The Economics of Investing in Green Buildings

by

Charbel Maroun Rizk

Submitted to the System Design and Management Program
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Abstract

This thesis discusses economics of green buildings. The need to reduce greenhouse gases emissions became clear. Buildings account for a large part of the greenhouse gases emissions, changing the atmosphere's composition. Climate changes will be unevenly distributed between regions; in early stages they might be beneficial for few but will eventually end up being costly for all.

Several worldwide rating systems were established with a common objective to determine metrics for measuring a building's performance and minimizing environmental footprint. In this research we selected LEED-NC version 2.2 by U.S. Green Building Council (USGBC) for our analysis. V-2.2 consists of a set of credits distributed in categories. We identified credit's requirements and analyzed their impact on cost and environment. We supported our analysis by looking into cost and benefit studies performed by different organizations, and summarized our findings in providing heuristics on green buildings.

Finally, a major take away from this research project is that there are numerous factors affecting difficulty of achieving, cost, and benefits of LEED credits. In addition to that, the correlation between credits and the large number of combinations to qualify for LEED certification levels, make it unreasonable to generalize about the incremental cost for any certification level.

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Finally, I would like to thank my family for their enormous support. I would like to thank my sisters Nathalie and Nadine and their husbands Roger Aboukhalil and Chadi Kawkabani for their continuous encouragement and for standing by me during my two years in the SDM program. I would also like to thank my mother May for all the help and guidance she provided and continues to provide. Lastly, I have been supported by the love and inspiration of my father Maroun; although he is not with us any longer he has guided me through this challenging process. I cannot thank him enough for making this happen, and I submit this work in his memory.

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Acronyms

IDP: Innovation Design Process
IEP: Indoor Environmental Quality
MR: Material and Resources
Poss.: Possible
Prerequ.: Prerequisite
Pt/s: Point/s
SS: Sustainable Sites
WE: Water Efficiency
WE: Water Efficiency

Chapter 1

Introduction

1.0 Climate Change & Greenhouse Gases:

During earth's history, climate has changed multiple times with extremes ranging from ice ages to long periods of warmth. In the last decades, scientists have observed some rapid changes caused by climate. In addition to the natural reasons behind these changes, human activities have substantially added to the amount of greenhouse gases in the atmosphere, changing its composition (EPA, 2009). The composition of the atmosphere at global and regional scales influences climate, air quality, stratospheric ozone, and precipitation, which in turn affect human health and the vitality of ecosystems (USGCRP, 2008). Greenhouse gases, defined by particular behaviors such as trapping heat, which enter the atmosphere solely as a result of human activities, are (EPA, 2009):

- Carbon Dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Fluorinated Gases

The challenging part and area of disagreement is in determining the fraction of climate change due to natural variability versus human activities.

The expected effects of climate change are unclear yet, however they may result in reduced diversity of ecosystems and the extinction of many species. Changes will be unevenly distributed between regions; in early stages they might be beneficial for few but will eventually end up being costly for all. These effects include:

- Rise of sea level
- Extreme weather such as hurricanes, tornadoes
- Glacier retreat and disappearance
- Temperature rise

Studies of today's effect of climate changes are being performed all over the world. In many cases results are discouraging with statements from involved individuals such as "What we would want to have people take away is that climate change is happening now, and it's actually beginning to affect our lives," (Karl,2009) or "Climate change is already killing people in Africa, and this commitment is simply insufficient to tackle the climate crisis," (Mwenda, 2009). The need to reduce greenhouse gases emissions is clear; however each country's commitment to doing so varies and that due to several factors including economical impact. *Figure 1.1* below shows the increase in emissions and shares of major contributors.

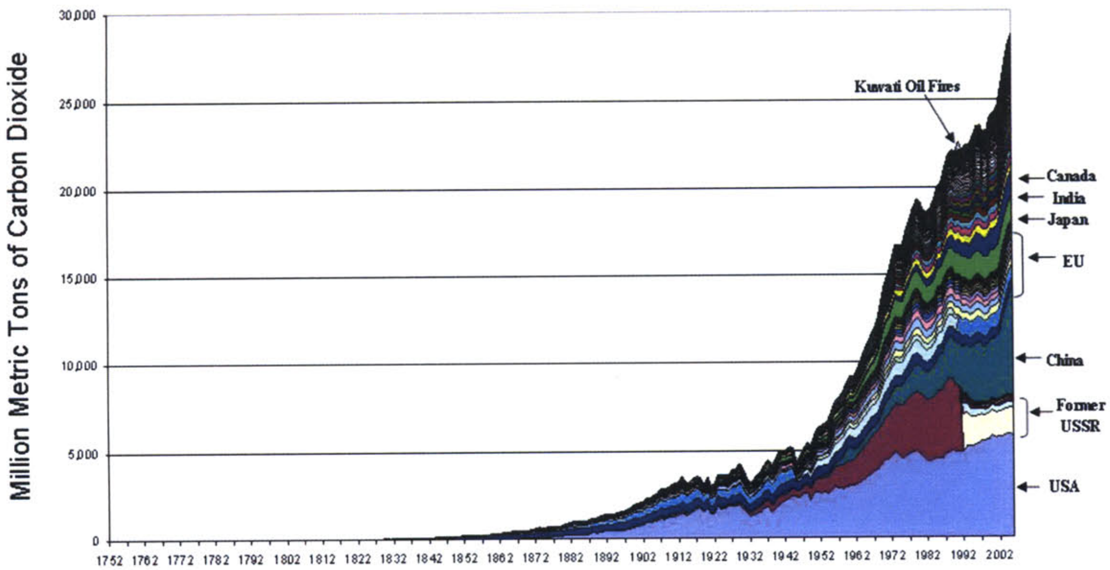


Figure 1.1: Word Carbon Dioxide Emissions (EPA,2009)

1.1 Construction Industry:

Realizing the importance of current climate changes, and being from a construction background, thesis topic was born. My interest is in understanding the economics of Green Buildings, or more specifically to answer:

- What is the Capital Cost impact associated with building green?
- What is the Operational Cost impact associated with building green?
- What are the major difficulties faced when building green?

As an industry, construction is a major source of Greenhouse Gases. Public awareness of this fact is very low, with a majority thinking that transportation is the highest contributor. On a high level, building emissions are a result of fossil fuel use and land use. Some statistics about buildings in the US:

- Buildings Account for 38% of CO2 emissions in the United States —more than either the transportation or industrial sectors (USGBC, 2007)

- Over the next 25 years, CO_2 emissions from buildings are projected to grow faster than any other sector, with emissions from commercial buildings projected to grow the fastest—1.8% a year through 2030 (USGBC, 2007)
- Buildings consume 70% of the electricity load in the U.S. (USGBC, 2007)
- 30% of raw materials use (GBRC,2009)
- 30% of waste output (GBRC,2009)
- Buildings have a lifespan of 50-100 years during which they continually consume energy and produce CO_2 emissions. If half of new commercial buildings were built to use 50% less energy, it would save over 6 million metric tons of CO_2 annually for the life of the buildings—the equivalent of taking more than 1 million cars off the road every year (USGBC, 2007)

Worldwide studies align with the statistics above and emphasize that buildings have a large share in GHG emissions. An example would be the research prepared by Riccardo Pravettoni, UNEP/GRID-Arendal for the 'World Resources Institute, Climate Analysis Indicator Tool (CAIT)'. Results of the research are summarized in *Figure 1.2* below.

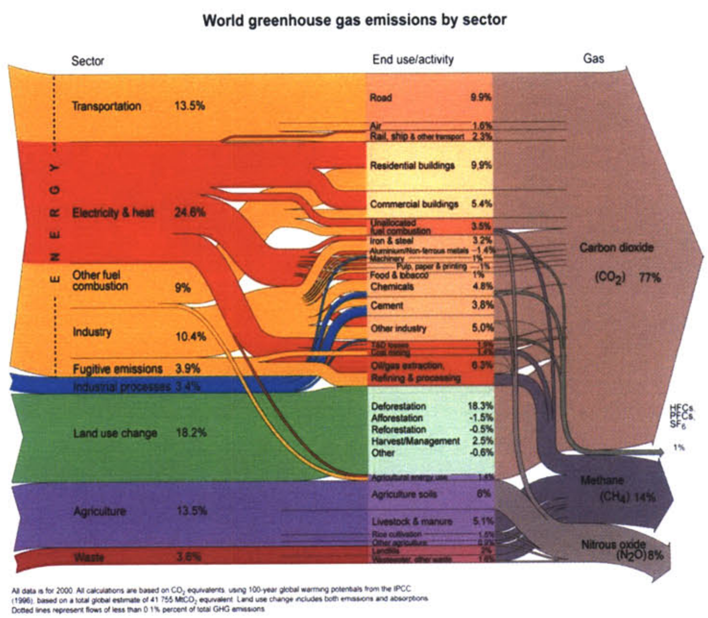


Figure 1.2: World Greenhouse gases emissions by Sector (Source: GRID-Arendal)

Figure shows that greenhouse gases emissions from transportation sector are about half those from Electricity & Heat. Additionally, looking at end use emissions, residential and commercial buildings emit more than all transportation systems.

1.2 Complexity of Construction

The majority of developments tend to be classified as complex systems. As defined by Ed Crawley (Crawley, 2008); a complex system is a system that is comprised of components and interconnections, interactions, or interdependencies, all of which are hard to describe, understand, predict, manage, or change. We will explain the complexity of the system by using a discussion, it is necessary to simplify it by making some basic assumptions; however, a better understanding on the complexity of a building system does emerge:

From a holistic view, as soon as developers pick a lot for construction some decisions have been made with direct or indirect impact on the environment. The project will change the site condition, for better or worth, depending on the original status and development type/size impact can be determined. In addition it will generate transportation needs, add loads to utilities, and might attract other developments.

Limiting ourselves to development boundaries, we will assume that a building system is only composed of 5 sub-systems that can be controlled. These 5 systems will be our decision variables (DV):

- External System (All external works: soft & hard landscaping)
- Structural System
- Architectural System
- Mechanical System
- Electrical System

Long term commitments are made each time we fix any of these DV. These will determine the behavior of building, and designers can only control DV's. We will only look at the following behaviors (BV):

- Construction with parameters: Area per floor; Number of floors
- Costs with parameters: Capital, Operational,

- Consumption with parameters: Water, energy
- Emissions with parameters: Greenhouse gases

What is important to note from the above example is:

- Most DV's 'depend on' and 'provide info to' each other
- Most BV's 'depend on' and 'provide info to' each other
- BV's depend on multiple DV's

The Object Process Diagram shown in *Figure 1.3* summarizes the dependencies between DV's and BV's (only).

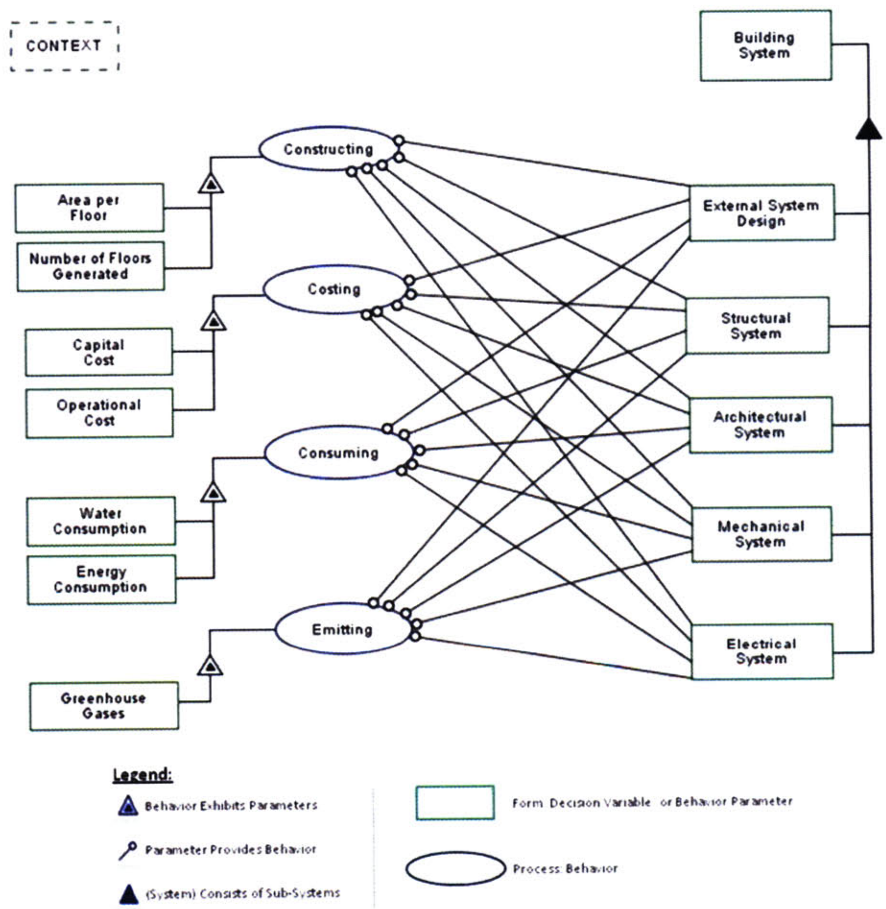


Figure 1.3: Building System Decomposition

For sustainability, optimization of performance is required. Because of dependencies and tradeoffs, we can anticipate how complicated and large our problem will be. In sum, designers/developers of sustainable buildings face key challenges, opportunities, and issues. They should focus on optimizing the system as a whole and not as sub-systems, since optimizing the parts does not necessarily optimize the whole.

In the chapter to follow, we will build on this discussion, and briefly talk about contemporary work.

1.3 Overview of Thesis

The purpose of this study is to understand the economics of green buildings. In order to do that, we need first to define green buildings; we rely on existing standard to determine whether a building is green or not and to compare green buildings.

In chapter 2 we briefly examine the history of sustainable developments, and discuss its benefits and the barriers to entry.

In chapter 3 we look at existing standards, and then identify the one which is the most relevant to our study. We also define costing terminology that will be used throughout the rest of the study.

In chapter 4 and after selecting the standard, we first explain the intent and requirement of every clause in the standard, and then analyze it. The analysis part includes: cost incurred to qualify for any particular clause, benefit resulting from sticking to requirement, difficulty of meeting requirement, and finally some other dependencies such as external factor.

It is important to clarify now the assumptions on which analysis in chapter 4 and onwards is based:

- We defined our system boundary to be the building itself; and thus any benefits flowing from any system outside this boundary are excluded. For example, benefits of using greener alternative to commute to and from the system are excluded.
- The most important benefits obtained from building green are non-monetary. Non-monetary benefits include but are not restricted to, reduction of greenhouse gases

emissions and increase in human health. In our study, we did not convert these benefits into monetary value; we only examined the financial implication of achieving these very important benefits.

In Chapter 5 we present and analyze the result of research done by two lead organizations. We will start with a research prepared by Davis Langdon, then we will present results from the U.S. General Services Administration (GSA). Davis Langdon is a global construction consultancy company and GSA is one of the largest building owners in the US.

In Chapter 6 we discuss two buildings in the Boston area as well as the new Sloan Building at MIT. We go more into the details of these case studies and extract the lessons learned from these experiences.

Chapter 7 is dedicated to comparing and drawing conclusions based on all work in chapters 4, 5, and 6. Our key findings will be summarized as heuristics on the standard. The concluding chapter also comprises any opportunity for improvement, and next steps or research which might help in improving and quickening the adoption of green building standards.

Figure 1.4 below graphically summarizes the thesis progression:

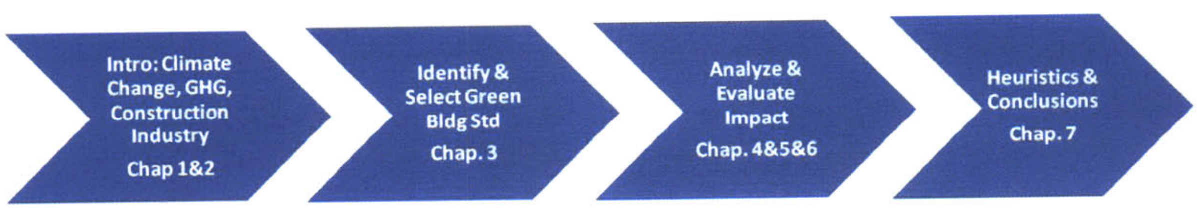
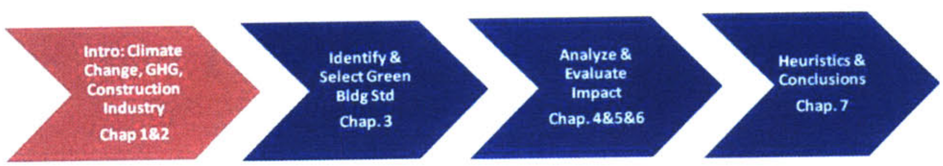


Figure 1.4: Summary of thesis

Chapter 2

Literature Review



2.0 Introduction:

Driven by the threat of climate change, sustainability has become a global concern. After briefly introducing our research topic in the previous chapter, we will now:

- Discuss sustainability in general
- Provide examples of green developments
- Summarize the history of Green Building in US
- Discuss Barrier to Entry of Green Buildings
- Examine Benefits of Green Buildings

2.1 Generic Sustainability Discussion:

Green thinking was initiated in order to preserve the environment, ensure a healthier life, minimize the waste and impact caused by human actions, and save resources for next generations. With the absence of one globally approved definition, we can deduce that sustainability tends to be frequently tied to the use of natural resources. We are currently experiencing some of the effects of pollution such as the frequency and severity of natural disasters (earthquakes, floods, etc...), and global warming. The stress and fear of the increasing impact, have led world leaders to gather and collaborate in developing and deploying clean energy technologies. Agreements and firm objectives for emissions cuts have resulted from these climate summits. In December 2009; Copenhagen hosted a climate conference with representatives from 170 countries on governmental level. Abundant scientific evidence proves that humanity is living unsustainably (EPI, 2009).

It is important to note again that the building industry is a major emitter of greenhouse gases. These emissions occur in construction phases as well as in operational phases. In addition to that, dumping of construction materials and equipments might lead to sever environmental impacts.

Just as sustainability has multiple definitions, so does Green or Sustainable buildings. The majority include the idea of optimizing use of resources. The definition used for the purpose of this discussion: "Green" or "sustainable" buildings use key resources like energy, water, materials, and land much more efficiently than buildings that are simply built to code (Kats-CA,2003).

The main challenge for architects and engineers is in creating green buildings to provide the same living standards for occupants while minimizing consumption of resources. Although most of the progress realized thus far has resulted from the last decade, some designers like Victor Papanek introduced this concept as early as the 1970's. He argued for the need for codes and standards to be followed by designers in order to guide them in reaching more ethical designs. Simultaneously, and following Papanek's work, many publications and programs were started. These efforts led to an increase in attention on green buildings, which resulted in the emergence of green buildings standards, motivations, innovations, and new construction designs and methods. Now, the use of technology and automation to achieve an environmentally sound and resource efficient building has become very popular. The main areas of impact can be viewed from different perspectives and include:

- Energy efficiency examples:
  - Photovoltaic Cells
  - Smart lighting
  - Motion sensitive lighting
- Material efficiency examples:
  - Use of recycled material
  - Reuse of materials
  - Improved materials specification
- Water efficiency examples:
  - Green roofs
  - Water Recycling
  - Water efficient fixtures

Generally speaking, improvements over the life cycle of items were made as well.

A factor with high impact on building emissions is energy efficiency. Let's examine this over the life cycle of a product/project, from production, distribution, operation and finally to the end of the project life.

Starting with the production, because of today's technology, embedded energy has become much lower. Processes have become more efficient, and much effort is put to reduce use of raw material, particularly virgin material.

The Supply chain management gained more weight in companies, and with the availability of software and other tools, and with the advancement made to delivery modes, energy needed to deliver has been reduced significantly.

For the operation; taking Photovoltaic cells, the earliest PV devices converted about 1%-2% of sunlight energy into electric energy while today's PV devices convert 7%-17%. (US, DOE). As for the consumption, fixture and appliance manufacturers are heavily investing in researches to improve efficiency and minimize losses in their systems. Many of these programs are co-sponsored by governmental institutions. As an example, Energy Star qualified compact fluorescent light bulbs (CFL) use 66% less energy than a standard incandescent bulb and last up to 10 times longer (US, DOI). "If every household in the U.S. replaced one light bulb with an ENERGY STAR labeled (CFL), it would prevent enough pollution to equal removing one million cars from the road." (US, DOI). It is clear that the objective is to minimize demand and optimize production.

