit systems. Otherwise, smaller activities such as car pool board can be also helpful. Owners should also provide the material storage for sorted recycle materials such as paper, corrugated cardboard, glass, plastics and metals, etc. Excellent sustainable activities can be found in the four globes and LEED platinum project (The American Institute of Architect [AIA], 2006) called Alberici Corporate Headquarters in St. Louis, Missouri (Figure 9). Packed with energy efficiency and sustainable practices, this building was intensively commissioned and equipped with sub-meters for monitoring major energy uses (GBI, 2006).

4.2 Green Technologies

The unique thing for technologies qualifying for certification in any E&E rating system is reliability. Technologies must be studied by many practitioners and proven to be tangible and effective. Sometimes, such technologies are required to be supported by trusted standards. In other words, it is not necessary for brand new technologies to be qualified for a green building project. In this section, selected technologies, i.e. Xeriscaping, green roof,

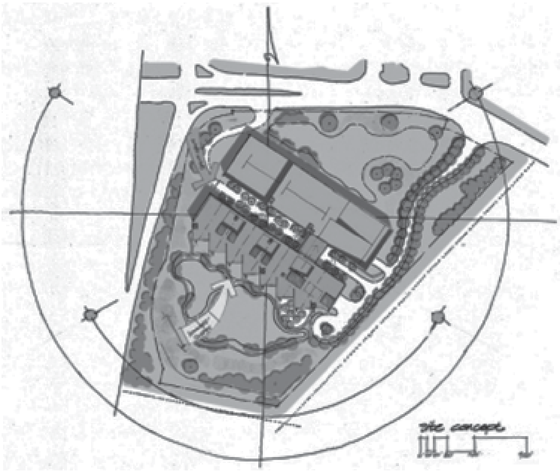


Figure 9. Alberici Corporate Headquarters in St. Louis, MO, designed by Mackey Mitchell Associates.

geothermal cooling, and other approved technologies by E&E rating such as LEED will be presented and discussed.

4.2.1 Xeriscaping

This term refers to sustainable landscape system that demands less or no irrigation. As descried in Chapter 10 in *Landscape: Principles and Practices*, there are seven principles for applying Xeriscaping which includes proper planning and design, proper soil analysis, appropriate plants selection, practical turf area, efficient irrigation, mulching, and appropriate maintenance (Ingel, 2003). This landscape system is widely successful in US particularly in arid states such as Arizona and California. Past studies show that 39 species in Southern California has no negative consequences after no irrigation (Harris, 1992). In Thailand, the record from Thai Meteorological Department shows that total precipitation in 2007 is more than 1,677 mm (Thai Meteorological Department [TMD], 2008). This amount of rain water exceeds the threshold of the US humid region which is 1,000 mm (USGBC, 2005); thus, applying Xeriscape in Thailand should be a lot easier. Further, choices of local plants are available for the designers. Local plants usually tolerate local weather, deceases, animals, and insects. Some local plants even demands the small amount of water for photosynthesis matching available rainfall or underground water. Examples of water conserving trees include bamboo (ไผ่), pudding pine tree (คูน), ficus (ไทร), rain tree (จามจุรี), tamarind (มะขาม), etc., and water conserving shrubs include aloe (ว่านหางจระเข้), desert rose (ชวนชม), bougainvillea (เฟื่องฟ้า), vetiver grass (แฝก), etc (Srisapapat, 2002). By utilizing rain water, practitioners should consider the efficient irrigation techniques such as drip and micro irrigation (small sprinklers and micro-jets or drippers) (USGBC, 2005; Thongaram, 2000). Xeriscaping is helpful for green building projects aimed at scoring for water efficient landscaping categories. Scoring in heat island reduction, open space, and stormwater design credits are the possible indirect benefits.

