DRAFT -- Opportunities for Green Building (GB) Rating Systems to Improve Indoor Air Quality Credits and to Address Changing Climatic Conditions

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Content

1. Introduction

The era of industrialization started the process of significant population migration from rural to urban areas (UN 2007). As a result, we live in a world with the majority of its population in urban environments. The trend is expected to continue at least through 2030 (Commission on Growth and Development 2008). This transition from rural to urban societies is very challenging from different perspectives including the infrastructure (Cohen 2003), where buildings play a vital role in this growth. The evidence of this growth is also present in data representing the energy consumption as well as CO_2 building-related emissions in the U.S. (EIA 2003 and 2007). This strong energy demand in residential and commercial buildings is to remain based on projections for year 2030 (EIA 2009). Interestingly, this is not the first time that the energy use in buildings became an obvious problem for economic growth and prosperity; we faced a similar problem in the 1970s, and at that time, the buildings were made more energy efficient by the use of tight construction and novel materials. The result was a reduction in energy consumption, but it also created a whole new set of indoor air quality problems (NIOSH 1997). Therefore, this new generation of buildings, which will be enabled by scientific developments supported through government agencies, need to take much broader perspective and include not only engineering of green building systems, but also outcomes for building occupants and building environmental impacts. This emerging research field could be labeled as urban eco-system analyses (United Nations University 2003), and certainly includes green buildings, their implications for indoor air quality and changing climatic conditions.

2. Green Building (GB) Rating Systems

In principle, green buildings represent responsible engineering of built systems with respect to their use of materials, energy, and water, as well environmental impacts. The aim of different green building rating systems is a reduction of building life cycle costs, while still accounting for environmental impacts on both environmental pollution and indoor air quality. A simple method to quantitatively account for all life cycle costs and environmental implications does not exists yet as the fundamentals of understanding urban eco-systems are still under development. Therefore, the existing Green Building (GB) rating systems are prescriptive suggestions to promote building design practices considered to be advantageous in reducing buildings' life cycle costs and other environmental impacts.

Several different GB rating systems emerged in recent years, including:

1. Building Research Establishment Environmental Assessment Method (BREEAM 1990)
2. High Quality Environmental standard (HQE 1992)
3. The Hong Kong Building Environmental Assessment Method (HKBEAM 1996)
4. Leadership in Energy and Environmental Design (LEED 1998)
5. Green Building Challenge Assessment Framework (GBTool/SBTool 1998)
6. Green Globes (2000)
7. Comprehensive Assessment System for Building Environmental Efficiency (CASBEE 2001)
8. Green Star (2003)

The U.S. Green Building Council (USGBC) established Leadership in Energy and Environmental Design (LEED 1998) targeting at first U.S. market, but its reach has expanded worldwide. Other international building rating systems include BREEAM (1990) from UK, HQE (1992) from France, HKBEAM from Hong Kong (1996), GBTool/SBTool (1998) from Canada, Green Globes (2000) from U.S. and Canada, CASBEE (2001) from Japan, and Green Star (2003) from Australia. This list is by no means an exhaustive list, and many new GB rating systems have been developed recently. In their most fundamental aspect, all of the rating systems provide guidelines on how to make a building "green" and some of the GB rating systems provide certification process, while others provide opportunities for a voluntary compliance. The building performance criteria that are typically considered include responsible management of resources such as land use, energy and water efficiency, recyclability of materials, reduction of CO_2 emissions, and improved indoor environmental quality. Detailed comparisons among different rating systems from different regions of the world are available in the literature (Bunz et al. 2006, Mao et al. 2009). An observation from these direct comparisons is that the energy and water efficiency criteria are mostly quantitative, while the indoor environmental quality criteria tend to be prescriptive.

3. GB Criteria Addressing Indoor Environmental Quality

In the oldest rating system, BREEAM, the indoor environmental quality is addressed in the section called “Health & Wellbeing”. The overall rating is on a scale of 100 points, and the total number of points assigned to the section on “Health & Wellbeing” is 15 points with each point being assigned to a single environmental quality issues (BREEM 2008). In BREEM, the minimal standards are set for High Frequency Lighting and Microbial Contamination points, but not for Indoor Air Quality point. Similarly to “Health & Wellbeing” in BREEM, the criteria that specifically address “Indoor Environmental Quality (IEQ)” in LEED certification process include ***two prerequisites*** (Prerequisite 1: Minimal Indoor Air Quality Performance and Prerequisite 2: Environmental Tobacco Smoke (ETS) control) as well as ***fifteen additional credits*** (USGBC 2010):