At their end-life, construction material and equipment tend to be highly toxic. Environmental agencies and manufacturers have worked closely to reduce the effect of these bad characteristics and have laid out better methods to deal with them.

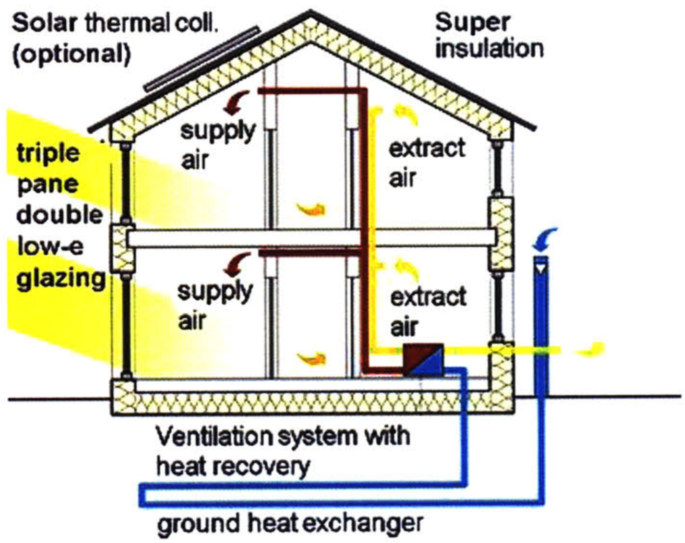
This entire move towards more sustainable buildings, including the changes in the technology, and the increase in demand, has made over 2,000 environmentally preferable products available in the United States today (Building Green, 2009). *Table 2.1* below provides a list of these product categories, number of products in sub-categories, and gives two key features as listed by one independent company: Build Green LLC. In most cases multiple products are available for each sub-category, leading to a price and quality competition between manufacturers.

Green Products		
Category	**Sub Categ.**	**Examples of Key Features**
Sitework & Landscaping	30	* Resource/Material efficient products * Pervious surface
Decking	7	* Sustainably harvested, long lating exotic hardwood * Local product (stone)
Outdoor Structures	14	* Recycled plastic & wood-plastic composites * Avoid use of treated wood
Foundations, Footers, and Slabs	21	* Recycled aggregate * Non-toxic backfill material
Structural Systems and Components	21	* Material that properly insulare homes * Engineered products that minimize waste
Sheathing	5	* Recycled content sheathing * Higher percentage use of tree
Exterior Finish and Trim	12	* Locally produced * Durable, elastic, and strong
Roofing	19	* Lighter Colored * Reflective
Windows	19	* Energy performance * Durable spcares for glass layers
Doors	6	* Wood from certified sources * Insulating values
Insulation	20	* Raw material and production process * Carcinogenicity
Flooring & Floorcoverings	33	* Low replacement frequency * Raw material
Interior Finish & Trim	37	* Low toxicity, low-permeability coating * Low virgin timber use
Paints & Coatings	19	* Waterborne products * No cross-linking agent
Caulks & Adhesives	5	* Low tocicity or Non-toxic * Low VOC adhesive
Mechanical Systems/HVAC	42	* Efficient and durable equipment * Low air pollution systems
Plumbing	36	* Water efficient fixtures * Wate water treatment systems
Lighting	11	* Energy efficient fixtures * Non-toxic fixtures
Electrical	16	* Non-Toxic wire and cable insulation * Deterioration characteristics of cables and wires
Appliances	5	* Energy efficient appliances * Water efficient appliances
Furniture & Furnishings	21	* Certified wood * Mechanically fastened (minimize use of adhesives)
Renewable Energy	13	* PV panels * Wind power
Miscellaneous	26	* Recycled tire rubber * Biodegradable oils

Table 2.1 Green Products (Prepared by Author based on Building Green, 2009)

2.2 Contemporary Sustainable Examples

Intensive work and research funded by private and governmental institutions allowed realization of passive house. By definition it is a house where energy consumption is reduced by at least 90% of a usual code-built one. Passive house can be mostly found in Europe, based on a report by New York Times (Rosenthal,2008) printed in 2008; there are currently 15,000 passive houses around the world and this market is expected to grow rapidly.



Pic 2.1: Passive House Example. (Source: Wikipedia)

Passive house principles mainly concentrate on increasing the efficiency level of heating and ventilation systems by increasing the insulation level of walls, roofs, floors, windows, and doors. By properly positioning the building and providing proper air circulation, we can attain the energy savings mentioned earlier. In picture 2.1 above, we have an example of a combination of low energy building techniques and technologies which successfully met these requirements. Passive house design is carried out using simulations such as Passivhaus Planning Package' (PHPP).

One of the most significant research related to indoor temperatures, is the one by Michael Humphreys (Humphreys, 2006). He has demonstrated that people who live in hotter climates are comfortable with higher temperatures, and vice versa. This has been developed further to prove that it is also a function of the season and not only geography. Equations for comfortable temperature as a function of external temperature have been developed and used on many projects.

Since during a cold season, individuals will be comfortable with lower temperatures than during other seasons, indoor temperature should be adjusted lower in order to reduce heat usage.

In sum, heating and cooling systems are done in "good enough" manner to keep occupants comfortable. This work proves how detail oriented designers are becoming; they aim to avoid any non-necessary energy consumption. Work is still in progress to develop better and deeper understanding of all factors which affect comfort levels including: humidity, activity levels, and surrounding temperatures.

Efforts are not only restricted to green buildings but have gone beyond that to the development of green cities. A good example of that is Masdar city (Masdar means source in Arabic) in Abu Dhabi, one of the world largest suppliers of oil.

Pic 2.2: Masdar City top View (Source: http://www.commtechservices.ca/images/masdar-city-uae-749854.jpg)

As seen in Picture 2.2, Masdar has defined boundaries, and is designed to become a zero carbon emission city. Masdar Institute of Science and Technology defined Zero Carbon Emission as:

- Within boundary no carbon is released
- Scope includes carbon emitted in construction and operation phase

- Minimize and offset any carbon related to the scope of the city. Example carbon emitted to produce fruit that is sold in the city will be compensated for by sending electric power to the grid.

Some of the systems used in the city have been tested in laboratories without the need for applying to actual projects; an example of that would be Personal Rapid Transit (PRT). This aligns with their goals of innovating, experimenting, learning, and sharing to become a knowledge source for green developers. In order to meet the Zero Emission objective, Masdar is also counting on the change of behavior of the occupants. For example, in Abu Dhabi the water consumption per capita is very high; it is 350 liter/capita/day (l/c/d) compared to 125-150 l/c/d in West Europe (EAD,2009). In Masdar the city design was made with the assumption that the consumption will be 146 l/c/d with only 65 l/c/d fresh (F+P, 2007).

In this section we have given examples of work on house level, on a building sub-system level, and city level. In the previous section, one of our discussions was on a product level. As mentioned in Chapter 1 Development projects, tend to be complex systems; with involvement of multiple stakeholders with different utility functions. The main challenge is to integrate work on different levels in order to reach more environmentally responsible products while meeting the needs of stakeholders.

We will now briefly present sustainable building history in the US.

2.3 US Green Building History

The earliest experiments with green buildings started in the late 1960's early 1970's. In the 1970, US were trying to reduce energy consumption in order to become less dependent on foreign oil. Then, in the 1980's oil prices went down taking away the interest in reducing energy use. In the 1990's, organizations and individuals working in this field began to come together more formally. Few early milestones in the U.S. include (EPA, 2009):

* American Institute of Architects (AIA) formed the Committee on the Environment Exit Disclaimer (1989)

* Environmental Resource Guide published by AIA, funded by EPA (1992)
* EPA and the U.S. Department of Energy launched the ENERGY STAR program (1992)
* First local green building program introduced in Austin, TX (1992)
* U.S. Green Building Council (USGBC) Exit Disclaimer founded (1993)
* "Greening of the White House" initiative launched (Clinton Administration 1993)
* USGBC launched their Leadership in Energy and Environmental Design (LEED) Exit Disclaimer version 1.0 pilot program (1998)

The Federal Commitment to Green Building: Experiences and Expectations (EPA, 2009), a report of the Office of the Federal Environmental Executive, provides a history of federal involvement with green building. Some of the key federal milestones include:

* The Energy Policy Act of 2005 includes federal building sustainable performance standards (2005)
* Nineteen federal agencies sign Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (PDF) Exit Disclaimer (10 pp, 152 KB, About PDF) at a White House Summit (2006)
* The Office of Management and Budget unveils a new Environmental Scorecard for federal agencies which includes a Sustainable Building element. (2006)
* Federal Green Construction Guide for Specifiers Exit Disclaimer is made available on the Whole Building Design Guide (2006)
* President Bush signs Executive Order 13423 - Strengthening Federal Environmental, Energy, and Transportation Management (PDF) (7 pp, 105 KB About PDF), which includes federal goals for sustainable design and high performance buildings (2007)
* The Energy Independence and Security Act of 2007 includes requirements for high performance green federal buildings (2007)

One of the standards used in US is LEED; it has emerged rapidly. "In 2006, U.S. Green Building Council's (USGBC) LEED green building rating system recorded a 50 percent increase in cumulative LEED registered projects (those intending future certification) and nearly a 70 percent increase in LEED certified projects. As of November 2007, more than 8,000 projects representing more than 1.5 billion square feet of space had registered under the LEED system and more than 1,100 projects had received certification"(USGBC,2009). This can be looked at as a shift in market and in customer requirements. Efficiency became a major criterion in addition to luxury, functionality, and all others which governed before.

2.4 Barriers to Entry of Green Buildings

One of the main entry barriers for green buildings is an economic one. To date there is a perceived belief that green buildings are much more expensive than conventional ones. In particular, people are worried about the initial capital to be invested in design and construction. Lack of data makes it difficult for green building defenders to argue for additional investment if needed. They don't yet have enough concrete data to demonstrate short term payback (or 0 years in case no additional investments are required).

Another entry barrier is the complexity due to lack of experience and exposure to new methodologies. Green buildings require some special methods in design and construction; few of the concerned parties (designers, contractors, sub-contractors, etc...) have had enough experience in green buildings. Integration, communication, and cooperation between different entities are highly favorable to facilitate the process and waive some unnecessary costs. Unfortunately, and to date, each party tends to work separately and with little transparency. A cultural change is required; new approaches like BIM (Building Information Modeling) are being developed to facilitate communication and integration on projects. Because of the growing need for optimizing efficiency specialized corporations were established. These corporations focus on developing tools and approaches to build greener. Lean Construction Institute (LCI), founded in 1997 has an aim of extending Lean production Revolution to the construction industry. LCI perform research to maximize value delivered and minimize waste by developing knowledge regarding project based production management in the design, engineering, and construction of capital facilities. However; companies should be willing to cooperate, share knowledge, invest in tools, and change their culture, in order to derive successful results.

Hygienic barriers are slowing the penetration of some water saving products; for example waterless urinaries are not widely accepted.

Other categories of barriers identified at Green Building conference hosted by EPA in Atlanta are (Shapiro,2009):

- Technical/Research: lack of performance data on green systems and technologies, lack of definitions of green terminology, lack of clearinghouse of information on best practices, inaccessibility of financial data and cost/benefit analyses
- Political: partisanship, status quo interests, unions, property rights advocates, lack of political champion for greening codes
- Financial: budget shortfalls (accentuated by the recession), jurisdiction for funding (state vs. local allocation) for code changes

The lack of awareness of environmental impact of buildings slows down the growth of green buildings. In chapter 1 we have seen the large share of buildings in global Greenhouse Gases emissions, but surveys still show very low awareness of this fact. For example, a survey reported that only 4% of U.S. adults realize that buildings are the leading source of greenhouse gas emissions in the United States. (Harris,2008)

A main take away of the conference as stated:

Some of these barriers are more of perception than reality, but perception is reality when it comes to making political change. In addition, most are very real---code changes require political will and resources, and good communication among stakeholders both within the government and with the regulated community (Shapiro,2009).

2.5 Benefits of Green Buildings

While talking about Green buildings the most important benefits that come to our minds are related to the environment and to operational cost. Environmental advantages are not restricted to atmosphere but also include indoor environment. Studies have shown that indoor environments have physical and psychological impact on occupants. Many studies were performed on the impact of daylight, and in particular its relationship with productivity at offices and in classrooms. In school cases, Heschong Mahone Group (HMG,2003) showed up to 20% better performance in classrooms because of increase in daylight. As for offices, workers were found to perform 10% to 25% better on tests of mental function and memory recall when they had the best possible view versus those with no view (HMG,2003). Indoor requirement does not only cover lighting but also requires a higher air volume per capita. This shows the commitment to ensure a more comfortable indoor environment for occupants. Gregory Kats (Kats-MA,2003) looked into 60 green buildings and compared them to traditional buildings. In his study, Kats quantified benefits obtained from improvement in internal air quality. Results claimed an increase of 10.1% in the productivity of the workforce; the improvement resulted from ventilation, temperature control, lighting, and daylight. "A 1990 study by the American Medical Association and the U.S. Army found that indoor air quality problems cost U.S. businesses 150 million workdays and about $15 billion in productivity losses each year. The World Health Organization puts the losses at close to $60 billion" (GBRC,2009).

The above study performed by Kats in Massachusetts, also compared the energy performance of green and traditional buildings. Results demonstrated that the Green Buildings are 25% to 30% more energy efficient, and have much lower peak consumption than traditional buildings. In Massachusetts the hourly rate at peak hours is about three times that of off peak hours, thus lowering peak demand is very beneficial and cost effective.

After showing some of the Green Building benefits, Kats evaluated financial savings per square foot for five categories and compared them to the extra capital cost for building green. The categories he investigated were:

- Energy Savings

- Emissions Savings
- Water Savings
- Operations and Maintenance Savings
- Productivity and health benefits.

In sum, Kats findings on a twenty year basis were that financial savings are much greater than costs. *Figure 2.1* below summarizes the research results.

Figure 3
Financial Benefits of Green Buildings
Summary of Findings (per ft^2)

Category	20-year Net Present Value
Energy Savings	**$5.80**
Emissions Savings	**$1.20**
Water Savings	**$0.50**
Operations and Maintenance Savings	**$8.50**
Productivity and Health Benefits	**$36.90 to $55.30**
Subtotal	$52.90 to $71.30
Average Extra Cost of Building Green	**(-3.00 to -$5.00)**
Total 20-year Net Benefit	$50 to $65

Source: Capital E Analysis

Figure 2.1: Summary of cost-Benefits of green buildings (Source: (Kats-MA,2003))

Sustainable buildings also accrue benefits which are not directly related to occupants or environment. Examples of some of these indirect benefits are:

- Economic Growth: Regarding materials, green buildings encourage use of local and regional materials which will increase growth of local economies.
- Avoiding increase of capacities: On city and state level, green buildings decrease the load on the infrastructure. In some high pace expanding cities, power companies didn't need to increase capacity because of the renovation of old buildings making them more efficient, and because of the high energy efficiency of new buildings. Power companies are even motivating their big customers to invest in energy savings. For example NSTAR, a large Gas and Electric utility in Massachusetts, collects a separate percentages from each customer "Energy Conservation" (NSTAR,2009) which goes to energy saving

programs. This revenue goes to big customers like MIT as a conditional amount to be invested in improving energy efficiency of their buildings.

- Marketing Advantage: Green buildings can be viewed from developers' perspective as a competitive advantage, and from a buyer's perspective an asset with higher resale value.

In sum, benefits of green buildings can be mapped to the following:

- Site selection,
- Energy efficiency,
- Materials efficiency,
- Water efficiency,
- Building operation and maintenance.

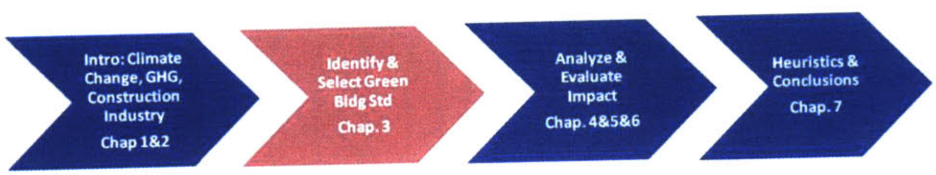
Depending on stakeholders, a larger list of benefits can also be found.

2.6 Conclusion

We started this chapter with an overview of the contemporary work and achievements of sustainable buildings. After that, we reviewed the history of American Green Buildings with the purpose of understanding its evolution with time. The last two sections emphasized the main barriers to entry and benefits of Green Buildings. As for the next chapter, we will study the methods used for evaluating how sustainable a building is, and will focus on the method which will be used throughout the rest of our analysis.

Chapter 3

Green Buildings Standards



3.0 Introduction

After getting a big picture of green buildings, a metric for classifying them is required for our further analysis. Starting with the incentives which led to these standards will help us understand their requirements. Incentives were created from the perspective of occupants, developers, utilities, cities, and residents in general.

3.1 Incentives

The rev-up of investments in energy efficient buildings resulted from several incentives and factors including:

- Rise of oil prices
- Water availability
- Emergence of new technologies and falling price of eco-efficient solutions
- Increase in public awareness and concern of environmental protection.
- City and State programs
- Attraction of investors due to higher profit margins and larger market size
- Augmented efforts by big institutions such as colleges and universities to minimize their environmental footprint

3.1.1 Oil Prices

Increases in oil prices have a major effect on consumer behavior. In the transportation sector for example, according to the Department of Transportation and the American Public Transportation Association, the cumulative Vehicles Mile Travelled (VMT) by December 2008 in the United States fell by 115 billion miles or 3.6% as oil prices increased (DOT,2008). In the building sector, since energy costs depend on oil prices; consumers reacted similarly. On-going studies at MIT are also demonstrating that by sending daily text messages to customer mobile phones, informing them about their bills, consumer conduct will be affected resulting in less energy consumption. *Figure 3.1* shows the fluctuation of oil prices, on February 5th of 2008 it was traded at $ 51.71 per barrel, on July 11th of 2008 it peaked at a value of $ 86.9. In about 7 months, an increase of approximately 68% occurred. Monthly utility bills of building occupants increased drastically in return, increasing their interest in looking for energy efficient alternatives. As a result of the changes in customer needs; architects, contractors, equipment manufactures, and all other related parties, began investing heavily in research for consumption reduction.

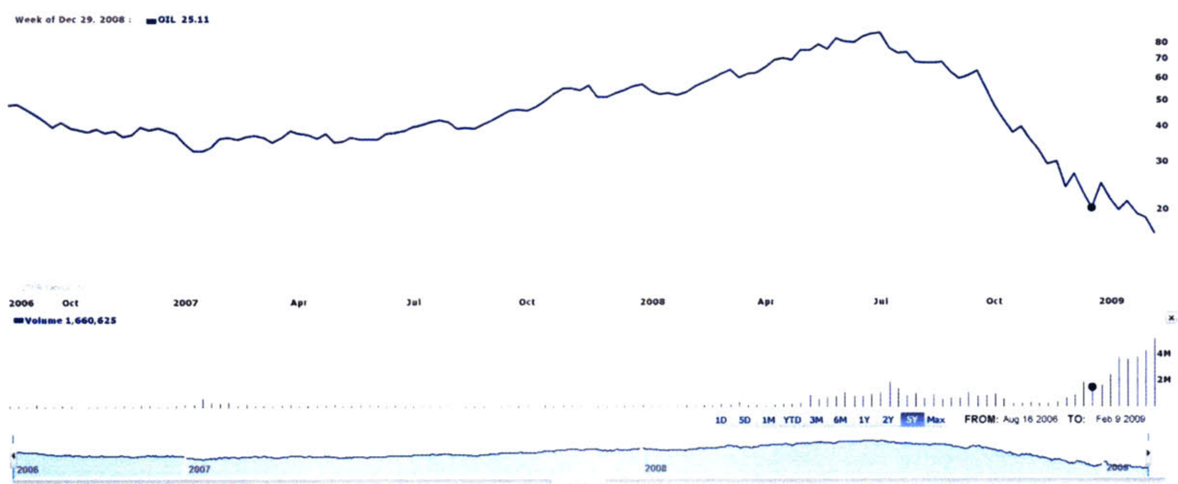


Figure 3.1: 5 Crude Oil Prices. (Source: (Yahoo,2009))

3.1.2 Water Availability

In contradiction with an earlier belief, "water will be the oil of the 21^{st} century". The main issues with water are availability (quantity, location) and quality. Water is unevenly distributed around the world; frequently requires costly distribution and costly treatment before safe usage. In commercial buildings water is mainly divided into four types: Potable or drinking water, grey water, black water, and storm water. Potable water refers to water which is suitable for human consumption; Greywater is the domestic wastewater from bathroom fixtures (such as basins, showers and baths), laundry fixtures (such as clothes washing machines and laundry troughs) and kitchen facilities (such as sinks and dishwashing machines); Blackwater refers to waste discharges from the human body (Australian Standards, 2000), which are collected through fixtures such as toilets, urinals and bidets; Storm water refers to run-off due to rainfall collected from roofs, impervious surfaces and drainage systems

(Australian Standards, 2003). This classification helps innovation in 'Reduce, Reuse, and Recycle', and it clusters water based on its necessity and pollution level. Similar to power discussed earlier, water demand correlates with cost. In addition, the concern to safeguard enough water for the coming generations motivates parties to invest in optimizing water usage.