4.2.2 Green Roof

In a small site where the land for green area is limited, green roof is one of the best alternatives. In stead of having paved roof with metal or concrete, planting trees, shrubs, and grasses can significantly improve the performances. Reduction of roof surface temperature from evaporation process can mitigate heat island effect. Past result shows that, by increasing green area by 10% in urban area, ambient air temperature might drop roughly 4°C (Gill et al., 2007). Green area on a roof is considered as pervious surfaces where water can be absorbed for drainage and evaporation; thus, green roof can help delaying stormwater run-off. Ground coverage, e.g. plants, is important because it maintains adequate moisture within green roof layers. Absorbed moisture cools down the ground temperature and, in turn, reduces cooling load (Yimsrual, 1998). Field study in Canada shows that green roof reduces cooling energy by 75% as compared to typical insulated roof. As shown in Figure 10, green roof can act as a good insulation system because heat flux before insulation layer decreases by almost 35 W/m^2 (Liu & Baskaran, 2003). These characteristics are less dependent in plant species but it is best to consider local plants first. There are two types of green roof systems for intensive and extensive uses. Intensive green roof is a functional roof garden where load can be up to 700-1,500 kg/m^2. Functioning as a roof with less activity, extensive green roof is light weight with load around 300-1,000 kg/m^2 and ground depth only 2.5-12.5 cm (1-5 inches) (Vienravee, 2005; Scholz-Barth, 2001). See Figure 11.

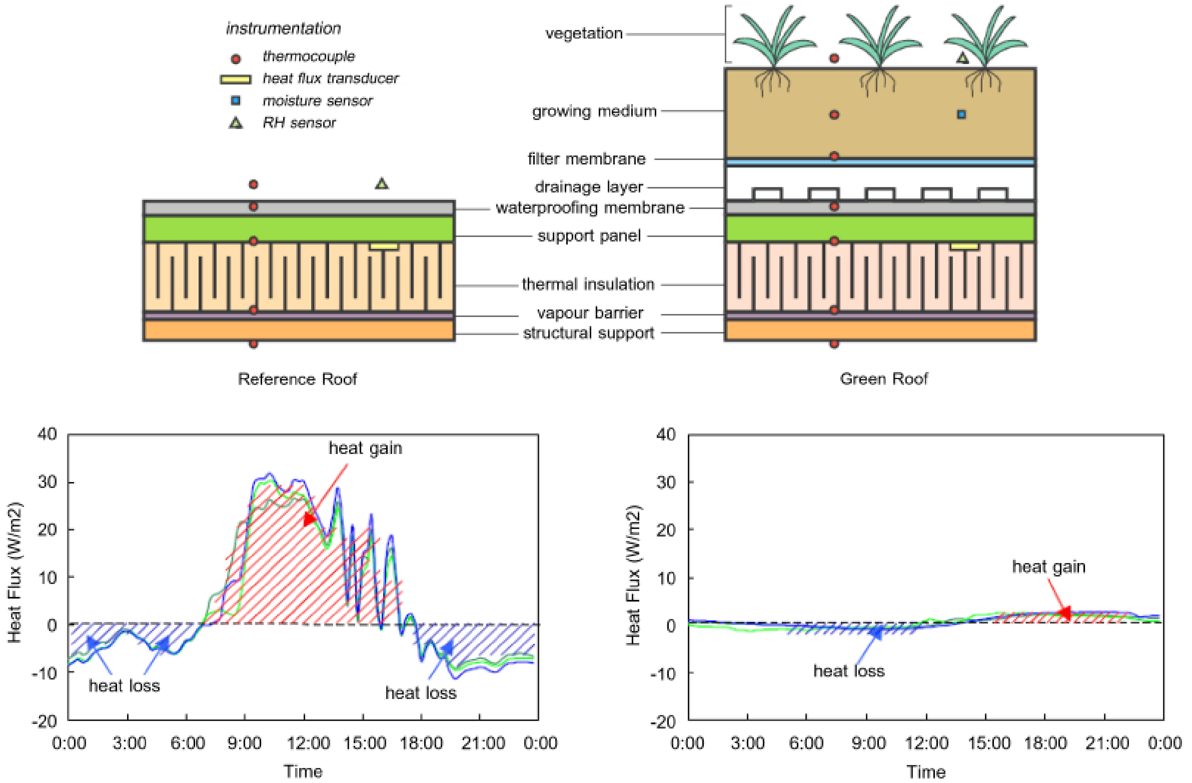

Figure 10. Cooling load reduction of typical roof (left) as compared to green roof (right) in Ottawa, Canada, on July 16th (Liu & Baskaran, 2003).

Figure 11. Extensive green roof of LEED platinum winner, California Academy of Sciences, designed by Renzo Piano.