1. Outdoor Air Delivery Monitoring (IEQ 1),
2. Increased Ventilation (IEQ 2),
3. Construction Indoor Air Quality Management Plan—During Construction (IEQ 3.1),
4. Construction Indoor Air Quality Management Plan—Before Occupancy (IEQ 3.2),
5. Low-Emitting Materials—Adhesives and Sealants (IEQ 4.1),
6. Low-Emitting Materials—Paints and Coatings (IEQ 4.2),
7. Low-Emitting Materials—Flooring Systems (IEQ 4.3),
8. Low-Emitting Materials—Composite Wood and Agrifiber Products (IEQ 4.4),
9. Indoor Chemical and Pollutant Source Control (IEQ 5),
10. Controllability of Systems—Lighting (IEQ 6.1),
11. Controllability of Systems—Thermal Comfort (IEQ 6.2),
12. Thermal Comfort—Design (IEQ 7.1),
13. Thermal Comfort—Verification (IEQ 7.2),
14. Daylight and Views—Daylight (IEQ 8.1), and
15. Daylight and Views—Views (IEQ 8.2)

Twelve of these LEED credits are directly or indirectly connected to indoor air quality, which does not include lighting controllability (IEQ 6.1), daylight (IEQ 8.1) and views (IEQ 8.2).

It is important to notice that with a total of 100 base points/credits, a building can get the highest possible “Platinum” certification in the LEED rating system (80 points and above) and “Excellent” rating benchmark in the BREEAM rating system (85 points and above) without ever addressing any of points/credits associated with ***Indoor Air Quality (IAQ)***. In practice, certified projects typically address some of IAQ-related criteria because they are not hard to incorporate into building design. Nevertheless, a debate on GB certification criteria is building up as measured performance outcomes are becoming available for certified buildings (Baker 2004, Gifford 2008, Newsham et al. 2009). Still the vast majority of these studies are focused on energy efficiency with its quantitative evaluation of energy consumption by itself, while there are only few studies on IAQ and human health implications. Overall, it is important to study building energy efficiency solutions together with IAQ and human health outcomes because they can have opposing building design requirements (EHHI 2010). As a result, the current building design certification criteria will probably need to be reexamined in the light of future research findings.

In this report, the existing GB certification criteria are examined from the perspective of IAQ and climate change. The evaluations are grouped into four categories, three on IAQ and one on climate: (1) Moisture, Ventilation Rates and Thermal Comfort, (2) VOCs and Other Airborne Chemicals, (3) Particulate Matter, and (4) Changing Climatic Conditions. All of these evaluations are directly applied to the LEED rating system because it is currently the most widely use GB rating system in the U.S., and other GB rating systems, such as BREEAM, have major overlaps with LEED.

4. Moisture, Ventilation Rates and Thermal Comfort in LEED

GB certification criteria that are of particular interest in preventing potential moisture and mold problems include, but are not limited to:

1. Ventilation Rates, Infiltration and Operable Windows
2. Building Enclosure and Interior Materials

A detailed list of all different LEED credits that could lead to moisture problems in LEED certified buildings is available in the literature (Odom 2009a). This list includes LEED credits in the categories of Sustainable Sites, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality and Innovation in Design. Specifically for Indoor Environmental Quality, the credits associate with potential moisture problems include: Prerequisite 1 on minimal indoor IAQ performance, as well as IEQ 1, IEQ 2, IEQ 3.1, IEQ 3.2, IEQ 5 and IEQ 6.2.

Considering ventilation rates, the Indoor Environmental Quality section directly addresses IAQ by requiring compliance with the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 62.1-2007. The main purpose of the ASHRAE Standard 62.1 is to "*provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects*." The standard outlines a ***Ventilation Rate Procedure*** to calculate the required amount of outdoor airflow rate based on the number of occupants, building floor area, and building occupancy types. This is a prescriptive method that is specifically designed to remove CO_2 resulting from occupational berating, and the additional floor-based component is included to address non-specified additional pollutants. The standard assumes that all of gaseous pollutants typically found in indoor environments, such as Volatile Organic Compounds (VOCs), will be sufficiently diluted. This might or might not be the case depending on the actual pollutant source strengths. Therefore, the standard offers an alternative ***IAQ Procedure*** for building designers who know the type and source strength of pollutants, which is not a typical building design situation. As a result, the only certain outcome that the building occupants have based on the minimum standard requirements is that the CO_2 will be sufficiently diluted. Nevertheless, if the outdoor CO_2 levels increase significantly, the recommended flow rates will have to be revisited.