3.1.3 New Technologies

The emergence of new technologies and the price decline of existing ones have made feasible and cost efficient technologies that were prohibitive in the past. Light occupancy sensors are a good example of an energy saving technique widely spread due to its lower cost, better performance, and higher return on investment. A rational decision maker before taking any decision should compare the added value to the cost of implementing a project; in the case of occupancy sensors investment became smaller and return became larger leading to a more attractive alternative. In return, the larger demand decreased the price of fixtures because of higher competition in the market place, and economies of scale and scope. With the MIT campus case, a large number of small projects substituting existing switches with automated sensors, or changing lighting fixtures has been completed in the last few years and the return on investment was high in all of them.

3.1.4 Awareness

Colleges, universities, publishers, global programs, media, governmental and private institutions are key players helping in educating people on the effects of global climate change. Most higher education institutions offer courses (some even 2 to 3 year programs) educating students on greenhouse gases emissions, the availability of natural resources, and providing strategies for minimizing human impact on the environment. In buildings, individuals can make difference with relatively little effort or change in comfort level; unfortunately, few people realize this and act accordingly. In response, plenty of articles have been issued to call attention and emphasize that 'every drop counts', and teach people to discipline their behavior. Some of the simple tasks proposed are switching off lights whenever leaving the room, making sure to properly turn off faucets, unplugging chargers while unused, and recycling and purchasing recycled products.

3.1.5 City and State Programs

In the US on federal, state, and city level, construction rules and regulations are being enacted to incentivize green buildings. They are also developing programs to persuade investors to build green. These programs range from funding in research with academic institutions and private organizations, to advertisement, tax incentives, and help for customers. For example, the United States Department of Energy and NSTAR announced in February 2009 that they are teaming up once again with MIT for clean energy competition; "to accelerate the pace of clean energy entrepreneurship" (NSTAR,2009). Based on NSTAR, this competition over the years gave birth to 85 companies in the clean energy field; thus increasing range, efficiency, and technology of products. A large portion of the 2009 economic package is for energy related incentives: Federal proposals include $32 billion to upgrade the nation's electrical distribution system, more than $20 billion in tax cuts to promote the development of alternatives to oil, and billions more to make public housing, federal buildings and modest-income homes more energy efficient (Taylor,2009).

3.1.6 Attraction to Investors

Earlier we gave examples of dependency of utility bills on factors such as oil prices. Due to the variance of these external factors, customers are willing to pay a premium to minimize this dependency, which can be seen as willingness to pay in order to hedge risks. Hedging can be done by purchasing houses with lower consumption rates. In addition, the emerging market is allowing higher profit margins for investors and attracting dealers, suppliers and sub-contractors. All this is leading to growing efforts toward green buildings, particularly because there are high expectations of ongoing growth in the coming years.

3.1.7 Effort by big Institutions

The effort by large energy consumers is mainly driven by incentives noted earlier in chapter 2, enticements mentioned in this section, as well as image issues Due to the number of occupants and stakeholders, high consumption, the return on investment becomes much more attractive to the larger bodies.

3.2 Summary of Existing Standards and Standard Selection

The initiation and evolution of green building standards were driven by the intent to promote sustainability and provide guidance for sustainable design. Several worldwide rating systems were established with a common objective to determine metrics for measuring a building's performance and minimizing environmental footprint. Or, as defined by the American Environmental Agency (EPA, 2009), it is the practice of:

- Increasing the efficiency with which buildings and their sites use and harvest energy, water, and materials
- Protecting and restoring human health and the environment, throughout the building life-cycle: sitting, design, construction, operation, maintenance, renovation and deconstruction

Several worldwide standards for green buildings exist, and new ones are being developed. The most popular are 27 used in 46 countries; *table 3.1* provides a per country list:

Australia: Nabers / Green Star	Brazil: AQUA / LEED Brasil
Canada: LEED Canada/ Green Globes	China: GBAS
New Zealand: Green Star NZ; Portugal: Lider A	France: HQE
India: GRIHANational Rating System by TERI /LEED India	Hong Kong: HKBEEM
Italy: Protocollo Itaca	Mexico: LEED Mexico
Netherlands: BREEAM Netherlands	Finland: PromisE
United States: LEED /Living Building Challenge /Green GlobesBuild it Green	
International Framework Committee (25 Countries): GBTool	
Spain: VERDE	United Kingdom: BREEAM
Japan: CASBEE	Germany: DGNB
Singapore: Green Mark	South Africa: Green Star SA

Table 3.1: List of standards. (Source: Wikipedia)

Many of these standards were created by modifying an original one; or by integrating some of them.

These standards concentrate on different areas of sustainable development such as life cycle assessment, performance evaluation, indoor air quality, operations and maintenance optimization. The major difference is that some of them go deep into the details of a particular system while others have a more holistic view and include the building with all its systems. Many studies comparing the different systems are available; two of them will be used for this analysis. Sustainable Building Rating Systems Summary (PNNL,2006) and Green Building Rating System-Comparison of the LEED and Green Globes Systems in the US (Smith,2006).

- A first selection criterion was to choose only the original systems for further analysis.
- Then, after excluding integrated or modified ones, screening was performed based on 4 criteria which are: Relevance, Measurable, Applicability, and Availability.
- Relevance to US market

Figure 3.2 below summarizes the selection criteria.

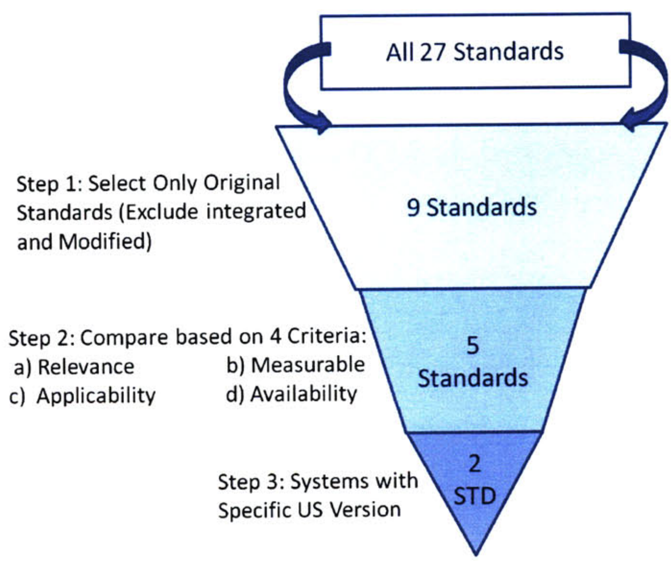


Figure 3.2: Standard Selection

The main point of differentiation between the 9 standards was the level of subjectivity. Our requirements were to select a system with clear metrics and consistency. We need to avoid or lessen the effect of different interpretations, and make it as widely applicable as possible. Only 5 systems scored positively based on these criteria, which are:

- BREEAM initiated in 1990(Building Research Establishment's Environmental Efficiency);
- CASBEE initiated in 2001(Comprehensive Assessment System for Building Environmental Efficiency);
- GBTool initiated in 1996;
- Green Globes US initiated in 2004; LEED initiated in 1998(Leadership in Energy and Environmental Design)

Green Globes and LEED have US specific versions while the others do not. Except for BREEAM, the government was involved in the development of the 4 other systems. Non Governmental Organizations were involved in all of them. In order to better understand the differences between the shortlisted standards, a set of criteria was chosen. While the definition of what constitutes sustainable building design is constantly changing, there are six fundamental principles that nearly everyone agrees on (WBDG,2009):

- Optimize Site Potential (OSP) covers: proper site selection including consideration of site reuse rehabilitation of existing building, orientation, landscaping, transportation methods
- Optimize Energy Use (OEU) covers: reduction of energy load, increase efficiency, utilization of renewable energy
- Protect and Conserve Water (PCW): reduce use of fresh water, control/treat site runoff, increase efficiency of water use
- Use Environmentally Preferable Products (UEPP) covers: materials that minimize life cycle impact, efficiently use resources, with 'low' or 'no' human toxicity
- Enhance Indoor Environmental Quality (EIEQ)
- Optimize Operational and Maintenance Practices (OOMP)

Table 3.2 below shows percentage of total score by category by standard:

	OSP	OEU	PCW	UEPP	EIEQ	OOMP	Other
BREEAM	15.0%	25.0%	5.0%	10.0%	15.0%	15.0%	15.0%
CASBEE	15.0%	20.0%	2.0%	13.0%	20.0%	15.0%	15.0%
GBTool	15.0%	25.0%			15.0%	15.0%	30.0%
Green Globes US	11.5%	36.0%	10.0%	10.0%	20.0%		12.5%
LEED	20.0%	25.0%	7.0%	19.0%	22.0%		7.0%

Table 3.2: Technical Standard's Comparison. (PNNL,2006)

In addition to the ratio of the total score, a good indicator in our opinion is the importance that standards gave to the different categories. In radar *Figure 3.3* below, we summarized the ranks based on the weight of total score a certain category is given. For example, OEU is ranked number one for all five standards, because in all of them it has the highest weight compared to the remaining six categories. In *Figure 3.3*, we can see that the five lines representing standards, for energy use category, merge at the line corresponding to the first rank.

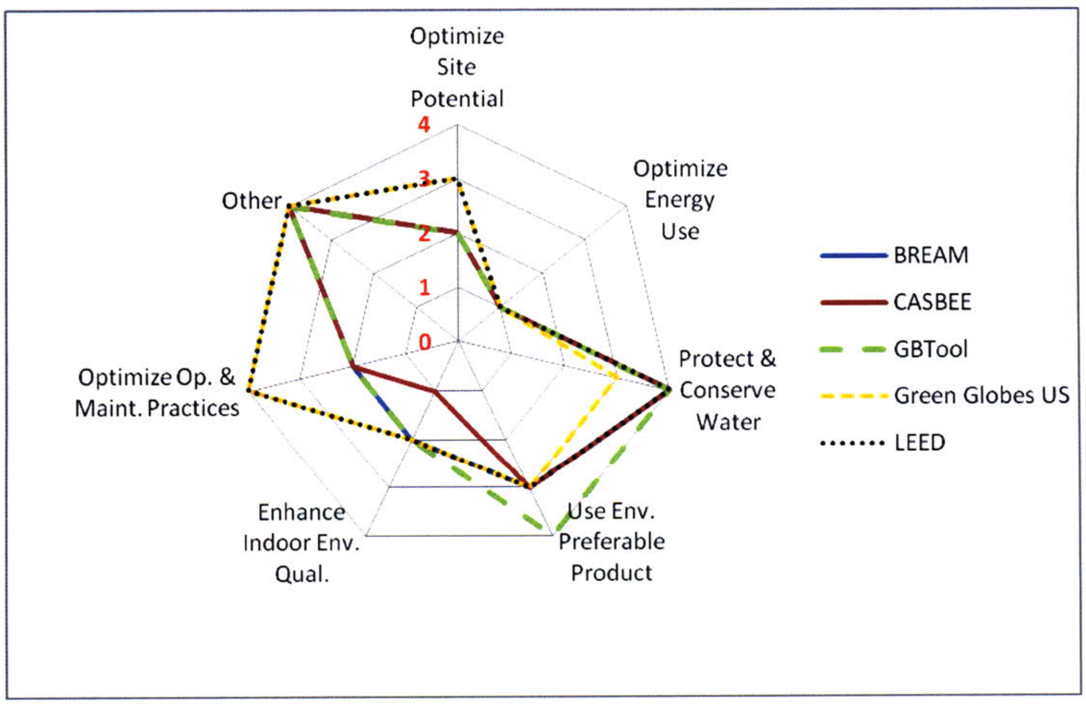


Fig. 3.3: Ranking of Standard Weights per Category

Looking to *Table 3.2* and *Figure 3.3* there are few things that we can notice:

- Except GBTool, the six principles selected by WGBL cover between 85% and 93% of the 4 other rating systems. This supports the point that most of the organization agrees on the importance of these principles
- Based on weight rankings, all standards agree that 'Optimize Energy Use' is the most important category
- Based on weight rankings, the least important and even not included in GBTool is the 'Protect and Conserve Water' category
- Indoor air quality is of high importance to all of them proving the intention to create a healthier environment

Even when the ranking by the five standards was the same, weights varied significantly. For example, 'Optimal Energy Use' ranked 1st by all standards; its weight varies from 20% to 36%. Thus, we used ranks only as an indicator of relative importance between the categories.

After having a better understanding of differences and similarities between the five standards, we will restrict ourselves to Green Globes Systems and LEED. This decision was made because both standards are the only ones with specific US version. As mentioned earlier those standards seem to compare quite closely; however when having a closer look differences are revealed such as:

- LEED require intensive paper work which turns up to be costly to administrate, in contrast with Green Globes a simple self assessment method.
- Both systems use point allocation toward certification, LEED has a maximum of 69 points while Green Globes has up to 1,000 points.
- A major difference is that LEED has some prerequisite points which don't count in the total of 69 points toward certification, while Green Globes doesn't.
- Unlike LEED, Green Globes allows use of 'Not Applicable' which removes points from the total of your project. LEED classifies on total number of points while Green Globes based on the percentage of total points.

LEED and Green Globes have four certification levels each. *Table 3.3* to follow show the scorecards of each of the standards.

LEED	Green Globes
Certified: 26 to 32 points (37.7% to 46.4%)	1: 35% to 54%
Silver: 33 to 38 points (47.8% to 55.1%)	2: 55% to 69%
Gold: 39 to 51 points (56.4% to 73.9%)	3: 70% to 84%
Platinum: 52 to 69 points (74% and up)	4: 85% and up

Table 3.3: Standards Scorecards

From the table above, it is clear that for each certification level Green Globes requires higher fulfillment percentage than LEED. It is also important to highlight the fact that Green Globes has a point allocation approach different than that of LEED. It awards points for strategies and for outcomes, while LEED awards only for outcomes. Allocating for strategies has some advantages and disadvantages. On one hand it motivates designers and all concerned parties to innovate and try to find better techniques, on the other hands these points might accumulate towards a certification with minimal impact on performance gains. As for the LEED strategy 'all or nothing', it also has some disadvantages since there is no incentive to innovate but it encourages targeting easy and lower cost points.

None of the systems discussed above are perfect, depending on the location, type, size of project, and other external and internal factors, one system would outperform the other. However by following any of these standards, the resulting building should be more environmentally friendly than not doing so. All these standards are in the early stages. Most of them have been revised multiple times and improvement work is still in progress. LEED, for example, is working on an edition newer than the one on which this thesis is based; it is expected to be available to the public by August 2009. The new version will try to capture some of the external factors which vary between geographic locations like weather change and daylight. Different classification rules will be applicable for buildings in cold areas than for those in hot and humid areas. Another important factor which limits the success of these standards is the level of understanding we have for durability and life cycle assessment of materials. For standards to improve their accuracy, standard's designers need to know the exact impact of each item to weigh its effect proportionally to its impact. Extensive research and work is being done in this area currently.

While acknowledging that today's available standards have some defects, it is important to note the complexity of the situation and the lack of information in other related fields. Taking materials as an example, there are ongoing debates about the correlation between their embodied[a] energy, and the amount of energy a material can store, and their life expectancy. There are tradeoffs to be made, but it is not clear yet which is better. In many cases generalization cannot be made due to building's particular conditions. For example, a heavy structure stores free energy and shifts temperature peaks, but has a high embodied energy. As for a light structure, the opposite occurs; it has a lower embodied energy but doesn't store much free energy.

a: Embodied energy is energy required for material to be produced

3.3 Why LEED:

LEED was developed by the United States Green Buildings Council (USGBC) a national non-profit organization. By the beginning of 2003, about 100 million square feet were undergoing LEED certification. As of December 2002, of all new construction projects in the United States, an estimated 3% had applied for LEED certification, including 4% of schools, 16.5% of government buildings and 1.1% of commercial projects (USGBC,2009). A relatively high rate of adoption of LEED certifications occurred, and it even became a requirement for some big cities like Boston, MA and Austin, TX. The LEED structure enhances change to meet evolving needs, and that is reflected in updates and or sub-versions which made LEED more compatible than other standards. As an example of sub-versions, you can find LEED EB which is specific to existing buildings. Or regarding LEED revisions, it should be noted that Energy and Atmosphere category in version 2.2 became much more challenging than version 1.1; leading to a cost impact. All these factors led LEED to become the dominant standard in the US and to be used in several other countries. Whenever following LEED standard outside the US; the version used is either the same as the US, or slightly modified to better meet the country's conditions. In the upcoming chapters discussions will be based on the LEED standard.

3.4 Costing:

Having decided to analyze the LEED standard, we will evaluate the cost impact of each of its credits, and then analyze classification levels. The cost impact evaluation is for the life cycle of the project, which includes capital cost and running cost (EAB,2007). In order to be systematic in our approach, and clarify our methodology, we will first define cost types. As used in multiple other studies; we will classify costs as hard and soft. Hard costs include:

- Green building materials
- Mechanical systems
- High efficiency items: windows, lighting sensors and all others

As for soft costs, they are composed of:

- LEED registration and certification
- Documentation of LEED features and credits
- Energy Modeling (computer simulations to evaluate design options to optimize building design and ensure a focus on those options that will result in the greatest savings)
- Engineering cost acquired during design phase
- Commissioning (assurance that a building performs as intended)

This split will help us in better understanding the project expenditures, and to some extent they can be compared to direct cost versus overhead.

Quantification of both types of costs is difficult; in fact they are a function of many variables. For hard costs, we are interested in the incremental amount incurred for achieving a greener building. Generalizing the additional cost required to obtain a credit is not an easy task. This is because there are many options to qualify for a credit, with large cost variance between these options. Additionally, the cost of the benchmark, or the built to code building, also has large cost variances.

As for soft costs, they depend on certification level, on employee wages, on an organization's familiarity with LEED requirements, market prices and project location. As noted, these costs tend to be less correlated with design particularities such as material and equipment used.

Experience is a key driver of costs; it seems that there is a steep learning curve in this field particularly for soft costs. Designers after working on a few green projects will accumulate information on good designs, material and equipment available in the market; will learn from successful practices and avoid pitfalls; and will be familiar with LEED requirements and processes. These learned skills will accelerate the job, reduce rework, and reduce cost.

In addition to experience, several other factors come into consideration when reviewing cost dependencies. The timing to seek certification has a large impact on both hard costs and soft. The earlier the decision is made, the easier and better it is for designing and implementing. This aligns with the idea of a design funnel where in early stages solution space is much larger than in later ones. For green buildings, if a decision to seek certification is made early on, designers will have control over more variables at no or lower cost.

On the other hand, evaluation of the benefits is even more complicated than that of cost. In this case, direct and indirect benefits result from building green, and these benefits are of different type such as financial, health, emission. Earlier in this paper, we mentioned a study proving better student performance in a green classroom where daylight was increased; this gives an idea of benefits difficult to monetize.

Due to difficulties discussed earlier, and commitment required from all parties to keep track of data and analyze running cost impacts of green buildings, few detailed cases about impact of green buildings have been studied to date. However, software is being developed to facilitate data collection and analysis. Numerous federal and state agencies including the U.S. General Services Administration (GSA) and U.S. Naval Facilities Engineering Command are involved in developing a continuous process of systematically evaluating the performance and effectiveness of a building's features. This process is referred to as Facility Performance Evaluation (FPE), its phases are summarized in *Figure 3.4*

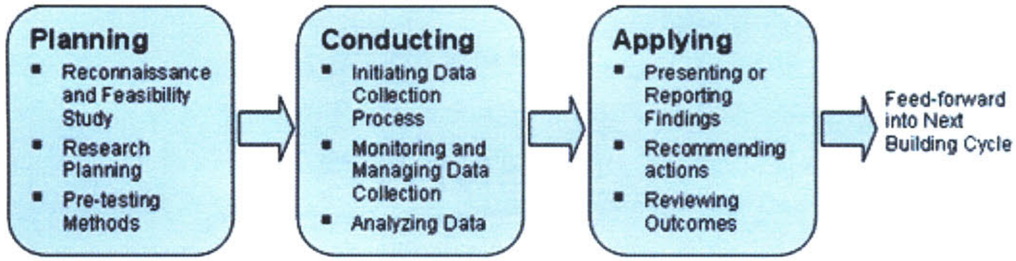


Fig 3.4: Summary of FPE phases. (Source: (WBDG,2009))

This and similar work seem promising since we are getting closer to a point where we can obtain a good approximation of the impact of building green. As mentioned in the barrier to entry section, there is a conceived belief that building green is a costly and non profitable investment.