To cut-down extensive green roof's weight, climbing-plant panel is an option that can be used as roof or wall surfaces. With the proper installation and plant density, climbing-plants can reduce peak surface temperature more than 6°C as compared to typical white masonry surface (Laopanitchakul & Srisutapan, 2007). By providing proper access, green roof can be also utilized as an open space for a green building. For any site where ground open space is limited, green roof might help directly scoring in multiple credits scoping site development (open space & wildlife habitat), storm water, and heat island. Indirect benefits might extend for scoring in an energy performance category.

4.2.3 Geothermal Cooling (Heating)

Typically, heat can be removed from an air conditioning space by using refrigeration cycle. Heat rejection to higher outdoor air temperature is possible because temperature of condensed refrigerant (up to 60°C) is much higher than the peak outdoor air temperature (Stein et al., 1992). Still, extreme outdoor air temperature is one major problem of a HVAC system. Overheated temperature of outdoor air blocks the heat rejected from a condensing unit or a cooling tower which their efficiency consequently drops. Founded in 1940's, geothermal cooling/heating takes the advantage of constant lower ground temperature for heating (cooling) discharges (EERE, 2008). Year round ground temperature of US temperature ranges from 7°C to 21°C (EERE, 2008), while in Bangkok the ground temperature ranges 27°C at 1-2 m depth as compared to peak temperature in Bangkok of 35-40°C (Khedari et al., 2001). Since the ground conditioning allows heat from a HVAC system to be removed much easier, the efficiency or Coefficient Of Performance (COP) is much improved to as high as 7-8 (Khedari et al., 2001). Past studies show that the electric energy in a US home can be reduced by up to 25-50% if the geothermal cooling (heating) is installed (Ochsner, 2007). To avoid excessive use of refrigerant, water loop is used to transport the heat into the ground. Heat rejected from a geothermal system can be also utilized for no-cost domestic hot water heating before going into ground loop for heat dissipation (Ochsner, 2007). See the diagram in Figure 12. Different ground loop types are available for different site conditions. Figure 13 (left) shows the open loop system that can be used when ground water is plentiful or large lakes are available on-site (Boonyatikarn, 2002a). The advantage of this system is low installation cost and high efficiency; however, the maintenance due to poor water quality is the main concern. To lessen the maintenance problems, the close loop system is an alternative. In Figure 13 (mid), a site with large landscape area is possible for horizontal loop system. A small site has not choice but to use vertical loop system which the ground must be drilled deeply for placing the water loop (EERE, 2008; Ochsner, 2007) See Figure 13 (right). In a large scale project, the geothermal cooling can be coupled with the typical cooling towers as demonstrated in Figure 14. Large amount of heat will be dumped in water loop before the rest will be dissipated by cooling towers. This hybrid system is successfully operated in a mid-rise hotel in Florida (Barfield, 2008). Many confirmed case studies in US indicate

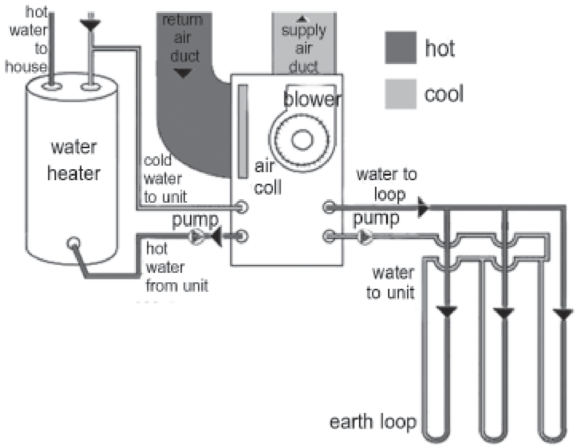

Figure 12. The geothermal cooling system with domestic hot water integration.