With an increased pollutant dilution rate as a goal, the LEED certification process encourages building designers to include additional amounts of outside air when compared to minimum ventilation requirement for regular buildings. While this is a good strategy for the dilution/removal of pollutants with the internal source location, it might be counterproductive for moisture removal in hot and humid climates. In regions with a high ambient dew point temperature and high relative humidity, there is a direct relationship between the mechanical ventilation rates and ***moisture problems***. The increased amount of outside air provided by mechanical ventilation system actually delivers additional moisture into buildings in hot and humid climates (Odom 2009b). Therefore, the regional weather should be an important factor in deciding whether an additional amount of outdoor air should be delivered to a building seeking LEED certification. LEED certification experts should look for trade-offs between selection of mechanical ventilation systems, building energy consumption, and acceptable risk of moisture problems (Huser 2010). In particular, to meet the IAQ requirements, building designers should provide appropriate Heating Ventilating and Air Conditioning (HVAC) systems to dehumidify additional moisture brought into buildings with increased ventilation rates, which also increase building energy consumption. In GB rating systems, HVAC design recommendations need to include effects of additional moisture due to the increased outdoor air volume. In particular, the U.S. is divided into 8 climate zones that could be further subdivided by their outdoor moisture content for better understanding of local design conditions and HVAC requirements (Huser 2010).

The moisture content in indoor environment is not only important for prevention of a potential condensation and consequent microbial growth, but also for indoor ***thermal comfort***. The three criteria, including controllability (IEQ 6.2), design (IEQ 7.1) and verification (IEQ 7.2), reference the ASHRAE Standard 55-2004. The standard defines air temperature and velocities, mean radiant temperatures and humidity levels acceptable to occupants. The maximum allowable humidity level or humidity ratio is 0.012 $lb_{water\ vapor}/lb_{dry\ air}$, which for the summer indoor air temperature of 75^{o}F results in relative humidity of 65% and indoor dew point temperature of 62.5^{o}F. It is important to notice that a typical HVAC supply air temperature is typically controlled to be 55^{o}F. Therefore, according to these allowable indoor design conditions, some condensation is quite possible in hot and humid climates, and if the HVAC dehumidification system is not sized properly to account for additional volume of outdoor air, the condensation is actually inevitable. It is important to notice that the moisture propagation into a building can also take place via infiltration and/or operable windows, which typically are not accounted for in design of dehumidification systems.

Overall, moisture control, increased ventilation rates, and maintenance of good thermal comfort, are all ***energy demanding*** processes. Current and future demands for building energy reduction will put pressure to compromise these IAQ parameters. It will be important to support LEED by providing optimization procedures to understand direct connections among IAQ parameters, building energy consumption and productivity/health outcomes for occupants. Table 1 summarized discussions in this category and identified opportunities to support future LEED developments.

Table1. Moisture, Ventilation Rates and Thermal Comfort

IAQ Considerations in LEED	LEED Credits/Prerequisites	Opportunities
Moisture	Prerequisite 1, IEQ 1, IEQ 2, IEQ 3.1, IEQ 3.2, IEQ 5 and IEQ 6.2	Provide climate based optimization strategies to include moisture, ventilation rates, thermal comfort and energy consumption
Ventilation Rates	Perquisite 1, IEQ 1, and IEQ 2	Outline quantifiable benefits of increased ventilation rates to IAQ as well as occupant productivity and health
Thermal Comfort	IEQ 6.2, IEQ 7.1, and IEQ 7.2	Include considerations of extended/adaptable thermal comfort zones based on different occupant populations and associated energy saving

5. VOCs and Other Airborne Chemicals in LEED

Building enclosure and interior materials are not only important for moisture and mold considerations, but also for their potential release of VOCs into indoor environment. An EPA (Environmental Protection Agency) study provided a benchmark ***Building Assessment Survey and Evaluation (BASE)*** case studies, which resulted in a comprehensive database for office buildings in the U.S. (EPA 2003a). The study included 100 offices, and it is the largest such study to date, so it provides a great benchmark for typical office environments in the U.S. The data collected in these offices included three different databases: (1) environmental measurements, (2) occupant questionnaire, and (3) building survey. The BASE database enabled comprehensive research efforts that can be classified into 4 groups of studies (Vukovic et al. 2008a):

1. methodology for collecting data and description of the dataset;
2. prevalence statistics of BASE parameters, including average, maximum, minimum, median values or percentage quotients, without analyzing impacts on building occupants;
3. comparisons between BASE and other experimental building studies; and
4. BASE data analyses to assess indoor environmental impacts on human occupants.