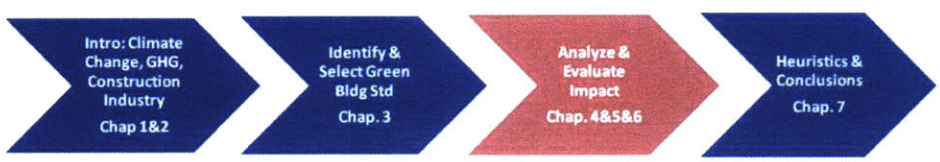
Few of the available case studies like "Renovation of the Harvard School of Public Health" (USGBC n.d.); "Greening America's Schools: Cost and Benefit" (Kats, 2007); concluded that green buildings additional capital budget varies between 1 and 6%, however these structures are less expensive to operate and maintain. Later on while discussing the LEED impacts we will compare them to these numbers.

3.5 Conclusion:

After discussing sustainability in general, then evaluating sustainability in the construction industry in particular, we introduced available standards for measuring sustainability levels for buildings. We started by stating the major incentives for establishing standards, compared existing ones, and then selected LEED for our analysis. Finally we set up the terminology and costing strategy which will be used in the following chapters.

Chapter 4

LEED Standard



4.0 Introduction:

In previous chapter, we introduced standards for evaluating sustainable buildings. We will now use LEED Version 2.2 to define elements that make a building sustainable. It is composed of 6 categories: Sustainable Sites, Water efficiency, Energy and Atmosphere, Material and Resources, Indoor Environmental Quality, and Innovation & Design Process. Each of these categories contains a set of optional credits, and 4 of them contain prerequisites. In total, there are 69 elective and 7 prerequisite points. Some of the credits are broken down into multiple ones. This is done in 2 cases, either when credits relate to the same topic, for example 'Alternative Transportation'; or when incremental saving levels are possible, for example 'Optimize Energy Performance', the more a project saves energy, the more credits it is awarded.

Looking at categories, the highest number of credits is for the 'Energy and Atmosphere' one. Summary of all percentages based on number possible points for each category out of total 69 possible points is shown in *Figure 4.1* below.

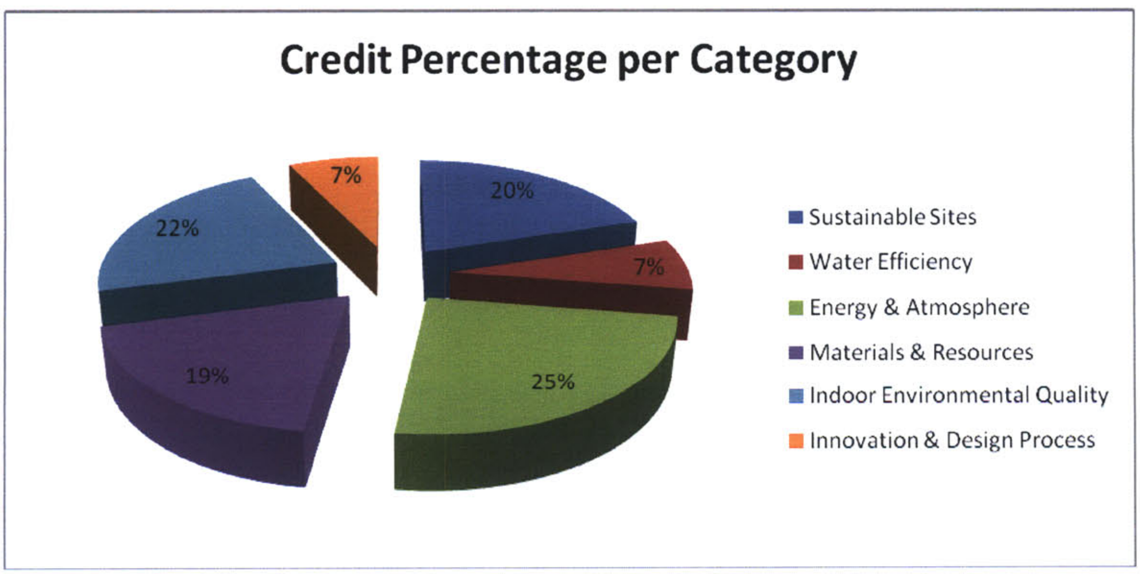


Figure 4.1: Credit % per category

We can notice from figure that 86% of the credits are in 4 out of the 6 (~66%) categories; the remaining 2 are given little importance.

In order to evaluate the economical impact, first we need to understand standard requirements, and then look for possible ways of meeting them. In following sections, we will take every credit, or group of credits whenever they are similar, and analyze them. Section 4.3 provides more details on the analysis approach.

4.1 Cost Discussion:

The cost for incorporating sustainable design is dependent on many variables. Studies show that there are 3 common approaches to determining the actual cost for incorporating sustainable design (Kats,2003) and (Langdon,2007):

- Comparison to original budget: At project completion, the difference between the actual cost and the budgeted amount is assumed to be the premium of building green. The weaknesses of this approach are 1) it assumes that prices used for budget are correct; 2) it assumes that all additional costs incurred are to make building greener, it does not account for other changes that may have occurred. These assumptions are erroneous in most cases; estimates are by their nature inexact, and it is common to have changes during construction phase.
- Calculation of the cost of individual added green features: In order to calculate additional costs, an assumption of a benchmark needs to be made. For some items, it is easy or straight forward to assume supplementary cost; however, for others it might be too complicated or even impossible. For example, in the case of air conditioning, an efficient zoning cost can be compared to a conventional one; unlike daylight where criteria such as orientation and space openness come into consideration.
- Comparison cost of a population of buildings: The main usage barrier is to find required number of comparable buildings. This approach is a data intensive one, and it also requires adjustments for factors such as location, time value of money, etc...

All 3 discussed methods are based on assumptions which are rarely applicable, thus leading to errors. However, results obtained should give a broad indication of impact resulting from perceiving sustainable structures.

In section 4.3, added cost if any of each LEED credit whether elective or prerequisite, will be determined. As discussed in chapter 2, added cost will be split into soft and hard costs. Two components of soft costs cannot be tracked by credit, and these are Certification cost, and documentation cost. Certification cost cannot be calculated per credit since it is found based on built up area. As for documentation, it cannot be tracked to credit level but it can be for the whole projects. Both of these soft costs will be treated in separate sections, sections 4.2 & 4.4.

4.2 Certification Costs:

The LEED certification's cost structure is provided in *Table 4.1*; it is fixed with respect to number of earned credits (either specified Lump sum or function of square footage). In table we can see that there is no cost associated with earned credit; there is only a cost for appealing a credit. LEED by avoiding cost per credit is encouraging projects to earn as many credits as possible.

Non-members have to pay a premium of about 18%, on average a member saves $5,000 per project and obtains other benefits. Annual membership varies from as low as $300 for a 'Contractor and Builder' with gross annual revenue less than $250,000, to as high as $12,500 for 'Product Manufacturers, building controls, service contractors and distributors' with gross annual revenue of more than $10 billion.

To make it affordable for everyone, LEED charges members based on their company's category, and Grosse Annual Revenue. More information about benefits or annual dues can be found on USGBC website.

LEED for: New Construction, Commercial Interiors, Schools, & Core and Shell full	Less than 50,000 ft² Fixed Rate	50,000-500,000 ft² Based on Square Footage	More than 500,000 ft² Fixed Rate	Appeals (if applicable) Per credit
Design Review				
Members	$1,250.00	$0.025 / sf	$12,500.00	$500.00
Non-Members	$1,500.00	$0.030 / sf	$15,000.00	$500.00
Expedited Fee*	$5,000.00 regardless of square footage			$500.00
Construction Review				
Members	$500.00	$0.010 / sf	$5,000.00	$500.00
Non-Members	$750.00	$0.015 / sf	$7,500.00	$500.00
Expedited Fee*	$5,000.00 regardless of square footage			$500.00
Combined Design & Construction Review				
Members	$1,750.00	$0.035 / sf	$17,500.00	$500.00
Non-Members	$2,250.00	$0.045 / sf	$22,500.00	$500.00
Expedited Fee*	$10,000.00 regardless of square footage			$500.00

Table 4.1: Rates for LEED Certification-New Construction

To better understand impact of Certification cost, we will give an example. Following are the assumptions 1) Design Review 2) non-member applying for certification; 3) a project where no appeal has been made; 4) no expedite action is required 5) building's area between 50,000 and 500,000 ft^2; 6) average cost of $\$600/ft^2$; certification cost would be 0.005% of total project cost. Augmenting the scope to cover design and construction review and holding all other assumptions constant, certification cost would be 0.0075%. Even though LEED doesn't give any incentive for project to choose combined design and construction review (Combined = Design + Construction not less), but certification cost even for combined in case everything goes well is negligible. An indirect benefit obtained if choosing design and construction review instead of construction alone would be minimizing appeal cost. Appeal cost in particular with experienced designers and construction managers shouldn't be a problem at all; but expedited fee if developers didn't allow enough time in their schedule is relatively high. Compared to the total building cost Expedited looks small; but looking from a different perspective it is equal to the certification cost for members on a 200,000ft^2 building.

4.3 LEED Credit's Discussion

Quantifying Building's 'Green' performance is LEED's main objective. Some of the main challenges faced by USGBC are:

- Adoption: Creating a standard which results in reducing environmental impact, while not making it hard and avoidable by most projects
- Applicability: LEED Version 2.2 is designed for all areas; this increase the difficulty for example what can be easily met in rural areas may be difficult in urban areas.

More detailed discussions on Credit's difficulty will follow. As for applicability, while scanning through the Credits we can notice that LEED tried to avoid penalizing a group more than the other. For example, number of credits favorable for rural and not for urban is about the same of those the other way round.

Next 6 sections will summarize and discuss requirements of LEED Version 2.2. Each of them will be dedicated for one of the 6 LEED categories; and will be labeled 4.3.1 to 4.3.6. Each section will contain a table, labeled similarly, listing all credits and possible points of a particular category. Sections will be divided into Sub-section, which will be labeled same as the section followed by a letter (e.g. 4.3.1-a). Sub-section will consist of 1 or multiple credits in case of similarity; discussion will focus on:

- Intent for including
- Requirements
- Soft & Hard Cost Incurred
- Important others such as difficulty of meeting or dependency on external factors.

Legend and notes for tables:

Between parentheses initials that will be used to refer to category
In later chapters we will refer to a credit by its number and to a category by its initials
Poss.: Possible
Pre-requisite
Optional credit number

4.3.1 Sustainable Sites:

Pic 4.1: Brownfield Examples (Left- Source: http://en.wikipedia.org/wiki/Brownfield_land)
Transportation Pollution (Right-Source: http://www.chinadialogue.net/UserFiles/Image/transport_pollution.jpg)

This is one of the 4 key categories, counting for 20% of the total score, as shown in *Figure 4.1*. Most of the services that people enjoy require a healthy ecosystem. An ecosystem is made up of plants, animals, microorganisms, soil, rocks, minerals, water sources and the local atmosphere interacting with one another (Biology online, July 2008). In this definition we can see the major roles sites play in ecosystem; thus impact when making land-use decisions. We can now better understand the reasons why LEED concentrated on this category. Sustainable Sites Credits are shown in *Table 4.2.1* below

Sustainable Sites (SS)		**14 Poss. Points**
Prereq 1	Construction Activity Pollution Prevention	Required
Credit 1	Site Selection	1
Credit 2	Development Density & Community Connectivity	1
Credit 3	Brownfield Redevelopment	1
Credit 4.1	Alternative Transportation, Public Transportation Access	1
Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rooms	1
Credit 4.3	Alternative Transportation, Low Emitting & Fuel Efficient Vehicles	1
Credit 4.4	Alternative Transportation, Parking Capacity	1
Credit 5.1	Site Development, Protect or Restore Habitat	1
Credit 5.2	Site Development, Maximize Open Space	1
Credit 6.1	Stormwater Design, Quantity Control	1
Credit 6.2	Stormwater Design, Quality Control	1
Credit 7.1	Heat Island Effect, Non-Roof	1
Credit 7.2	Heat Island Effect, Roof	1
Credit 8	Light Pollution Reduction	1

Table 4.2.1: 'Sustainable Sites' Credits (Source: USGBC)

4.3.1-a Construction Activity Pollution Prevention:

This is one of the 7 mandatory LEED requirements. The objective is to reduce air pollution by controlling soil erosion, airborne dust generation, and waterway sedimentation. In order to meet requirements an Erosion and Sedimentation Control (ESC) plan for all construction activities should be prepared. The ESC plan includes ways to (intheleed):

- Prevent loss of soil during construction by stormwater runoff and/or wind erosion, including topsoil by stockpiling for reuse.
- Prevent sedimentation of storm sewer or receiving streams.
- Prevent polluting the air with dust and particulate matter.

The implementation cost varies with geography, because of differences in soil types and weather. However, it is worth noting that the added costs are minor, and the ESC plan is already required by most jurisdictions. The majority of soil loss occurs during construction, resulting primarily from storm water. Protection methods to minimize this should be included in ESC plan, and performed during construction. Contractors will incur these small hard costs; as well as costs for dust control, water in case of demolition of an existing structure, etc... As for the soft costs, it is the responsibility of the design office. But since ESC is a legal requirement, designers should be experienced with the procedure and thus require little effort to prepare documents. As we can remark both hard and soft cost should decrease with more exposure to green projects.

This credit has no impact on the building's running cost; its advantages are restricted to environmental protection during construction phase.

4.3.1-b Site Selection:

One of the credits that a site qualifies for it or not; or in other words designers and contractors can't do anything to obtain it. The purpose behind it is to encourage developers choosing appropriates sites, or minimize developments (Buildings, roads,...) on sites that have any of the following criteria (intheleed,2009):

- Prime farmland as defined by *USDA* (U.S. Department of Agriculture)

- Habitat for any endangered or critical species
- Within 50ft. of a water body (lakes, seas, rivers, etc.) Comply with *Clean Water Act*.
- Below 5ft. above the 100 year flood elevation as defined by *FEMA* (Federal Emergency Management Agency)
- Within 100ft. of Wetlands as defined by *CFR* (Code of Federal Regulations)
- Public parkland (Park Authority projects are exempt)

It is rare to find decision makers who will select sites for their projects while taking into consideration the criteria listed above. But due to the scarcity and location of sites that has any of these characteristics; it is common to qualify for this credit.

Since contactors are unable to make any action to obtain this credit, of course no additional hard costs are incurred. On the design side, the documentation to prove the site appropriateness is the only expense. As mentioned in section 1.1 we will address documentation costs in a separate section.

There are no operational savings resulting from this prerequisite; it provides environmental benefits only.

4.3.1-c Development Density & Community Connectivity:

This LEED objective provides incentives for development in urban areas where infrastructure pre-exists thereby:

- avoiding usage of septic tanks since sewer systems are available, and
- minimizing work required and material used to connect to utilities due to its proximity,

In addition to spurring development in urban areas, this objective aims to protect greenfields and preserve natural resources. There are 2 options based on development density or on community connectivity for obtaining this point.

Option 1 is determined based on:

- Minimum 60,000 sq.ft. per acre
- compare to 2 story downtown building
- previously developed site

Option 2 is based on:

- previously developed site
- within 1/2 mile radius of 10 "basic services" (Banks, churches, stores, etc.)
- do not include undeveloped areas (parks, water bodies)
- pedestrian access between buildings
- *within 1/2 mile* of residential area averaging density 10/units per acre

Once again 'Development Density & Community Connectivity' belongs to a type of credits which are out of designers and general contractor's control. The only cost identified with this credit, therefore is the soft cost of research and documentation. It is important to mention that its requirements are much more stringent than those of 'Site Selection'. Eventually, for credit Credit2 both options to qualify for it require a developed site, in addition to that developers can pick between density obligations, which are relatively high; or vicinity to residential area and number of places relative to the radius are high, which are also tough. In 'Site Development' credit, it is likely to find sites as described.

4.3.1-d Brownfield Redevelopment:

By definition, a Brownfield site is a commercial or industrial site which is abandoned or underused.

The degree of contamination of Brownfield sites varies; as do the costs, methods, and duration, of treatment for contamination. The purpose of this objective is to spur (intheleed,2009):

- Rehabilitation of major sites where development is complicated by environmental contamination,
- Reduction of pressure on undeveloped land.

In order to make this credit more attractive, LEED reminds investors of government incentives and tax breaks resulting from choosing such a site. Hard costs consist of all equipment and material necessary to treat and ensure appropriate conditions for construction. In the process of cleaning sites, it is not uncommon to encounter surprises such as underground storage tanks or buried drums. Such situations will have a relatively high impact on costs and duration. This uncertainty in scope of work leads to relatively high soft and hard costs. In order to minimize the risk of losses, every party performs excessive research and tests to have a better understanding of site conditions. It also adds a buffer to the budget to account for unexpected future surprises.

It is clear that this particular point does not bring any operational savings. Due to all the aforementioned, 'Brownfield Sites' is often considered unfavorable and difficult to pursue.

4.3.1-e Alternative Transportation, Public Transportation Access:

To qualify for this credit the project be located (intheleed,2009):

- within 1/2 mi. from existing or future planned (and funded) train or subway station Or
- within 1/4 mi. from two public or campus bus lines.

The purpose is to encourage and facilitate mass transit which will reduce transportation impact on the environment. Other than lot price (which might include premium due to its location Close to public transportation), in general there are no other added hard costs. In the design there are little or no costs due to the ease of proof of requirements.

Access to public transportation is not related to building operation, thus no operational savings are gained...In big US cities like Boston, it is not difficult to obtain this credit, however in suburbs it is more difficult. In fact big cities are redefining themselves, aim to partner civil needs with economic growth with environmental benefits.

4.3.1-f Alternative Transportation, Bicycle Storage & Changing Rooms:

Once again LEED is not restricting itself to direct harm caused by building, but it is also considering impact caused by getting to and from certified structure. This credit is obtained by meeting the criteria outlined below (intheleed,2009):

Commercial or institutional buildings:

- provide bike rack based on 0.05 Full Time Equivalent (FTE) measured at PEAK periods within 200 yards
- provide changing room and shower based on 0.005 FTE within 200 yards

Residential buildings:

- provide bike rack for 15% of residents

LEED is facilitating biking to destinations by removing obstacles such as showering when getting to school or work. This credit looks like an inexpensive one; bike racks are cheap with low installation cost; however in commercial cases, showering requirement might be costly and complicated. Sometimes the FTE of a commercial building is high, so a large will be designated for showering facilities. If planned in early stages, these problems can be overcome by usage of dead space for showers, and by proper locating to minimize installation requirements such as piping, fixtures, etc... Thus costs will be significantly reduced. For residential buildings, the hard cost will be negligible since it only requires a larger percentage of bike racks. As for soft costs, even when showers are be added, additional costs are small.

We can conclude that 'Bicycle and Changing Rooms' is easy to attain with no running costs savings resulting, but even small expenses to operate and maintain showers for commercial or institutional buildings.

4.3.1-g Alternative Transportation, Low Emitting & Fuel Efficient Vehicles:

Like some of the aforementioned credits, this credit takes the whole system into perspective. Three options are available for obtaining it (intheleed,2009):

- providing low emission cars (yes, provide cars to people), with preferred parking for 3% of Full Time Equivalent (FTE)

Option 2:

- providing preferred parking for low emission cars (0.05 total parking spaces)

Option 3:

- providing charging station and refuel stations for low emission cars (0.03 total parking spaces)

Here, a low emission car is defined as a ZEV (zero emission vehicles) with a *minimum energy star of 40*. Additionally, it is important to note that preferred parking *EXCLUDES* handicap spaces

LEED sets a minimum parking requirement for ZEV's, then gives decision makers options to choose between reserving more spaces for low emission cars, or providing occupants with cars, or installing charging system. Option's impact, whether economical, or design, or feasibility, varies with markets and cities. For example in case ZEV's are not popular in building location at construction time, sticking with option 2 might be better because ZEV's would be expensive. But on the other hand can force an increase in parking capacity, thus require more design and time for completion.