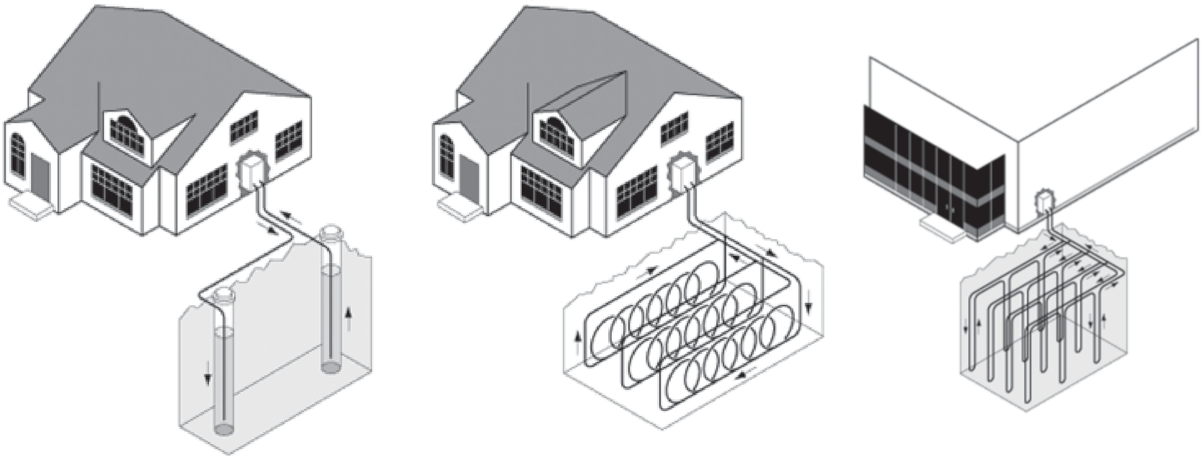

Figure 13. Geothermal ground loop systems: open (left), close horizontal (mid), and close vertical (right) (EERE, 2008).

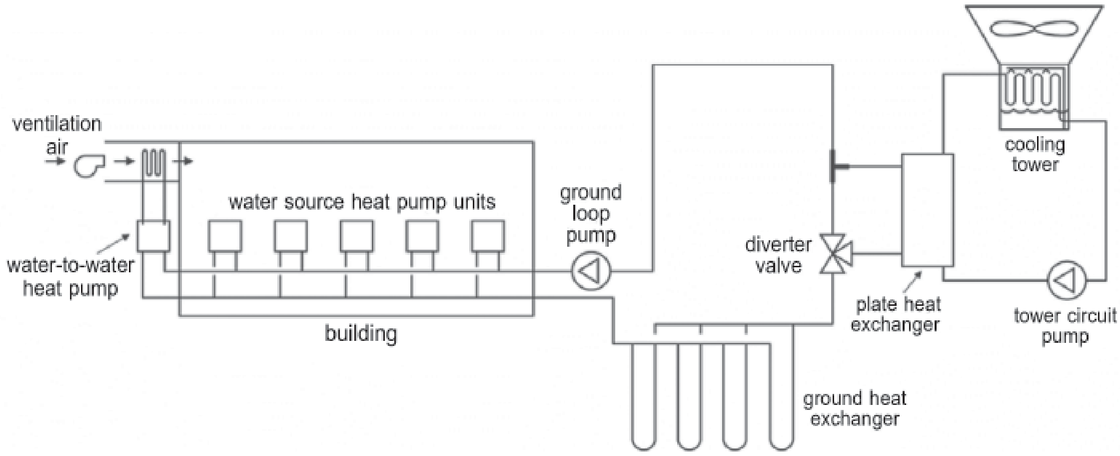

Figure 14. The hybrid geothermal cooling system with heat exchanger (DOE, 2001).

that hybrid system is more effective in hot climate and can improve the performances of typical geothermal system up to 20-60% depending on the control schemes (DOE, 2001). In colder climate where space heating is needed, geothermal heating is also more effective and feasible than typical furnace systems. In stead of rejecting the heat to the ground, the reversed refrigerant cycle or heat pump can bring the heat from the ground to warm up the space (Pahl, 2003; Yavuzturk & Spitler, 2000). Full details and sizing of both geothermal cooling and heating can be found in Chapter 32, *Geothermal Energy, of ASHRAE Handbook-HVAC applications* (ASHRAE, 2007). Because of its efficiency and versatility, geothermal system is already proven to be reliable for scoring in E&E rating system, particularly energy and atmosphere credits. In addition, since there is no need for water used in a cooling tower, a geothermal system can also score the water efficiency credit (USGBC, 2005).