The wide spectrum of collected data enabled linking IAQ with the perceived human health outcomes. For example, a study has found a link between mucous membrane symptoms and VOC concentrations (Apte and Erdmann, 2002). This study applied the principle component analysis to identify which of the 73 measured VOCs were associated with specific symptoms, and observed a direct association between these VOCs and mucous membrane/lower respiratory system irritation. The study reported up to 80% reduction of symptoms with increased ventilation rates, even in buildings already complying with the ASHRAE Standard 62.1.

Following the BASE study protocol, a recent study conducted an investigation in a LEED Gold Certified building (Vukovic et al. 2008b). Even though the building received all three points for Low-Emitting Materials for the LEED certificate, the study has found VOC levels comparable to typical office buildings. For example, ***Acetaldehydes*** were at the same level and ***Formaldehydes*** had 30% lower levels than the concentration levels in typical office buildings. Even though these results were disappointing for the building owner, it was an important finding to indicate that materials other than the base building materials were contributing to VOC concentration levels. Unfortunately, fixtures, furniture and equipment (FF&E) are not considered base building elements, and, therefore, they are not included into LEED credit for Low-Emitting Materials—Composite Wood and Agrifiber Products. Several experimental studies have demonstrated that furniture coating is a significantly contributor of VOCs (Salthammer 1997, Wang et al. 2010). More specifically, the tested furniture coating was the strongest source of formaldehyde concentration levels when compared to levels resulting from the tested wall surface latex paint and composite flooring material. In the current version of the LEED certification procedure, we might be missing major sources of VOCs when not considering fixtures, furniture and equipment (FF&E).

Another important LEED credit is available for Indoor Chemical and Pollutant Source Control (IEQ 5). The goal is to minimize occupant exposure to potentially hazardous chemical pollutants. This credit does not discuss use of ***cleaning products*** as typically those issues are not important in building design phase, but the operation and maintenance phase. Therefore, USGBC issued “LEED for Existing Buildings: Operation & Maintenance (O&M)” (2008), which is a set of recommendations for sustainable operation of buildings and the compliance is voluntary. In this report, LEED O&M credits are not discussed in details because in our experiences with the existing LEED certified buildings, building manager are typically using LEED O&M as educational materials rather than following specific credits. Interestingly, the studied LEED Gold certified building voluntary complied with exclusive use of green cleaning products and other green cleaning strategies (Vukovic et al. 2008b). Nevertheless, this experimental study has found almost five times higher levels of d-Limonene when compared to d-Limonene concentration measured in the BASE study. These elevated concentrations of d-Limonene could most probably be linked to cleaning products (Nørgaard et al. 2009). This finding indicates that prescriptive guidelines while useful to outline the scope of building design, maintenance and operation considerations, should be followed by more detailed recommendations based on measurable parameters.

Another group of chemicals, commonly found in indoor environments, include ***pesticides***. In LEED, pesticides are a part of two different credits for operation and maintenance in the existing buildings (LEED O&M). The two credits associated with the use of pesticides are: “Integrated Pest Management, Erosion Control and Landscape Management Plan,” and “Green Cleaning: Integrated Pest Management”. Interestingly, even these volunteer recommendations for certified green buildings are still using relatively weak language, which encourages the use of least-toxic pesticides and their minimal use. Because pesticides are designed as toxic substances to kill pests, they also can affect human health such as nervous system, endocrine system, skin or eyes and some may be carcinogenic (EPA 2010). Building managers would need to know exactly which pesticide they plan on using in either outdoor or indoor pest control and most probably would need to contact EPA to help with exposure assessments and risk characterization. Other than pest control, other common uses of pesticides include building materials such as carpets, paints, furniture, and many other consumer products (EHHI 2010). Nevertheless, the presence of pesticides in these building materials is not discussed in LEED.