All 3 options impose at least 3% of preferred parking space. This 3% will affect hard cost only when an expansion of parking area should be provided, but most probably this won't be required. For option 1, the additional hard cost is price of cars for 3% of the residents. This is a function of number of residents and price of vehicle or location and market. For option 2, developers have to pay to provide 2% additional parking space for ZEV's. Same as for the first 3% added hard cost might or might not be implied; but this time there is a much higher probability of need for expansion. As for the third option; compared to option 1 owner can decide to save paying for 3% ZEV and provide a charging system. And third option compared to 2nd one, decision is between an additional 2% parking space, and a provision of a charging system. In general we can say that no matter which option is picked hard cost will be incurred. Looking at soft costs, providing 3% parking space need to be considered during design phase and will result in little or no added cost. For option1 no additional soft cost will be added, developers only need to purchase cars. Soft cost of Option 2 can also be considered as a negligible since designing for 3% or 5% reserved parking will almost be the same. As for option 3, design for charging system is required, but it is a relatively simple and inexpensive task. Tradeoff between options can only be treated on a case by case basis; none of them clearly governs the others. In all cases we saw a cost impact, and FTE had a major role determining it. That being said, we can consider this credit as difficult to achieve.

4.3.1-h Alternative Transportation, Parking Capacity:

The purpose of this credit is to reward carpooling, use of public transportation, biking, and other alternative transportation system by limiting parking spaces. Discussions of 'Alternative Transportation' and dependency on lots of external factors is also applicable inhere.

4.3.1-i Site Development: Protect or Restore Habitat (1 Pt); Maximize Open Space (1 Pt):

The purpose of this credit is to encourage biodiversity and the conservation of existing natural areas.

To obtain the 'Protect and Restore Habitat':

- Case 1: Green Field Site:

  Disturbance should be limited to: 40 feet for buildings, 10 feet for walkways, 15 feet for roadways, and so on.

- Case 2: Previously developed sites

  Replace impervious surfaces with native or adapted vegetation for a minimum of 50% of site area (Excluding building footprint)

For more open spaces point building should:

- Case 1: there IS a local code for open space restriction

  open space should exceed local code by 25%

- Case 2: there is NO code (campuses or military bases)

  open space is to be same size as building footprint

- Case 3: there IS a local code, but ZERO open space requirement:

  open space should be 20% of site area

Those two points are more of constraints than of costly items; however in some particular cases meeting criteria might be very costly and difficult. For example in case of a previously developed site, solution might be avoided or even not feasible because of site conditions like thickness of impervious layer. Area codes also affect difficulty of requirements; combination of all these factors prevents us from generalizing cost and difficulty of these 2 points, but in all cases no future monetary benefits or expenses are expected.

4.3.1-j Stormwater Management: Rate & Quantity (1 Pt); Treatment (1 Pt):

This credits aims to limit the disruption and pollution of natural water LEED. To qualify for rate & quantity developers need to implement system that meet one of the following systems (intheleed,2009)

- *case 1*: for an impervious surface less than or equal to 50% of total site area, it is necessary to have a:
  - post-development peak discharge rate and quantity *equal to or less than* pre-development (for 1 and 2 year, 24-hour design storms) OR
  - a stormwater management plan that protects receiving stream channels from excessive erosion by implementing a *stream channel protection* strategy and quantity control strategies.
- *case 2:* For an impervious surface more than 50% of total site area it is necessary to have:
  - a post-development peak discharge rate and quantity *25% less* than pre-development (from the two-year 24-hour design storm)

To get the quality point, developers must implement a system that: (intheleed,2009)

- treats and captures 90% storm water runoff;
- removes 80% TSS (total suspended solids);
- and uses acceptable BMPs (Best Management Practices) considering the following:
  - sustainable design strategies: low impact, environmentally sensitive design)
  - alternative surfaces: vegetated roofs, swales
  - natural and mechanical treatment: constructed wetlands, vegetated filters and open channels

These requirements can only be met when properly designed for and in early stages. The primary expenses arise from hard costs, and these are dependent on multiple factors such as imperviousness at the site. For quality point, a moderate premium needs to be invested in order to capture and reuse stormwater; but it is important to note that this premium results in operational savings. Generally it is difficult to meet any of these 2 points because they need to be submitted early in design phase and systems may vary with planning and so does cost. For example, storage structure can be as simple as a pond next to the structure, or as difficult as a sophisticated underground tank.

4.3.1-k Heat Island effect: Non-Roof (1 Pt); Roof (1 Pt):

The aim of this credit is to minimize dark surface areas which absorb sunlight then re-emit heat energy, impacting microclimate, human, and wildlife habitat.

The non roof-point can be obtained in 2 different ways which are:

Option 1:

- Any combination of the following for 50% of the total site hardscape: provide shades within less than 5 years of occupancy; use paving material with Solar Reflectance Index (SRI) ≥ 29; use open grid pavement system.

Option 2:

- Provide at least 50% under cover parking with its roof SRI ≥ 29.

As for the roofing credit, 3 options are available::

Option 1:

- Use 75% of roofing materials with an:
    a) SRI≥78 if low-Sloped (Slope ≤ 2:12)
    b) SRI≥29 if steep-sloped roof (Slope>2:12)
- At least 50% of roof area to be vegetated soil
- Weighted combination of both options

The cost impact for Non-Roof considerations is negligible; in many cases shades are provided at walkways irrespective of whether or not it is a LEED requirement, parking is often underground to maximize space use, and if there is no basement, open grid can be installed without worries of water leak to basement. We can see that depending on project credit selection and combination can be made, but in all cases requirements are not costly and met by many designs even when not seeking LEED certification. For roof areas, situation is different. The cost impact can be more considerable especially in the case of a vegetated roof. This requires special consideration for a waterproofing system; creates structural considerations for the added load. In windy locations situation becomes even more critical in design and operations; for example insurance will cost client more because of the fact that roof plantation might be torn and result in damages. Cheaper alternative such as the use of reflective roof tiles may be considered; but in multilevel glazed buildings, this alternative has a disadvantage of reflecting heat from lower roofs to upper occupied areas.

Depending on the alternative and external factors these 2 points can cause operational savings or costs. For example having a vegetated roof will reduce the energy required to cool the last floor during hot season, but also will increase maintenance cost and heating cost during cold seasons. In sum, these 2 points are considered to be relatively difficult; planning for them must begin in early design phase.

4.3.1-I Light pollution Reduction (1 Pt):

The Rationale of this credit is minimizing the amount of light trespassing from building sites, therefore reducing the impact on nocturnal environments.

The requirements for this credit are divided into 2 categories Interior and Exterior and are: (intheleed,2009)

- For Interior Lighting it is necessary to:
  - stay inside and
  - shut down non-emergency lights at non-business hours

- For the Exterior Lighting, these must:
  - provide for comfort and safety only
  - NOT exceed 80% of lighting power densities for exterior area and 50% for building facades and landscape features as defined in ASHRAE/IESNA Standard 90.1-2004.
  - NOT install lighting more than 2.5 times building height from property line

- This credit, however, does not apply to 3 story buildings, warehouses, and manufactured homes.

In order to meet this credit, proper design of the exterior, perimeter, and interior lighting is required. This includes paying special attention to fixtures specifications and illumination levels to balance between LEED and safety requirements. Soft costs might be a little higher, but savings to hard costs are expected because of less number of fixtures, and lower illumination levels.

It is true that this credit needs to be submitted in design phase, but it is easy due to the flexibility and ease to switch between different fixture types. On the other hand and as mentioned earlier, safety requirements might prevent developers of getting 'Light Pollution' credit.

4.3.2 Water Efficiency:

SS WE EA MR IEQ IDP

Pic 4.2: (Left–Source: http://www.worldpress.org/images/20061023-water.jpg)
(Right-Source: http://www.h2oasisinc.com/FilesCustom/HTMLEditor/Images/toro/COMMERCIAL_BEAUTY2.jpg)

Even though it has the smallest share of the pie in *Figure 4.1* but we should keep in mind that water is a source of life. Sustainable sites derived its importance because of it being part of the ecosystem, water source is another part. We divided the credits in this category into 2 parts, first related to water supply and second related to waste water. Water supply also differentiates between use for irrigation and other use, but we will discuss them together. *Table 4.2.2* below summarizes these credits:

Water Efficiency (WE)		5 Possible Points
Credit 1.1	Water Efficient Landscaping, Reduce by 50%	1
Credit 1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	1
Credit 2	Innovative Wastewater Technologies	1
Credit 3.1	Water Use Reduction, 20% Reduction	1
Credit 3.2	Water Use Reduction, 30% Reduction	1

Table 4.2.2: 'Water Efficiency' Credits (Source: USGBC)

4.3.2-a Water Efficient Landscaping, reduce by 50% (1 Pt); Water Efficient Landscaping, No Potable Use or No Irrigation (1 Pt); Water Use Reduction 20% (1 Pt); Water Use Reduction 30% (1 Pt):

Aiming to optimize the use of resources, and especially critical ones like water; LEED decided to award credit for reducing water consumption, particularly for irrigation purposes.

By minimizing water use, projects maximize their own efficiency, while also reducing the load on water distributors on one side, and on the wastewater systems on the other end. In order to meet the standards, special fixtures, sensors, and flow controls need to be installed. Following are the levels to be met:

- For Efficient Landscaping, the project plan must account for proper plant species, considering the species factor including:
  size, growth rate, adaptability, texture, color, diversification of plant life on site.
- Additionally it is necessary to install high efficiency micro-irrigation system such as: Drip, or micro misters, or subsurface irrigation.
- Instead of using potable water use, sites must use either:
  Captured rainwater, or recycled wastewater, or treated water.
- An alternative to using on site treated waste water; buildings have the option of using treated water conveyed by public agency and specified to be for non-potable uses.
- In order to meet standard, it is also important to:
  Limit Turf Area and Use landscaping that doesn't require permanent irrigation systems

As for the 2 credits about efficient water use, LEED set flow rates for all fixtures to be installed in buildings. Doing that, it removed all ambiguities and misinterpretation of requirements, while securing a maximum water use. Following is a list of fixtures with their flowrate requirements; flowrates are measured in Gallons Per Minute [GPM].

- Shower/2.5 (lowflow/1.8)
- Lavatory/2.5 (lowflow/1.8) (ultra lowflow/0.5)
- Kitchen Sink/2.5 (lowflow/1.8)
- Faucets/2.5
- Aerator/2.5
- Water Closet/1.6 (lowflow/1.1)
- Dual Flush Water Closet/1.6 (lowflow/0.8)
- Urinal/1 (lowflow/0.5)

Often project's landscape plan is designed without considering plant's water requirements. The intent of LEED is to limit or even eliminate unnecessary water use by encouraging reuse of graywater or similar alternatives for irrigation, and by suggesting being more selective while designing soft landscape. Hard costs associated with limiting irrigation use depend on the alternatives decided since cost of capturing rainwater and recycling water are different, etc...Geography might also eliminate options; for example in a place with low yearly precipitation use of rainwater is not realistic. An important fact to keep in mind is that no matter which alternative we choose, hard cost will substitute irrigation cost to be paid during the life cycle of the project.

Efficient water fixtures cost a bit more, but generally speaking they have a short payback period. It takes not more than 1 year due to their competitive prices. The average water use per capita per day depends on several external factors like weather, cost and similar ones. While the average water use per capita per day in the United States in 2007 was about 150 gallons; there is a range from as low as 100 to as high as 195. Thus, future cash flow and benefits resulting from efficient fixtures vary significantly, and are highly dependent on future unknown unit prices. Also included in this credit is the reuse of graywater and/ or stormwater for non-potable water use; both of these suggestions are often avoided by designers because they are much more costly than using efficient fixtures.

Initially additional soft costs are significant but it diminishes with experience and understanding. This is particularly true for landscaping credits where designers need to explore several options to be able to find a balance between aesthetic and water requirements. Some alternatives might require design of small systems, which is inexpensive and most probably quick. In sum, designers need to go more into details of fixtures, appliances, plants and everything to be used; they cannot restrict themselves to aesthetics and performance anymore but need to understand efficiency and future requirements.

In addition to financial benefits of lower water consumption, systematic benefits of water conservation are produces. For example, for the water supplier, the amount to be treated and delivered for customers will be less, thus they will use less energy for that. The amount of waste water to be treated will also be lower and more concentrated with impurities (better

efficiency in treating). Once again we face a cyclic effect where by improving one part of the chain will also improve other parts.
Geography influences the costs of irrigation and other water use, LEED must consider this in later versions, and make it more customized depending on demand distribution weather and others. Meeting 50% reduction in irrigation or 20% savings in water consumption is neither difficult nor expensive, and it can be economically justified (NPV of installing better fixtures > 0). However, in order to obtain credit for no irrigation requirement or 30% savings in water use, it is much more costly and challenging. Only projects targeting high certification levels like Gold or Platinum attempt to get these credits.

4.3.2-b Innovative Wastewater Technologies:
In addition to encouraging water conservation, LEED also rewards the reduction of waste water generation. The benefits resulting out of such a technology are reduction of waste water quantity to be treated and/or discharged; and reduction potable water going to sewages. This is measure by (intheleed,2009):

- Treatment system cycle: transport –> store –> treat –> dispose

  Option 1: *Reduce potable water use by 50%*

  - use water conserving fixtures
  - reuse non-potable water for flushing
  - reuse *on-site* treated water

  Option 2: *Treat and reuse 50% of wastewater on-site (to tertiary standards).* Treated water must be used on site

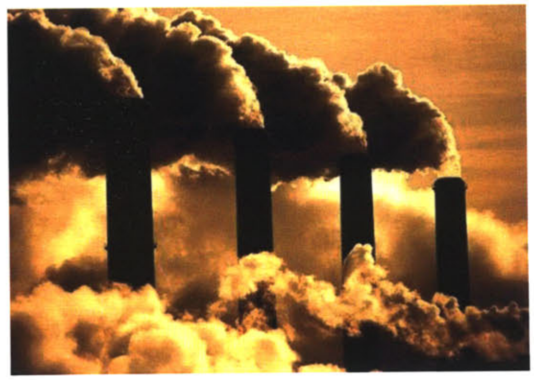
  - treated water must be treated by:
    1. biological systems
    2. constructed wetlands
    3. high efficiency filtration system

Percentages required for both options are high, and in general cannot be achieved by using low pressure fixtures only. In addition to these, in order to qualify, designers must therefore collect and treat any of the following: stormwater, greater, or blackwater.

Hard and soft costs of these treatment systems are significantly high; especially in urban area where infrastructure exists (Opportunity cost would be connecting to existing system at a much lower price). These systems require maintenance and operational cost, and their market prices are still high. These facts and complications make the credit difficult to earn.

4.3.3 Energy & Atmosphere:

SS WE EA MR IEQ IDP

Pic 4.3 Wind Turbines (Source: http://got2begreen.com/wp-content/uploads/2008/04/wind-turbines-370-x-283.jpg)
Coal Power Plant (Source: http://saferenvironment.files.wordpress.com/2008/09/pollution.jpg)

With the largest share in LEED standard, Energy and Atmosphere is also one of the first things that come to a person's mind when talking about 'Green Buildings'. This category has more prerequisite than any other one, which reflects intent of ensuring a minimum, and improving energy performance. Energy consumed by buildings has a large footprint on the environment, it also relates to the running cost to be paid by occupants and that's where its importance thrives. On a top level view, we can say that LEED is considering energy conservation and the reduction of harmful gases released by the building itself in this category. Details of credits are provided in *Table 4.2.3* below:

Energy & Atmosphere (EA)		**17 Possible Points**
Prereq 1	Prereq 1 Fundamental Commissioning of the Building Energy Systems Required	Required
Prereq 2	Prereq 2 Minimum Energy Performance Required	Required
Prereq 3	Prereq 3 Fundamental Refrigerant Management Required	Required
Credit 1	Credit 1 Optimize Energy Performance 1–10	1-10
Credit 2	Credit 2 On-Site Renewable Energy 1–3	3
Credit 3	Credit 3 Enhanced Commissioning 1	1
Credit 4	Credit 4 Enhanced Refrigerant Management 1	1
Credit 5	Credit 5 Measurement & Verification 1	1
Credit 6	Credit 6 Green Power 1	1

Table 4.2.3: 'Energy & Atmosphere' Credits (Source: USGBC)

4.3.3-a Fundamental Commissioning of the Building Energy Systems Required (Prereq.); Minimum Energy Performance Required (Prereq.); Fundamental Refrigerant Management Required (Prereq.):

The prerequisites ensure that the design, installation, calibration and performance of all energy related system in the building meet the client's requirements and are operating according to the design, while simultaneously having a minimum level of energy efficiency. LEED uses existing codes as standards as a measure for energy prerequisites, therefore prerequisites listed simply reinforce industry standards, and they are: (Integrated,2009)

- Engage a commissioning team that does not include individuals directly responsible for the design or construction management.
- Review design intent and basis of design documentation.
- Incorporate commissioning requirements in the construction documents.
- Develop and utilize a commissioning plan.
- Verify installation, functional performance, training and operation and maintenance documentation.
- Complete a commissioning report.
- Design the building to comply with ASHRAE/IESNA Standard 90.1-1999 (without amendments) or the local energy code, whichever is more stringent.
- Zero use of CFC-based refrigerants in new base building HVAC&R systems. When reusing existing base building HVAC equipment, complete a comprehensive CFC phase-out conversion.

We expect that the 3 prerequisites incur neither additional hard nor additional soft costs. An example to that is the commissioning report requested by LEED, today a clause requiring it is in almost all contracts.

We can conclude that once again in prerequisites LEED conditions are very realistic and easy to meet.

4.3.3-b Optimize Energy Performance (2-10 Pts):

These credits give the designers a chance of getting from 2 to 10 points. It was included in order to: (intheleed,2009)

- Achieve increasing levels of energy performance above the baseline in the prerequisite, and in order to
- Reduce environmental and economic impacts associated with building energy usage.

The number of points a building will get is calculated based on the energy cost savings; value of savings range from 10.5% for 1 point to 42% savings for full score or 10 points; at a 3.5% increase per point. New projects need to achieve at least 2 out of these 10 points (or a minimum energy saving of 14%). In addition to the percentage based point allocation LEED provide 3 options but, none of them gives the opportunity to earn more than 5 points. These options are applicable to specific projects, like building of certain types, or within a certain area range (square footage), or built before a certain date.

Strategy and costs whether soft or hard depend on the number of points targeted and on the location. For example in a location with extreme whether condition, energy savings resulting from better insulation will be much higher than in a moderate whether condition. To meet savings designers can do one or many of the following:

- Install High performance glazing,
- Build High insulated walls (e.g. use insulation boards),and roof,
- Avoid overdesign of lighting power densities,
- Provide proper air circulation,
- Provide fans to minimize air conditioning use,
- Install light dimming and occupancy sensors,
- Make better use of daylight, and
- Install proper cooling towers.

There is a minor cost premium associated with meeting the first 2 points; but the marginal cost for obtaining an additional point become much larger after the second point and it keeps on increasing. A study on office buildings (GSA,2004) showed an increase in total cost of 0.91% to meet 5 credits, and 2.39% to meet 7 credits. This looks logical since the increasing efficiency by the same amount at lower levels is easier than increasing it at higher levels, thus only projects targeting Gold or Platinum certification levels target more than 6 points.

For the operational costs, an additional 0.91% of the initial cost will save 17.5% on the operational cost for the life of a project. The percentage saved is clearly large, and for the lifecycle of the building, so it is expected that benefits outweigh costs.

While scoping our paper earlier, we excluded environmental and indirect benefit, but in this set of points, it is worth to stop and elaborate it a little bit. Currently losses in energy are enormous even small actions make a difference. It is very important to understand the cumulative effect of this credit. As we just saw, this average of this category is about 25% savings per building in return would imply about 20% savings on utilities. This 20% savings reduces pollution produced for production, and might postpone expansion in some cases. In addition, we should also consider inputs resources such as fossil fuel, supply of these resources is dwindling, and its extraction pollutes the atmosphere. As we were just discussing, there is economic, ecologic, impact with macro and micro effects.

4.3.3-c On-site Renewable Energy:

There is a possibility of getting up to 3 points for reducing fossil fuel usage. The 3 points are awarded based on the renewable energy produced on site, cost savings is used as the metrics, and they are:

- For 1 Point minimum savings required are 2.5%.
- For 2 points minimum savings required are 7.5%.
- For 3 points (max. number of points) minimum savings required are 12.5%.