4.2.4 Displacement Ventilation and Under Floor Air Distribution

An air distribution system acts as a mean delivering fresh air which is necessary for occupants. In *Ventilation of Buildings*, Awbi (2003) categorized five available room air distribution systems including mixing, local exhaust, piston, displacement, and impinging jet system. The physical setting of these system is shown in Figure 15 (Varodompun &

Navvab, 2007). The most common practice is mixing jet system where high supply velocity mixes room temperature and pollutants homogeneously. Pollutant level depends on purely the dilution process driven by the fresh air system within an air-conditioning unit. Further reduction of the pollutants level is possible if stratification is properly introduced and maintained. As demonstrated in Figure 16, when air velocity is low, heat and some pollutants float toward the room ceiling and, consequently, room air down below is left cleaner for breathing (Nielsen, 2000). By supplying low velocity, DV (Displacement Ventilation) can capitalize the benefit from stratification (Awbi, 2003; Skistad, 1994). Low supply velocity can be introduced by side-wall supply terminals near floor or by floor diffusers. In *ASHRAE Handbook of Fundamentals,* Chapter 33, the displacement system that employs floor diffusers is referred as Under Floor Air Distribution (UFAD) system (ASHRAE, 2005). The unique advantage of UFAD is the feature that allows users to independently control his/her thermal environment (Bauman & Webster, 2007). For UFAD and displacement ventilation, the indicator for justifying the performance of different air distribution systems called Air Change Effectiveness can be 1.2, while that of mixing system is 1 or even lower (ASHRAE, 2004c). See confirmed simulation result of DV in Figure 17. When Effectiveness is higher than one, IAQ of a given space is enhanced. Otherwise, the fresh air intake

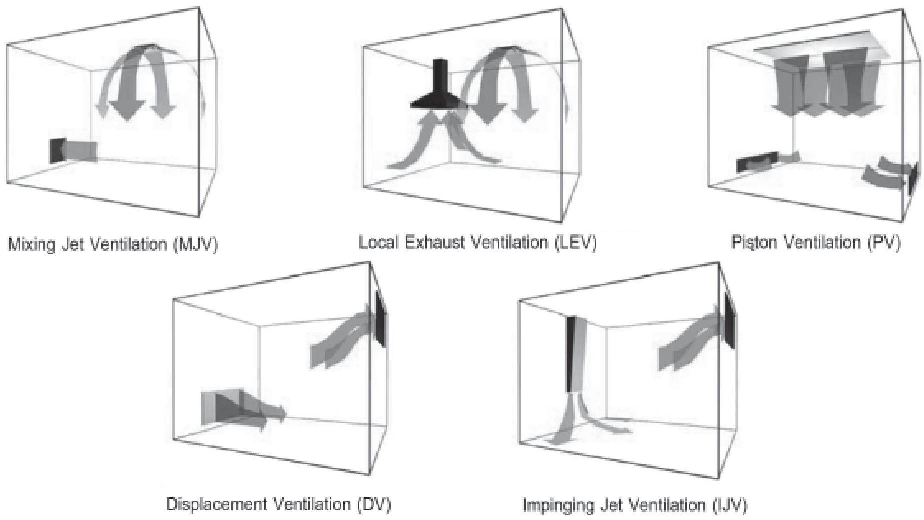

Figure 15. Five air distribution systems.

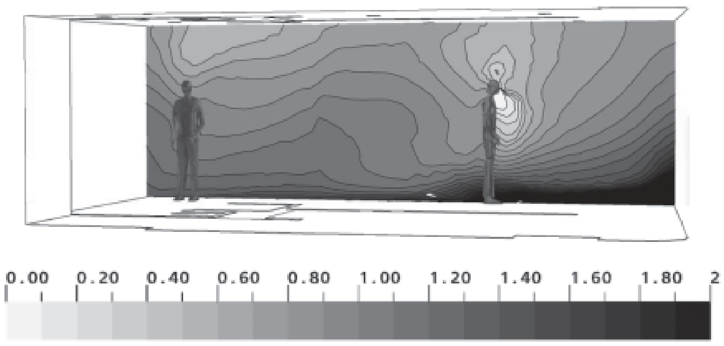

Figure 16. Shadow graph technique revealing stratification of DV system (left) (Settles, 1997).