Many other common consumer products and building materials, such as carpets, furniture and insulation materials, contain different type of ***flame retardants***. These flame retardants produce volatile organic compounds with measurable emission rates (Salthammer et al. 2003). Unfortunately, even a low-level exposure to flame retardants may cause thyroid, liver and neurodevelopment toxicity as well as fertility problems (EHHI 2010). Therefore, future versions of LEED for operation and maintenance of existing buildings should encourage minimal use of building materials and consumer products treated with flame retardants. As with any other volatile chemicals, a well operated and maintained ventilation system can significantly reduce occupants' exposure rates as an already available building maintenance strategy.

Table 2 provides a summary of suggested opportunities for continuous improvements in enabling building manager to assess IAQ outcomes in their LEED certified buildings. One of potential augmentations is to supplement the existing lists or recommended/certified products with simple and cheap methods for measuring concentrations of indoor airborne chemicals. In this way, building mangers can be certain that the used products were appropriate or in a case of elevated indoor pollutant concentrations, building managers could hire specialized consultants to trace the source(s) of IAQ problems. These kinds of recommendations could be included in LEED O&M as educational materials with data on typical concentration levels in the existing indoor environments such as tested office environments in the BASE study.

Table2. VOCs and Other Airborne Chemicals

IAQ Considerations in LEED	LEED Credits/Prerequisites	Opportunities
VOCs	Prerequisite 1, IEQ 1, IEQ 2, IEQ 3.1, IEQ 3.2, IEQ 4.1, IEQ 4.2, IEQ 4.3, IEQ 4.4, IEQ 5, and LEED O&M	Identify additional significant sources of VOCs that are currently neglected, such as furniture coatings
Cleaning Products	LEED O&M	Provide recommendations for quantifying IAQ outcomes associated with cleaning products
Pesticides	LEED O&M	Recommend assessment of pesticide levels based on measured data
Flame Retardants	None	Include recommendations on flame retardants in LEED O&M

6. Particulate Matter in LEED

In addition to VOC dilution rates, ventilation systems also directly influence Particulate Matter (PM) concentrations in indoor environments. Nevertheless, for indoor particle concentrations, the particle size distributions are crucial in addition to the source locations and ventilation system performance. The particle sizes are divided into three categories by their aerodynamic diameters, which include: (1) coarse particles with diameters from 2.5 to 10 microns, (2) fine particles with diameters less than 2.5 microns, and (3) ultrafine particles with diameters less than 0.1 microns.

For all indoor air conditions being the same, the concentrations of fine particles are proportional to ventilation flow rates, so for higher ventilation airflow rates, as recommended by LEED, the finer particles will have lower concentrations in the occupant berating level. Nevertheless, concentrations of coarse particles are much more dependent on source location and local airflow pattern, rather than the overall ventilation airflow rates (Rim and Novoselac 2010). The particles sizes that are of interest for indoor air quality are particles of 10 microns (PM10) and finer because they are small enough to be easily inhaled into occupants' lungs and even get into the bloodstream (EPA 2003b). Epidemiological studies have shown that elevated particle concentrations have a positive association with number of deaths due to cardiopulmonary diseases and lung cancer (Dockery et al. 1993, Valavanidis et al. 2008). Interestingly, the positive association with lung cancer was only observed for long-term exposure that included intermittent events of high particle concentration levels. Therefore, indoor air quality needs monitoring of particle concentration time series, rather than gathering just an averaged indoor particle concentration value.

In LEED, the certification for new construction addresses particles in two credits, including "Construction Indoor Air Quality Management Plan—Before Occupancy" (IEQ 3.2) and "Indoor Chemical and Pollutant Source Control" (IEQ 5). The first credit is directed towards protection of construction workers, which does not account for the time period when buildings are fully occupied. The specific LEED requirement is that ***PM10 does not exceed 50 micrograms per cubic meter*** as an averaged concentration value for a minimum of 4-hour period. The sampling is required at the breathing level (3-6 feet from the floor surface) for several locations in a building depending on its floor area. As discussed, the selection of sampling location for coarse particles (PM10) can be significantly affected by the source location and local airflow pattern (Rim and Novoselac 2010). Therefore, future versions of LEED certification documents should make users aware of this potential bias due to a high spatial variability of course particle concentration levels.