Cost associated with gaining points for this credit varies with the system used to meet requirements. Examples of systems that would be eligible to convert energy are: wind, photovoltaic, geothermal, or biomass. It is important to note that in this credit, only systems or methods to produce energy will gain points, ways to avoid or minimize its use won't. For example, solar hot water heating will not qualify for any of these points.

Compared to other LEED credits, the relative cost of achieving points in this subset is significantly high. The hard costs incurred for PV system, for example, include, installation, panel, mounting structure, backup system and battery, wiring, conduits.

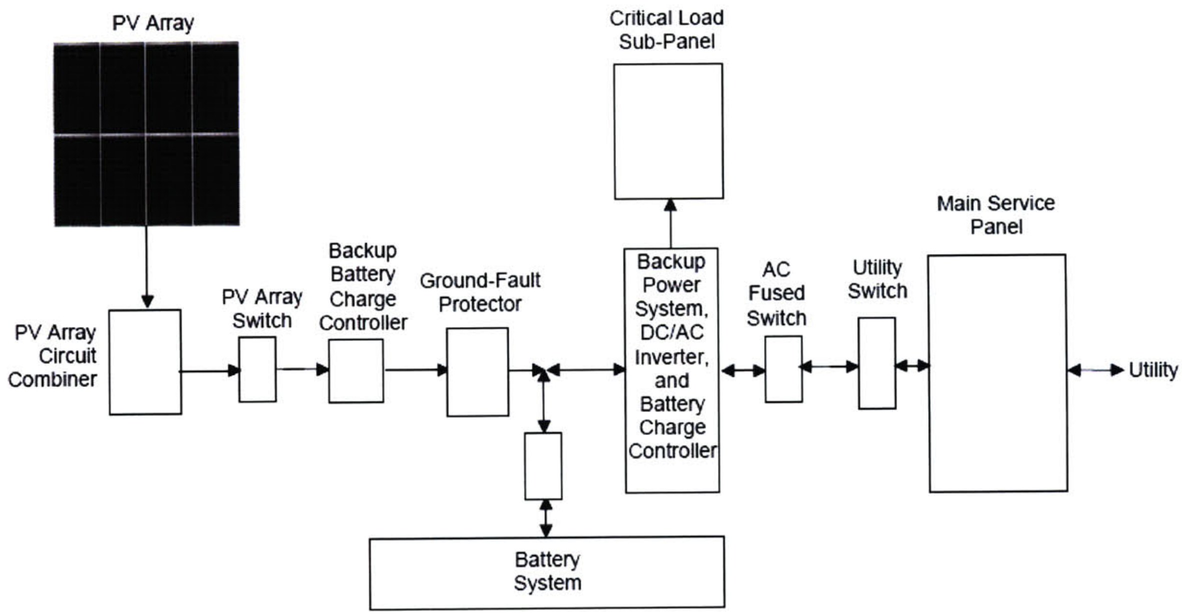


Fig: 4.2 Typical PV System Components: A guide to PV system design and installation, California Energy Commission Consultant Report. 9/4/2001

As we see in *Figure 4.2*, this typical energy renewable system is a fairly complicated system that requires maintenance during building lifecycle. System is composed of several components with 1 or 2 way relations between them. The soft costs, in addition to the calculations and documentation to be presented for LEED, include a proper design for location, performance, and aesthetic needs to be performed. As a summary to cost discussion, soft and hard costs incurred from renewable energy credits tend to be on the high side.

Operational savings for sure result in qualifying to this credit; in fact the number of points earned is determined based on them. The total amount of savings for sure varies with location, system used and other external factors, but in all cases owners benefit is over as long term.

Finally, renewable energy can be classified as one of the difficult and expensive credits to obtain. Same as for the earlier energy credits, indirect benefits also flow from the renewable energy, but we are restricting our discussions to the direct ones.

4.3.3-d Enhanced Commissioning (1 Point); Enhance Refrigerant Management (1 Point):
These 2 credits tie back and develop more the prerequisite requirements of the energy and atmosphere section. In the prerequisite LEED was not more stringent than current regulations and standards; in these two optional credits, it is increasing the expectations. The main intent is to ensure proper performance and reduce contribution to global warming.

For enhance commissioning, the requirements are: (inthelled,2009)

- designate CxA (commissioning authority) to lead/review/oversee completion of all commissioning process activities
- CxA must REVIEW OPR (Owner's Project's Requirements), BOD (Basis of Design), and Design Documents prior to 50% CD.
- CxA shall REVIEW SUBMITTALS for compliance with OPR and BOD.
- Develop a SYSTEMS MANUAL for operating staff
- Verify that requirements for TRAINING STAFF & OCCUPANTS are completed
- REVIEW BUILDING OPERATION 8-10 months AFTER SUBSTANTIAL COMPLETION

As for the enhanced refrigerant two options are available:

- Option 1: Do not use any refrigerants
- Option 2: use refrigerants and HVAC that minimizes or eliminates emission of compounds that cause ozone depletion & global warming.

In general, building commissioning starts near the end of construction; however it would be better if it is started at the beginning. LEED is suggesting starting it as early as the design phase. The majority of hard costs are for calibration, testing, mostly there is no need for additional material or equipment. As a rule of thumb, building commissioning cost constitute 1 to 2.5% of building cost. LEED is suggesting involving the commissioning authority earlier in the process little premium cost will follow. This requires commitment, more coordination, and a few delays due to design verifications, and reviews.

No operational cost savings will result out of this credit, since it is mainly verifying that systems are performing as they were designed to do. It is important to mention that creating checkpoints early in the project will waive costs if any caused by errors in design, and/or installation.

4.3.3-e Measurement and verification:

This credit requires verification of energy and water consumption of buildings post occupancy. This requires tracking and comparing the consumption for the applicable systems in the following list: (Energy Corporation, 2004)

- Lighting systems and controls
- Constant and variable motor loads
- Variable Frequency Drive operation
- Chiller efficiency at variable load
- Cooling load
- Air and water economizer and heat recovery cycle
- Air distribution static pressures and ventilation air volumes
- Boiler efficiencies
- Building specific process energy efficient systems and equipment
- Indoor water riser and outdoor irrigation systems

This credit is considered an expensive one due to the fact that control points, meters, or other measuring tools need to be installed on most systems. The hard costs will include the price of purchasing these tools, installing them, installing supporting systems, labor to read measures and keep track results, and etc... On the soft cost side, design for measuring systems needs to be done, plans for how measuring and verification will be done. Examples of the points which need to be included in the Plan are list of equipment to be monitored, baseline for comparison, contingency plan and corrective measures.

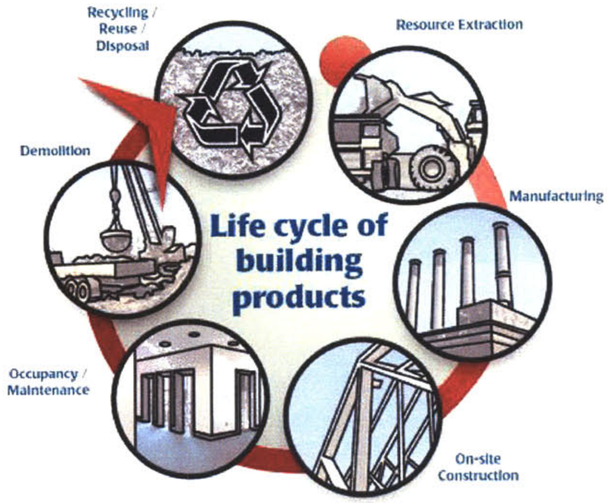
There are no operational benefits resulting from obtaining this credit, it has a verification role. Meeting this credit is not difficult; requires additional time at early stages and requires documentation.

4.3.3-f Green power 1:

LEED is encouraging the use of renewable sources for power supply; or giving an option to sponsor them whenever it is not possible to buy from them. Benefits are not restricted to individual buildings, but it also enhances researches and development of such ideas to create a zero pollution grid-sources. Examples of renewable energy systems can be found in 'on-site renewable energy' section. In addition to its correlation with 'renewable energy use' it also correlates with 'optimize energy use'. However here it is necessary that at least 35% of the electricity use for a minimum period of 2 years is from a renewable energy source. Calculation, constraints, and suggested systems to meet requirements of the 3 mentioned credits are similar. But what can be noted is that requirements for this credit are much more stringent that in the case of the first 2. Once again we see cost of the credit, in particular hard costs, are dependent on external factors such as geography.

The operational cost might be a little more expensive due to scarcity of renewable energy sources and higher cost to produce it. This is one of the drivers which make "Green Power' credit difficult to obtain. Difficulty rises from the context as a whole and not necessarily from conditions related to the project.

4.3.4 Material and Resources:



Pic 4.4 (Source: Material Life Cycle: http://www.tca.gov.bc.ca/heritage/images/LCA_AthenaInstitute.gif)

Aligned with the rising concern of occupants about the material used for construction, LEED gave a share of 19% for this particular category. What is important to mention is that LEED took into consideration the life cycle and other major characteristics of the material and didn't limit itself to toxicity only. We should worry about the selection of material because it might affect our health in different ways such as:

- Hazardous material used; for example Lead paint
- Sustainably harvested; in case it is not it will create an imbalance in the ecosystem
- Rapidly renewable or abundant
- Waste resultant from material disposal

We can notice that even if the material is not toxic to occupant and to installers; it still might affect the environment. LEED divided this category to 7 sub-categories where each of them concentrates on a type of impact. Following *Table 4.2.4* gives a breakdown of these requirements:

Materials & Resources (MR)		13 Possible Points
Prereq 1	Storage & Collection of Recyclables Required	Required
Credit 1.1	Building Reuse, Maintain 75% of Existing Walls, Floors & Roof	1
Credit 1.2	Building Reuse, Maintain 95% of Existing Walls, Floors & Roof	1
Credit 1.3	Building Reuse, Maintain 50% of Interior Non-Structural Elements	1
Credit 2.1	Construction Waste Management, Divert 50% from Disposal	1
Credit 2.2	Construction Waste Management, Divert 75% from Disposal	1
Credit 3.1	Materials Reuse, 5%	1
Credit 3.2	Materials Reuse, 10%	1
Credit 4.1	Recycled Content, 10% (post-consumer + 1/2 pre-consumer)	1
Credit 4.2	Recycled Content, 20% (post-consumer + 1/2 pre-consumer)	1
Credit 5.1	Regional Materials, 10% Extracted, Processed & Manufactured Regionally	1
Credit 5.2	Regional Materials, 20% Extracted, Processed & Manufactured Regionally	1
Credit 6	Rapidly Renewable Materials	1
Credit 7	Certified Wood	1

Table 4.2.4: 'Materials & Resources' Credits (Source: USGBC)

4.3.4-a Storage & collection of recyclables:

This is a prerequisite credit with the aim of improving use when possible of waste resulting from building occupants, and in return reduces volumes on waste going to landfills. The requirements are an easily accessible area that serves the entire building and is dedicated to the collection of storage of non-hazardous materials for recycling, including (at a minimum) paper, corrugated cardboard, glass, plastics and metals (LEED). The area required in most of the cases is less than 0.5% of the building area. LEED left it open to designers to decide on the collection method (Collect from individual Vs collect fro common areas), but in all cases soft and hard costs are negligible.

It is easy to meet this prerequisite, and even buildings not aiming to certify for LEED requirements are separating recyclables.

4.3.4-b Building Reuse, Maintain 75% of Existing Walls, Floors & Roof (1 Point); Building Reuse, Maintain 75% of Existing Walls, Floors & Roof (1 Point); Building Reuse, Maintain 50% of Interior Non-Structural Elements (1 Point):

These 3 credits are applicable to projects that are reusing, restoring or renovating existing buildings which is not applicable to our study. Our analysis is restricted to new buildings.

4.3.4-c Construction Waste Management, Divert 50% from Disposal (1 Point); Construction Waste Management, Divert 75% from Disposal (1 Point):

Intent of LEED is to encourage 50% (75% for an additional credit) waste diversion from disposal landfill, by finding alternate uses such as recycle or reuse. The percentage can be measured by volume or by weight. It is necessary to: (inthelled,2009)

- Develop a construction waste management plan to **at a minimum**, *identify* materials to be diverted: salvage, refurbish, recycle, reuse

  Include:

  - doors and windows,
  - salvaged flooring, paneling, cabinetry, beams,
  - recycled cardboard, metal, brick, acoustical tile, concrete, plastics, clean wood, glass, gypsum board, carpet and insulation.
  - MEP (mechanical, electrical, plumbing).

  But do not include:

  - soil, rocks, vegetation and
  - hazardous material.

Additionally to obtain this credit, it is necessary to:

- Designate a site in construction area for separation process
- Track recycling through construction process (*general contractor* to keep records i.e. receipts, of recyclable and waste diversion pickups)
- Diversion can include donation to charitable organizations as well.

The involvement of design and construction team is necessary to gain these possible points. The hard costs are incurred because of the additional administrative effort to manage and document additional labor and equipment to separate waste types, to find proper disposal, transport to different location, and fees imposed by appropriate disposal landfills. Due to the amount of special work required, often this job is subcontracted to specialized firms. For soft costs, the design team needs to develop a Construction Waste Management Plan in early phases and specify the targeted waste savings. These costs depends on several factor such as project scope, regional infrastructure development, local laws and regulations, fees imposed by landfills and similar others. Cost premium to obtain these points and due to all the points discussed earlier have a large variance.

Diverting disposal waste in general not difficult and it is also important to note that several cities are imposing rules on disposals as stringent as LEED requirements.

4.3.4-d Material Reuse 5% (1 Point); Material Reuse 10% (1 Point):

These credits have 2 direct effects: first the reduction of waste, and second reduction of the demand for virgin material. The reduction percentage is based on total costs of material. However, MEP, recycled, and Elevator materials shouldn't be included as part of costs, rather salvaged items such as doors, beams, refurbished items, and reused items should be counted. A rough estimate of the material costs on a project is 45% of the total construction costs. Out of this, to qualify for 2 credits you need to reuse at least 10% which mean 4.5% of the total construction. Typical examples of reuses items are furniture and wood flooring, and as we saw cost impact if any would be small if we want to meet minimum requirements. On the soft cost side this credit does not have any impact.

Material reuse classifies as a difficult requirement due to its scarcity of such material, cost structure of buildings in general, and particular handling requirements to salvage material.

4.3.4-e Recycled Content, 10% (post-consumer + 1/2 pre-consumer) (1 Point); Recycled Content, 20% (post-consumer + 1/2 pre-consumer) (1 Point):

LEED by encouraging use of recycled material is again aiming to reduce demand of virgin material. The substitution of new material by recycled material implies saves on the impact for extracting that material, and for processing it. Example of impact for extraction or processing would simply be the energy used to perform any of these steps. There are 2 major types of recycled materials: Post-consumer means material which was used by a consumer and then recycled for use in a new product, examples of that would be paper, plastic, etc...and Pre-consumer material means it did not reach user, it is in general result of manufacturing or processing stage. Both of these are approved by LEED; in fact in both cases usage of resources is optimized, or at least used at a higher efficiency level. Calculation basis and exclusions applicable to recycled content are the same as those for material reuse.

Depending on the types of projects, the difficulty for attaining this credit varies. Sometimes, by simply using products that incorporate recycled content as standard industry practice (e.g. Steel) might qualify, but other times use of specific high recycled product is required (e.g. ceramic tiles with recycled glass, wall covering with recycled papers and/ or polymers). Therefore, the cost impact varies from no premium to moderate premium. However, the cost impact occurs only in hard costs since most of the calculations and decisions on materials can be modified during construction phase without need to abrasive changes.

Meeting the first 10% is not difficult at all, and can in general be met by using standard structural material such as steel beams or concrete with fly ash, etc... But targeting the additional credit (or meeting the 20%) becomes much more difficult. What make it more difficult to reach high levels are the limited choices of sizes, colors, styles available, and the monopoly of these products.

4.3.4-f Regional Materials, 10% Extracted, Processed & Manufactured Regionally (1 Point); Regional Materials, 20% Extracted, Processed & Manufactured Regionally (1 Point):

In order to help local economic growth and minimize the construction materials transportation impact of, LEED is rewarding projects which attain this credit. The requirements include using material that has been either extracted, or harvested, or recovered or manufactured within 500 miles of the site. Once again percentages are based on cost, and exclusions are elevator and MEP materials.

Same discussions of costs, difficulty, dependency on several factors, large variance, as those for recycled content are applicable.

Project location is a major contributor to this credit, for example being in a city like Boston which is surrounded by water, limits the option available within that radius. Some the materials which are almost always found within 500 miles of the project:

- Cast in place Concrete
- Concrete Masonry unit
- Gypsum Board

Project specifications also present constraints for that, for example if a designer is asking for brick tiles from a particular manufacturer and not only asking for certain specifications; it will become much more difficult to qualify for this credit.

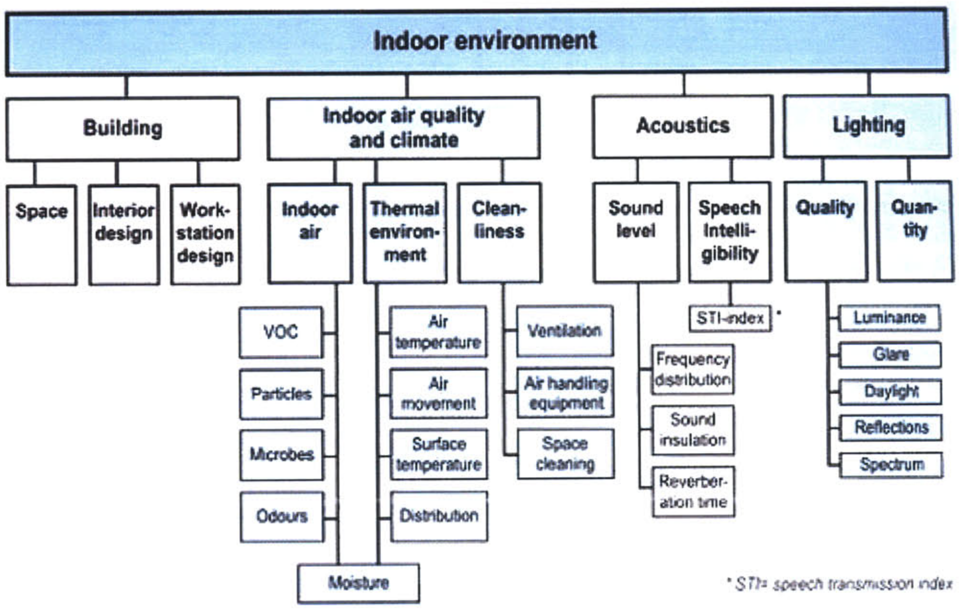
4.3.4-g Rapidly Renewable Material (1 Point); Certified Wood (1 Point):

LEED aims to enhance the use of rapidly renewable material in general, materials that are harvested from plants having a 10-year or smaller cycle of growth (Jonathan Ochscorn, 2008). It also adds a credit for wood in particular which encourages forest management programs. A minimum of 2.5% of the total material cost should be rapidly renewable material product; of the materials to be considered are bamboo flooring, wool, and cotton insulation. As for the wood, a minimum of 50% of wood-based materials and products, which are certified in accordance with the Forest Stewardship Council's (FSC) Principles and Criteria must be used. These components include but are not limited to, structural framing, flooring and sub-flooring. (LEED)

Regarding the soft costs, both of these credits need to be submitted during the construction which means that they have minor impact on the soft cost. In addition, in general supplier or sub-contractors have the required documentation for qualification which also reduces soft costs. Even though in case of a renewable material more can be obtained for less, it is still more expensive to purchase. For the wood, it needs a large premium to meet criteria especially that a minimum of 50% is required. FSC-certified products currently represent only a small share of all wood products available. It is important for project teams to investigate the availability and lead times associated with certain wood species, grades, and products, particularly for large orders. (Integrated,2009)

Some of the material which meets the criteria have a longer life cycle, therefore savings on operational and maintenance costs is arguable especially in case of a public places. As a conclusion, both of these credits can be classified as difficult.