Figure 17. Air Change Effectiveness of DV system (right) (Varodompun & Navvab, 2007).

can be reduced without giving up proper IAQ. In extreme climate condition such as Bangkok, this reduction can decrease both air-condition energy and size of a system that has the fresh air intake features. Since high Air Change Effectiveness can only happen when a system is operated under cooling mode (ASHRAE, 2004c; Stanke, 2005), Thailand might be the ideal place for such systems. However, there is the restriction on supply temperature for DV and UFAD systems and it leads to a major drawback. To avoid stratification discomfort as defined in *ASHRAE Standard 55* (ASHRAE, 2004b), DV is allowed to supply only cooler than the room temperature only 2-3°C (Skistad, 1994). This leaves the problem for a HVAC system which supply temperature is usually at 13°C (or lower) for dehumidification process (Stein et al., 1992). To avoid high humidity problem, supplying at 22°C demands either reheat coils or Parallel Fan Power (PFP) boxes that can draw the return air to warm up the supply temperature (ASHRAE, 2005). Thus, the additional system can cost a building with DV system. To mitigate this consequence, new systems such as Impinging Jet and Confluent Jet are invented to be the alternatives. Past studies show that both systems allow typical cool supply temperature and, at the same time, stratification is properly maintained (Varodompun & Navvab, 2007; Karimi-panah et al., 2005; Karimipanah & Awbi, 2002). Currently, E&E rating system such as LEED only permit the building with DV system to be scored in IEQ (increased ventilation, thermal comfort controllability) and energy credits (USGBC, 2005). More advanced systems as motioned earlier needs to be tested by many institutes until the formal approval is granted.

4.2.5 Demand Control Ventilation

Besides the air distribution systems, Demand Control Ventilation (DCV) is another technology that can lower the air-conditioning energy. A major portion of energy is spent toward cooling or heating the outdoor/fresh air that must meet the codes or requirements such as *ASHRAE standard 62* (ASHRAE, 2004c). Introduced through a typical air handling unit, the volume of fresh air is normally fixed for ensuring the maximum ventilation demand (Bobenhausen, 1994). Under the normal operation, this demand is inconsistent as the number of occupants varies. Thus, it makes sense to control and vary volume of the fresh air to match the actual needs. Practitioners and researchers agree to use CO_2 as a threshold to control the fresh air (ASHRAE, 2004c). By placing the CO_2 sensor within the return air stream, it is possible to control the fresh air dampers for adjusting the proper rate of fresh air intake (Schell & Int-Hout, 2001). The balance between IAQ and energy conservation can be achieved through high precision damper control such as Fuzzy Logic Control which uses both outdoor air temperature and CO_2 concentration as indicators (Karunakaran et al., 2007). Past studies also indicated that DCV is good for densely occupied spaces such as classrooms, auditoriums, open offices, etc. Such spaces can not avoid high CO_2 concentration and occupancy fluctuation leading to excessive fresh air volume (Fisk & De Almeida, 1998). Having less CO_2 problem, lower densely occupied space should at least equipped with simpler system such as outdoor air monitoring system for ensuring the adequate fresh air rate (Fisk, 2006). After adopting DCV for decades, practitioners still improve the performances of DCV toward proper implementation and available technologies such as better sensors. Recent guideline indicates that DCV should be considered if the space has occupant area less than 3.7 m^2 per person and CO_2 sensor should be placed in the breathing zone (room height from 0.6-1.7 m (ASHRAE, 2004c)) not within the return air duct. Threshold for maximum CO_2 concentration should not exceed 600 ppmv (Apte, 2006). DCV using other means besides CO_2 is yet popular but there might be the needs for VOC, other gases, particle, as the demand for better IAQ grows. For the E&E rating system, DCV and outdoor air monitoring system can help obtaining energy performance and IEQ credits, particularly outdoor air monitoring category (USGBC, 2005; Lawrence, 2004).