A study performed sampling in 99 locations for 26 buildings seeking LEED certification during building regular occupancy as well as renovation activities (Horner et al 2009). Majority of the locations, slightly more than 80%, satisfied the LEED criterion for PM10. Nevertheless, certain spot values for one minute averaged PM10 concentrations significantly exceeded the LEED criterion. In this way, the real exposure to PM10 is underestimated as the intermittent events of high particle concentration levels are filtered when reporting the average PM10 values, which further can lead to underestimates of adverse health outcomes for occupants (Dockery et al. 1993). Overall, the averaging of particle concentration data is inappropriate, if the occupant exposure is to be accounted for. Furthermore, fine particles are also very important for health outcomes as their toxicity levels are most likely to be higher than for coarse particles and they penetrate lungs more deeply through the breathing process (Miller et al. 1979, Marra et al. 2009). Therefore, monitoring of fine particles should be included in the future versions of LEED. More recently, engineered nanoparticles, which are similar in size to ambient ultrafine particles, but different in their toxicity need to also be monitored due to the proliferation of nanofabrication (Marra et al. 2009).

The second LEED credit associated with particles in new construction, "Indoor Chemical and Pollutant Source Control" (IEQ 5) is very similar to the one credit In LEED O&M for the maintenance and operation of existing buildings "IAQ Best Management Practices: Reduce Particulates in Air Distribution." Both of these credits require building air handling units to use specific ***filters*** rated according to the ASHRAE Standard 52.2-1999. The rating uses to the minimum efficiency reporting value (MERV) to describe filter performance tested under standard conditions for ultrafine, fine and coarse particle sizes. The specific LEED credits require MERV 13 or higher, which has the minimal composite average particle size efficiencies of 75%, 90%, and 90% for ultrafine, fine and coarse particles, respectively. Nevertheless, these filters cannot address poor indoor air distribution with recirculation and stagnation areas due to poor ventilation design or filter bypass due to improper installation and maintenance (Novoselac and Srebric 2003, Vershaw et al. 2009). Furthermore, a part of the outdoor air particles does not go through the air handling units and filters, but it enters a building directly through infiltration (Abt et al. 2000). In the case of infiltration, the particles with smaller aerodynamic diameters have higher effective penetration efficiencies due to smaller deposition losses. It is also important to notice that internal particle sources can create intermittent events of high particle concentrations, which can even be misinterpreted as perceived dryness of air (Wargocki et al. 2002). These types of insights could help building mangers to appropriately address occupant feedback on indoor air quality (Vukovic et al. 2008b).

As one of potentially major indoor particle and chemical sources, ***Environmental Tobacco Smoke (ETS)***, is addressed as the second prerequisite in the Indoor Environmental Quality section. The goal of this prerequisite is to prevent or minimize occupant, interior surface and HVAC exposure to ETS. While the earlier versions of LEED requested prevention of exposure to ETS, the newest version actually rephrased this request to “prevent or minimize”. Overall, the easiest way to deal with ETS is certainly source elimination, and individual institutions are responsible for implementation of appropriate policies.

Table3. Particulate Matter

IAQ Considerations in LEED	LEED Credits/Prerequisites	Opportunities
PM 10	IEQ 3.2, IEQ 5, LEED O&M	Identify importance of high special and temporal variability of particle concentrations
PM 2.5	None	Include in LEED
PM 0.1	None	Include in LEED
Nanoparticles	None	Include in LEED
Filters	IEQ 5, LEED O&M	Outline limitations of the existing filtration technology
ETS	Prerequisite 2	Consider recommending source elimination in and around public buildings

7. Changing Climatic Conditions in LEED

In LEED, climate change is only directly mentioned in the energy and atmosphere section on ozone depletion due to HVAC refrigerants and resultant contributions to global warming. More specifically, in the section on Energy and Atmosphere (EA), LEED has a prerequisite for “Fundamental Refrigerant Management” (EA Prerequisite 3), and offers two credits for “Enhanced Refrigerant Management” (EA 4). These two credits and prerequisite are aimed at zero use of chlorofluorocarbon (CFC) and its replacement with refrigerants that have reduced ***ozone depletion potential***. Also, LEED encourages cooling strategies that do not use refrigerants such as natural ventilation and night cooling, but the opportunities for passive cooling strategies depend on local weather. Interestingly, the local weather is influenced by the long-term climatic changes. Nevertheless, even though the climatic changes are clearly documented and future projections and scenarios are available, predictions of direct climate change influences on local weather are still limited (IPCC 2007).