4.3.5 Indoor Environmental Quality:



Pic 4.5 Components of Indoor Environments (Source: http://www.fahcsia.gov.au/nter/docs/container_issue/fig_3.gif)

This category focuses on building's indoor environment; LEED is making sure to provide safe and appropriate conditions for occupants. Most of us spend daily many ours in the same room whether it is workplace, school, and we barely question the quality of air at that space. Researchers have shown correlation between Indoor Environmental Air quality and some health problems, example of these are: Allergies, Hypersensitivity Pneumonitis, Athma. LEED also concentrated on it by making it the second category with a 22% of the total possible points; *Table 4.2.5* below shows all these requirements.

Indoor Environmental Quality (IEQ)		15 Possible Points
Prereq 1	Minimum IAQ Performance	Required
Prereq 2	Environmental Tobacco Smoke (ETS) Control	Required
Credit 1	Outdoor Air Delivery Monitoring	1
Credit 2	Increased Ventilation	1
Credit 3.1	Construction IAQ Management Plan, During Construction	1
Credit 3.2	Construction IAQ Management Plan, Before Occupancy	1
Credit 4.1	Low-Emitting Materials, Adhesives & Sealants	1
Credit 4.2	Low-Emitting Materials, Paints & Coatings	1
Credit 4.3	Low-Emitting Materials, Carpet Systems	1
Credit 4.4	Low-Emitting Materials, Composite Wood & Agrifiber Products	1
Credit 5	Indoor Chemical & Pollutant Source Control	1
Credit 6.1	Controllability of Systems, Lighting	1
Credit 6.2	Controllability of Systems, Thermal Comfort	1
Credit 7.1	Thermal Comfort, Design	1
Credit 7.2	Thermal Comfort, Verification	1
Credit 8.1	Daylight & Views, Daylight 75% of Spaces	1
Credit 8.2	Daylight & Views, Views for 90% of Spaces	1

Table 4.2.5: 'Indoor Environmental Quality' Credits (Source: USGBC)

4.3.5-a Minimum IAQ Performance (Prereq); Environmental Tobacco Smoke (ETS) Control (Prereq):

The intent of this subset is to contribute to the well being of occupants, ensure a minimum Indoor Air Quality (IAQ), and minimize exposure of occupants, systems, or indoor surface to Environmental Tobacco Smoke (ETS). This is accomplished by meeting the following regulations: (intheleed,2009)

- Meet minimum requirement of Sections 4 thru 7 of ASHRAE 62.1-2004: Ventilation for Acceptable Indoor Air Quality
- Mechanical Ventilation Systems: designed using Ventilation Rate procedure OR applicable local code (whichever is more stringent)
- Naturallly Ventilated buildings: comply with ASHRAE 62.1-2004

Additionally, smoking building need to do on of the following:

- Prohibit Smoking
- Or: Provide designated smoking areas
- Or for residential buildings: No smoking in common areas

Except the expensive exhaust system that needs to be provided in case developers want to have smoking rooms, no additional hard nor soft costs are associated with meeting the IAQ. Like all other prerequisite, these two conditions are easy to be achieved. These conditions are already established in majority of US cities.

4.3.5-b Outdoor Air Delivery Monitoring (1 Point):

To sustain occupants comfort and well being, LEED is rewarding projects that install ventilation systems performance measure devices. Project to receive the points should (intheleed,2009):

- Install Permanent monitoring systems that provide feedback on ventilation system performance.

An alarm should sound and notify occupants or maintenance team when conditions vary by 10% set point. Conditions vary with ventilation type (Natural, or Mechanical) and space density. Sensors installed measure the amount of outside air delivered to a space, and notify once the amount is inadequate for the number of occupants. Outdoor air delivery monitoring, result in a moderate premium. For hard costs, the purchasing and installation of these systems is not inexpensive, and will require maintenance costs; however its use is becoming more frequent in projects.

The requirements are clear and don't require any special work, and there is a certain cost associated with it. The benefits are arguable since the alarm itself doesn't do anything, the reaction after hearing the alarm is what matters. It is also important to mention that the baseline for LEED compliance is set low in this credit.

4.3.5-c Increased Ventilation (1 Point):

To provide a healthier environment for occupants, LEED gives one credit for providing effective delivery and mixing of fresh air whether by:

- **For Mechanically Vented Spaces:**
    - Increasing breathing zone outdoor air ventilation rates to **30%** above minimum *ASHRAE 62.1-2004* rates

- **Or for Naturally Venting Spaces:**
  - Designing system to meet *Carbon Trust Good Practice Guide 237 (1998),*
  - ensuring ventilation is effective by flow diagram in Figure 1.18 of *CIBSE Application Manual 10: 2005; and*
  - using diagrammatic calculations to show design meets CIBSE or..
    - use macroscopic, multi-zone, analytic mode to predict room-by-room airflows naturally ventilate **90%** of occupied spaces per *ASHRAE 62.1-2004*

Current research has shown that LEED requirement in this credit are low. Even USGBC, in a seminar suggested higher rates. Both hard and soft costs to meet this credit are negligible, but this credit needs to be submitted early during the design phase.

The 30% above ASHARAE requested by LEED is to compromise between energy efficiency and indoor air quality; however it is still expected to cost more than without it.

4.3.5-d Construction IAQ Management Plan, During Construction (1 Point); Construction IAQ Management Plan, Before Occupancy (1 Point):

Planning to protect workers and occupants by ensuring a proper Indoor Air Quality, LEED included this credit.

Project must: (Integrated,2009)

- During construction meet or exceed the recommended Design Approaches of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guideline for Occupied Buildings under Construction, 1995, Chapter 3.
- Protect stored on-site or installed absorptive materials from moisture damage.
- If air handlers must be used during construction, filtration media with a Minimum Efficiency Reporting Value of 8 must be used at each return air grill, as determined by ASHRAE 52.2-1999.

- Replace all filtration media immediately prior to occupancy. Filtration media shall have a Minimum Efficiency Reporting Value (MERV) of 13, as determined by ASHRAE 52.2-1999 for media installed at the end of construction.

Before occupancy phase, projects must also meet these regulations: (integrated,2009)

- After construction ends and prior to occupancy conduct a minimum two-week building flush-out with new Minimum Efficiency Reporting Value (MERV) 13 filtration media at 100% outside air. After the flush-out, replace the filtration media with new MERV 13 filtration media, except the filters solely processing outside air.

Or

- Conduct a baseline Indoor Air Quality testing procedure consistent with the United States Environmental Protection Agency current IAQ and materials, for the research triangle park campus, section 01445

As shown in requirements above both IAQ credits require additional testing, and/or materials. This leads to a low premium on the hard cost, but it doesn't have any impact on soft ones(filters, protection, etc…).

IAQ credits looks easy to be attained, but actually both of them need commitment from owner and construction team. A minimum management level should be maintained to meet requirements to qualify for these points.

4.3.5-e Low emitting Materials: Adhesive & Sealants (1 Point); Paints & Coatings (1 Point); Carpet Systems (1 Point); Composite Wood & Agrifiber Products (1 Point):

In order to reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well being of installers and occupants. This sub-category is based on existing codes as follow:

- <u>Adhesive & Sealants</u>: a) SCAQMD Rule# 1168

  b) GS 36

  Flooring and Sealants include: flooring adhesives, fire-stopping sealants, caulking, duct sealants, plumbing adhesives, cove base adhesives.

- <u>Paints</u>: GS 11

Anti-corrosive and Anti Rust Paints: GS 03

Coatings: SCAQMD Rule# 1113

Coatings include: Clear Wood Finishes, Floor Coatings, Stains, Sealers, Shellacs

- Carpet & Carpet Cushion: a) Carpet and Rug Institute's Green Label Plus Program.

  b) Adhesive Meet EQ4.1 (Shown above)

- Composite wood and Agrifiber: No Added Urea Formaldehyde Resins for internal use.

  Products: MDF, particleboard, plywood, wheatboard, strawboard, panel substrates, door cores

SCAQMD: South Coast Air Quality Management District

GS: Green Seal Standard for Commercial Adhesives

In order to gain the first 3 points no or negligible cost premium is required, and that because the majority of products, and/or materials available in market meet requirements. As for the last one, Composite wood and Agrifiber, it will imply a high cost premium on hard costs; but has no effect on soft costs. Commercially available products do not meet specifications, and thus developers will have to put special orders at higher cost and longer lead time.

It is easy to obtain the 4 points just discussed; even though one of them was expensive. Some regional or local ordinances, such as California State impose these rules.

4.3.5-f Indoor Chemicals and Pollutant Source Control (1 Point):

The intent here is to minimize building occupants' exposure to hazardous chemicals from exterior pollutants and interior processes that release it excluding construction material. To minimize entry and cross contamination between occupied areas, designers should: (Integrated,2009)

1) Employ permanent entry way systems (Grills, grates, etc.) to capture dirt, particulates, etc. from entering the building in high volume entryways.
2) Provide segregated areas with deck to deck partitions with separate outside exhaust at a rate$\geq 0.5 ft^3/min/ft^2$, no air recirculation and maintaining a Negative pressure$\geq$7PA in rooms where chemical use occurs such as housekeeping, copying/printing.

3) Provide drains plumbed for appropriate disposal of liquid waste in rooms where Water and Chemical concentrate mixing occurs.

As we can see above, additional ducts or pipes might be necessary in order to fulfill conditions. Depending on building type, partitioning, space, and others requirements, costs vary. For example, buildings with few rooms where chemical use or water and chemical mixing occurs both hard and soft costs tend to be very low.

This credit doesn't bring any operational cost benefits; in some cases it might be difficult to meet it requiring involvement of different parties or sub-contractors.

4.3.5-g Controllability of Systems: Lighting (1 Point); Thermal Comfort (1 Point):

The intent here is to provide high level controllable system, doing that occupants can regulate level which makes them comfortable and can save when possible.

For lighting: (inthelled,2009)

- Individual lighting controls for 90% minimum of building occupants
- Multi-occupant lighting system controls that meet group needs and preferences

For Thermal Comfort: (inthelled,2009)

- Individual comfort controls for **50% min.** of building occupants.

Or

- Operable windows are OK instead if:
  - occupants are stationed within 20'-0" inside and 10'-0" to either side of the window opening.
  - meets standards of ASHRAE 62.1-2004 for natural ventilation

And

- Also provide thermal comfort controls for multi-occupancy rooms, adjustable to suit needs of various groups to occupy the space.
  - thermal comfort conditions under **ASHRAE 55-2004**

The hard costs associated with successfully meeting the above requirements are relatively high. Light controls are cheaper than thermal controls, but both of them incur a premium. This premium results from higher material (control unit price, additional wiring, etc.) and labor costs. In addition to that, due to the high percentages of occupants request total number of control units will be higher than in a code based building because of the high percentages of occupants required. On the soft cost side, no additional cost is expected.

In return, providing adjustable controls should lead to operational cost savings. Comfort levels vary with individuals, with task, and with time; this variance in preferences is the driver of savings. As for the difficulty, to some extent it is easy to gain these credits, in general no complications are added; it is a simple but more expensive and time consuming task.

4.3.5-h Thermal Comfort: Design (1 Point); Verification (1 Point):

In the same logic of other points discussed earlier; LEED first verifies design, then ensures that system is performing according to its design.

For design: (inthelled,2009)

- Design HVAC systems and Building Envelope per ASHRAE 55-2004
- Coordinate with EQ P1. EQ 1, & EQ 2

For Verification: (inthelled,2009)

- Survey within 6-18 months after occupancy (anonymous responses of overall satisfaction of thermal performance
- If 20% or more of building occupants dissatisfied, develop a plan for corrective action

The financial impact of these points is a function of geography, especially for hard costs. For example more insulation layers or different material might be necessary in unlike other place with a more moderate wheather. These points are correlated with HVAC system, buildings envelop (external walls, curtain walls...), and roof. In the case of verification, the corrective measure clause in case added to sub-contractor contract will trigger them to have additional safety buffer. It is true that they always provide warranty on their equipment; however warranty covers defects and liability and not performance of the whole system.

Energy and IAQ are, in fact, linked; yet LEED Treats them independently. There is no penalty under the LEED guidelines for choosing to save energy at the expense of indoor environmental quality. At the extreme, even if none of the 12 EQ credits are complied with, there are still plenty of points left for platinum certification (Jonathan Ochscorn, 2008).

4.3.5-i Daylight & Views: Daylight 75% of Spaces (1 Point); Views 90% of the spaces (1 Point):
LEED intention is to introduce daylight and views into regularly occupied areas of the building. Requirements are:

Daylight: (intheleed,2009) and (Ochscorn, 2008)

The basic criterion is to supply daylight to 75% of the building's regularly-occupied interior spaces. This is defined in three different ways, any of which can be used to demonstrate compliance.

<u>OPTION 1 - GLAZING FACTOR CALCULATION</u>

- achieve min. 2% glazing factor in minimum of 75% of regularly occupied areas.

<u>OPTION 2 - DAYLIGHT SIMULATION MODEL</u>

- through computer simulation, demonstrate min. daylight illumination level of 25 footcandles in min. of 75% of regularly occupied areas.

<u>OPTION 3 - DAYLIGHT MEASUREMENT</u>

- through records of indoor light measurements, demonstrate daylight illumination level of 25 footcandles in min. of 75% of regularly occupied areas.

View: (intheleed,2009)

Achieve direct line of site to outdoor for occupants in 90% of all regularly occupied areas

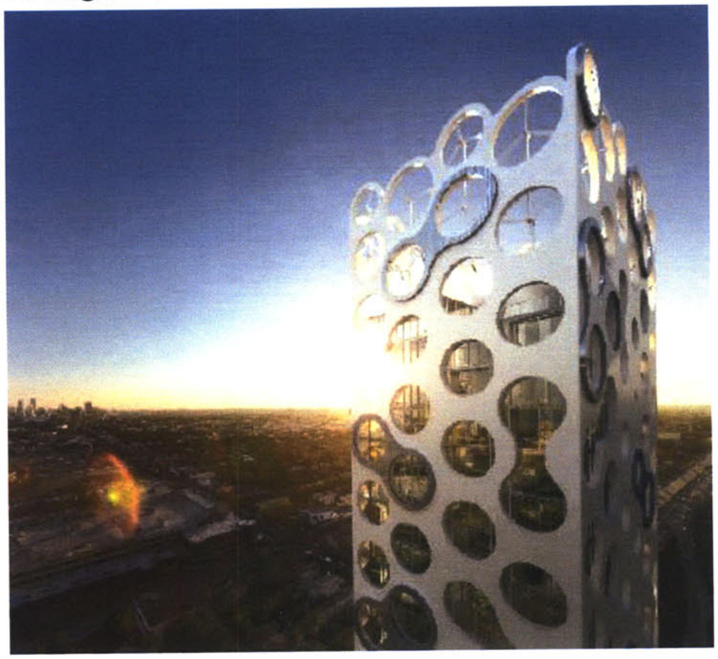
- glazing between 2'-6" & 7'-6"
- Plan View:
  - area within sight lines drawing from perimeter vision glazing

- Section View:
    - direct line of sight can be drawn from area to perimeter vision glazing

Daylight and views are function of building orientation, ceiling height, dimensions and layout of fenestration, floor layout plans, and other basic design characteristics. If a building is being designed to meet LEED requirement it will have a large cost impact since as mentioned the impact is from excavation to finish material. However what happens commonly is after design is complete, qualifications are checked and in case minor modifications are required it will be performed.

Additional daylight provided affect power cost, occupants might not need to turn on lights during daytime, and it also has an impact on heating and ventilation. Other external factor like weather also comes into consideration, these affect glazing type size. It is quite complicated to evaluate running expenses effect of these 2 criteria, and it is also difficult to take any design and then try to accomplish its points.

4.3.6 Innovation & Design Process:



Pic 4.6 Innovative green tower in the city of Miami.
December 11, 2006. Daily Commercial News
(Source: http://www.dailycommercialnews.com/images/archives/2006/12/11/150.jpg)

In order to reward strategies that address sustainability issues which are not included in LEED, and to reward systems which exceeds performance standards, LEED included these 4 credits. As for the accreditation point, it encourages involvement of individuals aware of LEED requirements from early stage, this should facilitate the process. A credit breakdown can be seen in *Table 4.2.6* below.

Innovation & Design Process (IDP)		5 Possible Points
Credit 1.1	Innovation in Design	1
Credit 1.2	Innovation in Design	1
Credit 1.3	Innovation in Design	1
Credit 1.4	Innovation in Design	1
Credit 2	LEED Accredited Professional	1

Table 4.2.6: 'Innovation & Design Process' Credits (Source: USGBC)

4.4 Documentation Costs:

Large part of soft costs associated with credits is documentation cost. Comparing LEED Version 1 and Version 2.2, we noticed that, due to industry critics, LEED version 2.2 also attempts to reduce paper work. Documentation cost varies with credit, project type, expertise of concerned parties, and several other external and internal factors, which make it time consuming to quantify impact per credit. However, the amount of money spent on documentation tends to be independent of project size, thus its percentage of total cost for large projects will be much smaller than for small ones. In general, developers, contractors, designers, and every party will have dedicated employees to follow up all paper work related to green buildings. Their efforts or time spent is not tracked per credit, so we can have an idea of the total documentation cost; but not of detailed one. Documentation costs include but are not restricted to the following:

- Data Gathering
- Measurement and calculations
- Submissions to USGBC: filling templates...
- Communication with reviewers and request for clarifications

Following are documentation costs results from different case studies:

- \$600 up to \$2000 based on (LEEDBlogger,2009)
- 226 Working hours to complete all proper LEED documentation. (NEMC,2003)
- Documentation per project \$8,000 to \$ 70,000. (NEMC,2003)
- For smaller projects, the costs can be a significant burden.0.7% small project, 3.8% large ones. (NEMC,2003)
- The costs reported for the three CH2M Hill Office Buildings are less than \$3,000 per building, or \$0.02/sf, while those for the Snowmass Clubhouse are \$25,000, or \$2.5/sf. There is no correlation on a cost per square basis. (EEI,2006)
- As low as \$10,000 for an experienced team; Most first-timers report costs of \$30,000 - \$60,000. (Brendle,2009).

All these studies are aligned with each other and with the discussion we had. Cost can be as low as $8,000 or as high as $90,000, and since they are not influenced by project square footage, percentage of impact varies. In general documentation cost is not a major barrier for not developing green buildings, and with time its impact should significantly decrease.

4.5 Conclusion:

In this chapter we presented LEED requirements and analyzed them. We evaluated cost of credits and highlighted other factors such as dependencies. It is important to emphasize on the fact that in our analysis we did not include or evaluate the environmental impact we only mentioned whether or not and how it affects it. The important conclusions:

- Cost per credit varies significantly; it can have no cost at all or be expensive.
- Impact of credits varies significantly; some credits are designed considering the eco-system others taking impact of building alone.
- Few credits conflicts with safety requirements of some cities, an example of that would be external lighting; while other credits are already part of city requirements, an example of that would be waste disposal.
- Requirements of some credits are not aligned with people mentality, this is particularly true for water reduce, re-use credits.

The main challenge facing LEED is adaptability; there is no point of having a perfect standard covering all attributes but not being followed by any project. We can see that LEED did a great job in that field putting together a realistic standard and the proof to that is its penetration in the market. Lot of researches and revision are currently under progress with the hope of spreading more the zero emissions building and thus harming less our environment.

After understanding the standard in this chapter, we will show results of studies and analyze further them in chapter 5. Then, based on chapters 4 & 5, we will draw conclusions on costs, difficulties, and applicability of LEED standard.

Chapter 5

Green Buildings Analysis

5.0 Introduction

In chapter 4, we analyzed every LEED credit, explained the necessary requirements and analyzed the impact of each. In this chapter we will look at results from two research works on real projects performed by Davis Langdon and the General Services Administration (GSA) respectively.

Figures 5.1 & *5.2* below provide a brief summary of the Davis and GSA research. Sections 5.2 & 5.3, dedicated to the Davis and GSA studies respectively, will give an overview of relevant results.