4.2.6 Building Automation Systems

It is not mandatory for a green building to have a large complex and computer-based BAS (Building Automation System) although they do help the operators to control building systems easier. Rather, the simple automation systems that can responses to climate, occupancy patterns, and needs should be prioritized in a green building. Different types of sensor are the mechanism that allows building to react with current conditions. Estimated to save electric light energy up to 60% in US (Ihm et al., 2009), daylight responsive system of a green building can compensate the demand for electric lights by using lighting sensors. Series of energy efficient light bulbs and fixtures such as T5 fluorescent, Induction lamp, and LED (Light Emitting Diode) should be dimmable and correctly positioned with respect to room functions and daylighting pattern (Saihong & Srisutapan, 2007). Effective dimming system can provide additional saving up to 5% (Doulos et al., 2008). In unoccupied space, light and exhausted fan that are unnecessarily operated result excessive energy waste. Occupancy sensors can detect the movement of occupants and activate or deactivate both electric lights and exhaust fans to match the actual usages. In previous study, saving of office space and restroom with light occupancy sensor was 26% and 21%, respectively (Neida et al., 2001). This occupancy sensor also ensures light pollution reduction because lights are surely turned off after hour. For any large HVAC system, static pressure sensors can help AHU (Air Handling Unit) maintaining proper fan speed if VSD (Variable Speed Drive) of both supply and return fans (if necessary) are equipped (Kettler, 2004). A green building having proper automation system might be eligible for scoring in both energy performance and light pollution credits.

4.2.7 Other Potential Technologies

In addition to the technologies mentioned previously, readers should aware that there are other qualified technologies yet mentioned. Among such technologies, run-off water retention and treatment, on-site renewable energy, Combined Heat and Power (CHP), and advanced air conditioning techniques are all good examples which should be at least briefed. In addition to green roof, rain garden can reduce the amount or water run-off, while bioswales can improve the quality of storm water before discharging off-site. Considered as on-site renewable energy, photovoltaic (PV), Wind turbine, geothermal energy (not geothermal cooling), and on-site biomass are applicable sources for both energy efficiency and renewable energy credits (USGBC, 2005). If the energy source comes from CHP system which generates both electricity from fossil fuels and having chilled water or thermal energy as by-products, a green building might have a high chance to get big scores from energy performance credits. Though the score for CHP is not simple to be determined, LEED already adopt the rule for supporting buildings with this system (ASHRAE, 2003; USGBC, 2006). In addition to geothermal cooling, many technologies have been invented to improve HVAC efficiency. Fresh air supplementary system is one option to simultaneously improve energy efficiency and enhance IAQ (Stein et al., 1992), while a new air-conditioning technique called evaporative-cooled condenser promisingly increases the efficiency of small air conditioners (Yu & Chan, 2005).

5. Conclusions

As the demand for sustainability grows, the term "Green Buildings" is increasingly being referred by architects, engineers, and practitioners. Design solutions claimed to be green used to be fragmented and incomprehensive until E&E rating systems became available. Many rating systems such as BREEM, LEED, Green Star, Green Globe, TEEAM, and others, are considered as brands for green buildings. Each brand customizes its categories and benchmarks though the principle remains similar. Green building must be clean throughout the design and construction processes. Also, it must consume less resource, generates less waste, and enhances occupants' well being. Mechanism of E&E systems is the scoring systems that can quantify these practices and implementations. At the same time, different scoring system distinguishes one rating system from others. As one of the world leading systems, LEED is famous for its simplicity and flexibility. LEED provides a vast array of methods and options for six measures ranging from site, water, energy, materials, IEQ, and innovation in design. As already summarized in this article, there are practices and technologies assisting green building applicants for not only LEED but also others. As readers develop better understanding of green building and its E&E rating system, we should be aware of possible limitations. Similar to any civil law, there are still loopholes in every E&E rating system. It does not matter of how good the rating systems are. The fact is the systems to quantify green building are yet perfected. For many times, certified green buildings are skeptical and requested for investigation. Though new E&E rating system such as LEED 2009 will be released with the hope of reducing past weaknesses, it might not perfectly answer future negative comments. After all, it depends on practitioners to utilize E&E rating system with integrity, ethic, and knowledge for creating genuine green building which, in turn, functions as it has been intended for.

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Appendix

Table 1 is the criteria and points of each category of LEED-NC 2.2, excluding Innovation & Design Process (ID). It includes the standards and regulations for compliances to achieve desirable rank. Full details can be found in LEED-NC Reference Guide V2.2 (USGBC, 2005).