The available data point to future outdoor weather conditions that will require either different or increased capacity HVAC systems for the maintenance of appropriate indoor environmental conditions. The outdoor conditions that will most directly influence the HVAC system size, indoor thermal comfort and IAQ can be categorized as extreme weather conditions and increased outdoor air pollution. The ***extreme weather conditions*** include episodes of intense rain, wind, droughts, floods, and heat waves, while increased ***outdoor air pollution*** includes elevated ground-level ozone concentrations, allergens and smoke from wild fires (Levin 2008, Girman 2010). LEED does not directly address the extreme weather conditions and increased outdoor air pollution because the discussions on indoor environments and climatic changes are fairly recent (Mudarri 2010). The main idea of LEED was to reduce environmental impacts of buildings on their surrounding environment. Nevertheless, new research studies are emerging, so it will be possible to understand more detailed building impacts on its environment as well as to develop new strategies for addressing intermittent environmental impacts on the building itself due to extreme weather conditions and increased outdoor air pollution.

The current version of LEED indirectly addresses some of the intermittent environmental impacts in the Sustainable Site (SS) section through two credits available for “Heat Island Effect” including Nonroof and Roof (SS 7.1 and SS 7.2). The local ***heat island effect*** refers to the outdoor environmental temperature being higher for urban and suburban areas than for rural areas under the same weather conditions (EPA 2008). The annual average air temperature increases by 1.8^{o}F to 5.4^{o}F for a city with one million or more people when compared to its surrounding temperatures (Oke 1997). Basically, the heat from the incoming solar radiation is first absorbed and stored in construction materials and then it is released to the surrounding environment. For rural areas, plants shade the ground from direct exposure to the solar radiation and use a part of the incoming energy for the evapotranspiration and photosynthesis. Therefore, to reduce the heat island effect, LEED suggests use of reflective payments and landscaping plants (Nonroof) as well as reflective coatings or vegetated roofing (Roof). Vegetated roofs also contribute to the “Site Development” (SS 5.1) and “Stormwater Design—Quantity Control” (SS 6.1) credits.

The local weather considerations play a role in ***building energy performance*** assessments. LEED has a prerequisite for “Minimum Energy Performance” (EA Prerequisite 2) and up to 19 credits to “Optimize Energy Performance” (EA 1) based on the local weather data. When the weather was relatively stable, it was sufficient to look at the historic weather data when designing building HVAC and structural systems. These historic data are not any more sufficient, so future building energy performance assessments will need to look into weather and climate forecasts. The building energy optimization has to also include the related green house gas emission because residential and commercial buildings are responsible for 38.5% of the total U.S. Carbon Dioxide Emissions for the Energy End-Use Sector Sources (EIA 2002). Therefore, optimized building energy performance presents an enormous opportunity not only to save the primary energy, but also to reduce green house gas emissions.

Table4. Changing Climatic Conditions

IAQ Considerations in LEED	LEED Credits/Prerequisites	Opportunities
Stratospheric Ozone Depletion	EA Prerequisite 3, EA 4, and LEED O&M	Provide guidelines for passive cooling strategies based on local weather and projected scenarios for climate change
Extreme Weather Conditions	None	Recommend planning for provisional capacity of building systems or shelter
Outdoor Air Pollution	None	Recommend planning for provisional capacity of building systems or shelter

8. Conclusions

In conclusion, many critiques have been published with respect to different GB rating systems. Nevertheless, these rating systems serve a great educational purpose to disseminate knowledge typically available to few experts, who deeply understand concepts of built systems with respect to their use of materials, energy, and water, as well environmental impacts and human health. The public awareness is one of important driving forces in enabling the governmental agencies to develop appropriate polices. The other important driving force is the accumulation of scientific knowledge on different aspects of urban eco-systems, including IAQ and its links to energy and materials used in the built infrastructure. One of potential contributions to support improvements of the existing GB rating systems could be to provide quantitative measures of IAQ that can be then associated with energy efficiency strategies and human health outcomes, so that the energy is not saved at the expense of IAQ and population health. In this way the effectiveness of the existing prescriptive recommendations could be improved and the accumulated knowledge could be used for continuous maintenance of the existing IAQ recommendations and standards. This approach is already underway for the building energy use assessments because energy measurements and simulations lend themselves to an easier consensus in creating quantitative standards and measures than the IAQ area. With the expansion of the existing knowledge in the IAQ area, the quantitative analyses should be possible.

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