Table 1. LEED-NC 2.2 components and compliance methods.

SS	Sustainable Site	14 Points	Required Standards	Compliance Methods
SSP1	Construction Activity Pollution Prevention	-	Chapter 3 (EPA, 1992)	Standard (National Pollutant Discharge Elimination System, 2005)
SS1	Site Selection	1	(USCFR, 2008a, 2008b; FEMA, 2008; USFWS, 2008a)	Standard & Prescriptive
SS2	Development Density & Community Connectivity	1	None	Prescriptive
SS3	Brownfield Redevelopment	1	(ASTM, 2002) or (EPA, 2008)	Standard
SS4	Alternative Transportation	4	none	Prescriptive
SS5	Site Development	2	none	Prescriptive
SS6	Stormwater Design	2	Phase II Ch 4 (EPA, 1993)	Performance & Standard
SS7	Heat Island Effect	2	(ASTM, 1998)*	Tradeoff & Prescriptive
SS8	Light Pollution Reduction	1	(ASHRAE, 2004d)	Prescriptive & Baseline

WE	Water Efficiency	5 Points	Required Standards	Compliance Methods
WE1	Water Efficient Landscaping	2	none	Performance
WE2	Innovative Wastewater Technologies	1	none	Performance
WE3	Water Use Reduction	2	(US Congress, 1992)	Performance

EA	Energy and Atmosphere	17 Points	Required Standards	Compliance Methods
EAP1	Fundamental Commissioning of the Building Energy Systems	-		Prescriptive
EAP2	Minimum Energy Performance	-	(ASHRAE, 2004d)	Standard
EAP3	Fundamental Refrigerant Management	-	none	Prescriptive
EA1	Optimize Energy Performance	10	(ASHRAE, 2004a, 2004d; NBI, 2007)	Performance or Standard
EA2	On-Site Renewable Energy	3	(ASHRAE, 2004d)	Performance
EA3	Enhanced Commissioning	1	none	Prescriptive
EA4	Enhanced Refrigerant Management	1	none	Tradeoff
EA5	Measurement & Verification	1	(IPMVP, 2003)	Standard
EA6	Green Power	1	(Green-e, 2008)	Performance & Prescriptive

* Refer to most relevant ASTM standard and skip other indirect ASTM standards.

MR	Material and Resources	13 Points	Required Standards	Compliance Methods
MRP1	Storage & Collection of Recyclables	-	none	Prescriptive
MR1	Building Reuse	3	none	Tradeoff
MR2	Construction Waste Management	2	none	Tradeoff
MR3	Materials Reuse	2	none	Tradeoff
MR4	Recycled Content	2	(ISO, 1999)	Tradeoff
MR5	Regional Materials	2	none	Tradeoff
MR6	Rapidly Renewable Materials	1	none	Tradeoff
MR7	Certified Wood	1	(FSC, 2008)	Tradeoff

IE	Indoor Environmental Quality	15 Points	Required Standards	Compliance Methods
IEP1	Minimum IAQ Performance	-	(ASHRAE, 2004c)	Standard
IEP2	Environmental Tobacco Smoke (ETS) Control	-	(ASTM, 2003), Ch 4 (CEC, 2005)	Standard
IE1	Outdoor Air Delivery Monitoring	1	none	Standard & Prescriptive
IE2	Increased Ventilation	1	(ASHRAE, 2004c; CIBSE, 2005)	Standard & Prescriptive
IE3	Construction IAQ Management Plan	2	(SMACNA, 2007; ASHRAE, 1999)	Standard & Prescriptive
IE4	Low-Emitting Materials	4	(SCAQMD, 2003, 2004; GreenSeal, 1997, 2000, 2008; CRI, 2008)	Trade off & Prescriptive
IE5	Indoor Chemical & Pollutant Source Control	1	(ASHRAE, 1999)	Standard & Prescriptive
IE6	Controllability of Systems	2	(ASHRAE, 2004c), (ASHRAE, 2004b)	Prescriptive
IE7	Thermal Comfort	2	(ASHRAE, 2004b)	Standard & Prescriptive
IE8	Daylight & Views	2	none	Trade off & Baseline