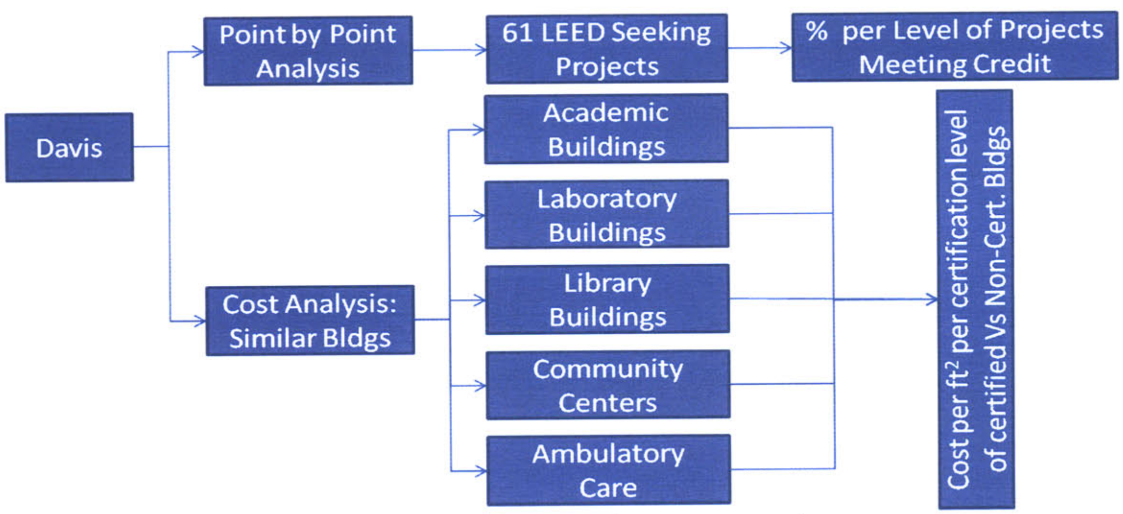


Figure 5.1: Summary of Davis Research

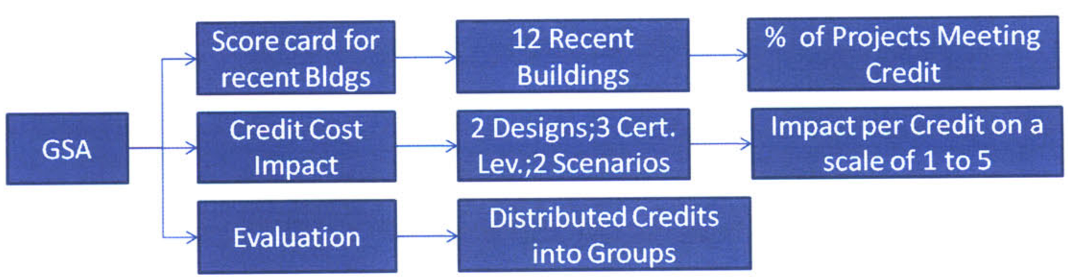


Figure 5.2: Summary of GSA Research

The figures above show that we are using more than one study from each organization. The findings of these studies are complementary and mutually supportive. Therefore, the following two sections will be structured:

1) An introduction to each research organization
2) A summary of each study including data, results, and our own analysis which will place this research in the context of our own questions (2 sub-sections for Davis and 3 for GSA)
3) and finally draw conclusions based on the analysis done for each organization

In this chapter, the results of the two organizations will not be compared.

5.1 Davis Langdon – Papers (July 2004 & July 2007)

5.1.1 Introduction:

Davis Langdon, a company originally established as a project cost management firm, has expanded their services to different sectors to include project management and sustainability consulting. With the high focus on green buildings that has emerged in the industry, the firm issued a paper in 2004 that addressed the question of whether building green necessarily costs more. Then, in 2007 the research group revisited the question and expanded their research. Because we are interested in the economics of investing on green buildings, we selected the following two analyses presented in both papers:

- Point by point analysis which shows the percentage of projects meeting every LEED credit for all certification levels.
- Cost analysis of similar buildings in which Davis Langdon compares cost per square foot for different certification levels and also for non-certified buildings for five different building types.

Figure 5.1 is a schematic summary of these studies.

5.1.2 Point by point analysis:

Using a database of 61 LEED seeking projects, the percentage of projects meeting every credit were calculated by certification level. The Langdon research results are included by category in

Tables 5.1.1 to *5.1.6* below; the tables include credit's number only, their description can be obtained from tables in chapter 4. LEED standard has 4 certification levels; however Langdon's research combined the highest 2, Gold and Platinum.

Our objective is to find out whether on the basis of the Langdon study we can cluster credits into the following three groups:

- Easy to meet
- Difficult to meet
- Non-classified

Then, we will draw conclusions based on the number of credits in each group. In order to reach our goal, in addition to analyzing the distribution of the results, we performed two rounds of selection:

- Round 1: we selected credits which are clearly easy or difficult
- Round 2: out of the remaining credits; we identified potential entrants to any of the 2 groups; then we analyzed and decided of whether or not to add them to that particular group.

For round 1, we defined a clearly easy credit as a credit met more than 80% by the lowest LEED certification level (Certified). As for difficult, we assumed that any credit met <5% by the highest certification level (Gold & Platinum). *Tables 5.1.1* to *5.1.6* include Langdon's results, values that are larger than 80% or smaller than 5% are marked by a special color formatting and fill. At the end of each category, in order to check whether any conclusion can be made on category level, we calculated average of projects meeting that category for each certification level. A column showing differences between maximum and minimum percentage met, is also included in tables; this will be used later for our Round 2.

Tables 5.1.1 to *5.1.6* exclude percentages for prerequisites, because obviously the last have to be met in all cases. Distribution of results by percentage of projects meeting criteria is summarized in *Figure 5.3*; for simplicity in above tables we only showed upper and lower bounds (>80% or <5%).

Legend:

	Prerequisite: In order to claify for any level project shall meet it
x %	Cell has the following format whenever % is > 80%
x %	Cell has the following format whenever % is < 5%
x %	Represent the average for a certain Category

Gld & Plt.: Gold & Platinum

Differences = Max(Met) – Min(Met) No Matter which level had each value

e.g. for SS Credit 3 = 100 - 69

Sustainable Sites		% Certified	% Silver	% Gold & Plati.	Difference
Prereq 1					
Credit 1	1	82%	95%	82%	13%
Credit 2	1	9%	32%	33%	24%
Credit 3	1	1%	0%	0%	1%
Credit 4.1	1	73%	69%	100%	31%
Credit 4.2	1	81%	81%	82%	1%
Credit 4.3	1	10%	11%	16%	6%
Credit 4.4	1	59%	34%	37%	25%
Credit 5.1	1	37%	43%	34%	9%
Credit 5.2	1	35%	69%	35%	34%
Credit 6.1	1	34%	62%	67%	33%
Credit 6.2	1	47%	62%	67%	20%
Credit 7.1	1	61%	81%	66%	20%
Credit 7.2	1	41%	62%	83%	42%
Credit 8	1	61%	95%	83%	34%
Average of Sustainable Sites		45%	57%	56%	12%

Table 5.1.1: SS - Summary of Langdon's results. Source: Davis Langdon

Water Efficiency		% Certified	% Silver	% Gold & Plati.	Difference
Credit 1.1	1	82%	94%	82%	12%
Credit 1.2	1	17%	31%	66%	49%
Credit 2	1	5%	25%	50%	45%
Credit 3.1	1	81%	95%	100%	19%
Credit 3.2	1	11%	19%	92%	81%
Average of Water Efficiency		39%	53%	78%	39%

Table 5.1.2: WE - Summary of Langdon's results. Source: Davis Langdon

Energy & Atmosphere		% Certified	% Silver	% Gold & Plati.	Difference
Prereq 1	Required				
Prereq 2	Required				
Prereq 3	Required				
Credit 1	1-10				
Credit 1.1 a		94%	95%	93%	2%
Credit 1.1 b		94%	95%	93%	2%
Credit 1.2 a		57%	78%	74%	21%
Credit 1.2 b		57%	78%	74%	21%
Credit 1.3 a		8%	43%	59%	51%
Credit 1.3 b		8%	43%	59%	51%
Credit 1.4 a		0%	2%	18%	18%
Credit 1.4 b		0%	2%	18%	18%
Credit 1.5 a		0%	0%	18%	18%
Credit 1.5 b		0%	0%	18%	18%
Credit 2	1-3				
Credit 2.1		11%	23%	50%	39%
Credit 2.2		9%	23%	33%	24%
Credit 2.3		0%	5%	15%	15%
Credit 3	1	42%	87%	82%	45%
Credit 4	1	59%	77%	82%	23%
Credit 5	1	23%	38%	66%	43%
Credit 6	1	9%	0%	18%	18%
Average of En. & Atm.		28%	41%	51%	23%

Table 5.1.3: EA - Summary of Langdon's results. Source: Davis Langdon

Materials & Resources		% Certified	% Silver	% Gold & Plati.	Difference
Prereq 1	Required				
Credit 1.1	1	5%	5%	0%	5%
Credit 1.2	1	2%	0%	0%	2%
Credit 1.3	1	0%	0%	0%	0%
Credit 2.1	1	100%	100%	100%	0%
Credit 2.2	1	72%	69%	100%	31%
Credit 3.1	1	2%	5%	36%	34%
Credit 3.2	1	0%	0%	0%	0%
Credit 4.1	1	95%	94%	100%	6%
Credit 4.2	1	18%	25%	36%	18%
Credit 5.1	1	98%	100%	100%	2%
Credit 5.2	1	2%	11%	66%	64%
Credit 6	1	9%	7%	50%	43%
Credit 7	1	30%	43%	50%	20%
Average of Mat. and Res.		33%	35%	49%	16%

Table 5.1.4: MR - Summary of Langdon's results. Source: Davis Langdon

Indoor Environmental Quality		% Certified	% Silver	% Gold & Plati.	Difference
Prereq 1	Required				
Prereq 2	Required				
Credit 1	1	54%	70%	82%	28%
Credit 2	1	18%	30%	68%	50%
Credit 3.1	1	96%	96%	100%	4%
Credit 3.2	1	89%	92%	100%	11%
Credit 4.1	1	100%	100%	100%	0%
Credit 4.2	1	95%	94%	100%	6%
Credit 4.3	1	93%	100%	100%	7%
Credit 4.4	1	41%	76%	100%	59%
Credit 5	1	62%	69%	68%	7%
Credit 6.1	1	25%	31%	66%	41%
Credit 6.2	1	5%	5%	50%	45%
Credit 7.1	1	79%	93%	100%	21%
Credit 7.2	1	25%	50%	82%	57%
Credit 8.1	1	32%	58%	65%	33%
Credit 8.2	1	32%	62%	66%	34%
Average of IEQ		56%	68%	83%	27%

Table 5.1.5: IEQ - Summary of Langdon's results. Source: Davis Langdon

Innovation & Design Process		% Certified	% Silver	% Gold & Plati.	Difference
Credit 1.1	1	66%	81%	82%	16%
Credit 1.2	1	30%	43%	66%	36%
Credit 1.3	1	8%	25%	50%	42%
Credit 1.4	1	0%	11%	17%	17%
Credit 2	1	98%	100%	100%	2%
Average of Inn. & Des.		40%	52%	63%	23%

Table 5.1.6: IDP - Summary of Langdon's results. Source: Davis Langdon

	% Certified	% Silver	% Gold & Plati.
# credits Met ≥ 80%	15	20	27
# credits Met]60%-80%[	7	13	14
# credits Met]40%-60%]	9	7	8
# credits Met]20%-40%]	10	11	7
# credits Met]5%-20%]	13	5	8
# credits Met ≤ 5%	15	13	5

Table 5.2: IDP - Summary # credits met by projects. Source: Davis Langdon

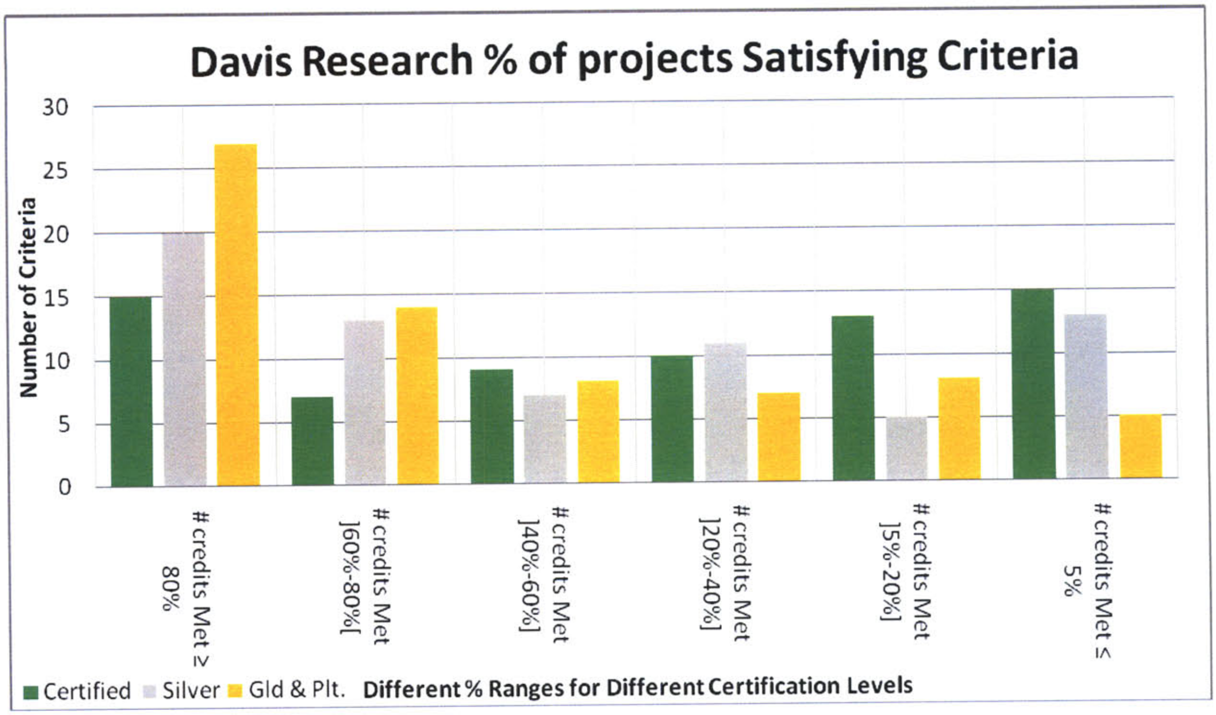


Figure 5.3: Ranges of %s for different certification levels. Note:]x,y] ,means x value excluded from range, y value included in range.

From *Figure 5.3*, we can tell that for the lowest certification level (certified), 15 credits were met in more than 49 of the 61 considered projects (≥80%). Going back to *Tables 5.1.1* to *5.1.6* we can find each of these 15 credits, and their exact percentage. For example, Sustainable Sites credit 1 was met about 82% of the times or in 50 out of the 61 projects. From *Table 4.1.1* of chapter 4 we can find its description, 'Site Selection', we can also find its intent, requirements, and discussion in section 4.3.1 of the same chapter. In sum, *Figure 5.3* shows a top level view of different ranges selected to reflect how frequently credit was met; additional information/details can be obtained from *Tables 5.1.1* to *5.1.6* and/or chapter 4.

After explaining the mechanics of the analysis, we can now compute the results of round 1. The outcome of Round 1 is that 15 credits can be classified as easy. They are:

- SS (2 out of 14): credit 1; credit 4.2
- WE: credit 1.1 (2 out of 5): credit 1.1; credit 3.1
- EA (2 out of 17): credit 1.1a; credit 1.1b

- MR (3 out of 13): credit 2.1; credit 4.1; credit 5.1
- IEQ (5 out of 15): credit 3.1; credit 3.2; credit 4.1; credit 4.2; credit 4.3
- IDP (1 out of 5): credit 2

As for the difficult ones, based on Round 1 criteria only 5 credits can be classified as the most difficult ones:

- SS (1 out of 14): credit 3
- MR (4 out of 13): credit 1.1; credit 1.2; credit 1.3; credit 3.2

In round 1, the purpose of the rules were set in order to be more conservative; if, instead, we look at the maximum inside the more than 80% category and less than 5% category, based on *Figure 5.3*, we would have obtained 27 instead of the 15 in easy category and 15 instead of 5 in difficult category. Evidence of meeting the objective of being conservative in round 1 are the facts that the average for certified level of these 15 credits selected as easy is 92%; and for the Platinum and Gold certification levels, 10 out of the 15 credits were met in 100% of the cases.

After this initial step, we are left with 49 credits (69 – 15 – 5) as shown. For the next step we will define the criteria for identifying potential entrant credits, and then set the decision rules for determining whether or not the selected credit should be added to the appropriate group. Starting with the 'Easy Group'; we defined a potential entrant as a credit which meets either of the following criteria:

- For any certification level more than 80% of the projects met credit
- Or, the 'Difference' shown in *Tables 5.1.1* to *5.1.6* is high

In the first screening process, we excluded credits which were met more than 80% by projects with a Silver or higher certification level. In this round we will first select them as potential and then evaluate whether or not to add them. As for the 'Difference' criterion; the logic behind it is that when its value is high it means that many projects seeking higher certification levels decided to pursue this particular credit. Thus the premium and/or difficulty of achieving this credit are probably smaller relative to the remaining ones. For sure, having a large difference might lead credit to become more than 80% in higher levels; thus we might have an overlap between results. The first condition qualifies 13 additional credits to be added to those considered as potential entrants; the second one qualifies 11; and 4 of these are common between both conditions. This information is obtained from *Tables 5.1.1* to *5.1.6* and/or *Figure 5.3.* In order to decide whether or not potential should be added to the 'Easy' category, we referred to previous chapter, to understand requirements and looked at tables above. Below, we will show the ones selected to be added with a brief explanation.

- SS: Credit 4.1 because in Gold and Platinum this credit is met in 100% of the cases and in Certified buildings it is also met in a high percentage of cases. In chapter 4 we saw that the cost impact of this credit is negligible, and since it is frequently met in studied projects we are assuming that its requirements are not that stringent.

  Credit 8 same as for 4.1 before, As noted above, a high percentage of cases in have met this requirement; up to 69% in Silver.

- WE: credit 3.2 Even though there is a cost associated with obtaining this point, it results in operational savings and is easy to implement. Therefore we see a high percentage of cases meeting this requirement. What is also noticeable about it is that its met percentage varies from 11% to 92% for certified and platinum respectively.

- EA: Credit 3 Because of the large number of cases which sought this credit in order to have higher certification levels, and because of its relatively low requirements (shown in chapter 4) we can consider it an easy credit.

- MR: Credit 2.2 The percentage of cases meeting this credit is high enough to justify including it.

- IEQ: Credit 4.4 This credit has been met in 100% of the cases of platinum or gold. In other words, all projects seeking higher levels chose it, and in our opinion this is a proof that relative to others it is easier.

- IEQ: Credit 7.1 This should have been included from initial selection since for certified level it is 79% and it goes up to 100% for gold and platinum.

- IDP: Credit 1.1 The percentage of cases meeting this credit is high enough to justify including it.

As a result of Round 2, the number of credits in 'Easy' category increased from 15 credits to 23. Remember, these were added because the certification level was met more than 80% of the time, OR the 'Difference' shown in *Tables 5.1.1* to *5.1.6* is high.

Now a similar process will be followed to determine what to add, if anything, to the 'Difficult' category. We defined a potential entrant as either:

- Any certification level less than 5% of the projects met credit
- Or, the 'Difference' shown in *Tables 5.1.1* to *5.1.6* is low

The First condition led us to take into account 8 more credits. The second condition did not add any additional credits. So, out of the eight selected, we decided to add 6 credits to the difficult set. These credits are:

- EA (5 out of 17): credit 1.4a & b; 1.5 a & b, credit 2.3
- MR (1 out of 13): credit 3.1

Six of these credits have very similar cases; they require higher levels for particular criteria like energy efficiency, and it seems this level requires major changes to be made. Additionally, for Certified and Silver levels they were met at most 5% of the time. It appears that those that achieved this credit also achieved a higher level of certification, in part, by doing so.

After this second round of analysis, then, the number of credits that can be labeled "Difficult" is 11 instead of 5.

After Round 1 & 2, we are left with some cases where the percentage of projects meeting a credit is less than 5% or higher than 80%; however, due to the values in the other 2 levels we were unable to classify them in any of the 2 sets. For example, the 'Indoor Environmental Quality' credit 1, has been met more than 80% of the projects (54, 70 and 82 for certified, silver, and Gold & Platinum respectively); but still because of the remaining ones we didn't consider it to be easy.

Left with 35 points, we will graphically show the filtering process. *Figure 5.4* below, shows the percentages of projects meeting credit for all 69 projects while *Figure 5.5* shows post classification (35 only). The major difference between *Figure 5.4* and *Figure 5.5* is that extremes, or credits scoring very high or very low, were removed to 'Easy' and 'Difficult' classes respectively. Thus, *Figure 5.5* shows only credits for which no conclusion can be made because they have intermediate values.

In this section, we are using percentage of projects meeting credit as an indicator to its difficulty, and cost. In other words, the assumption is that if most of the projects met a credit but didn't mean another, it implies that the first is easier and less expensive to obtain then the latter.

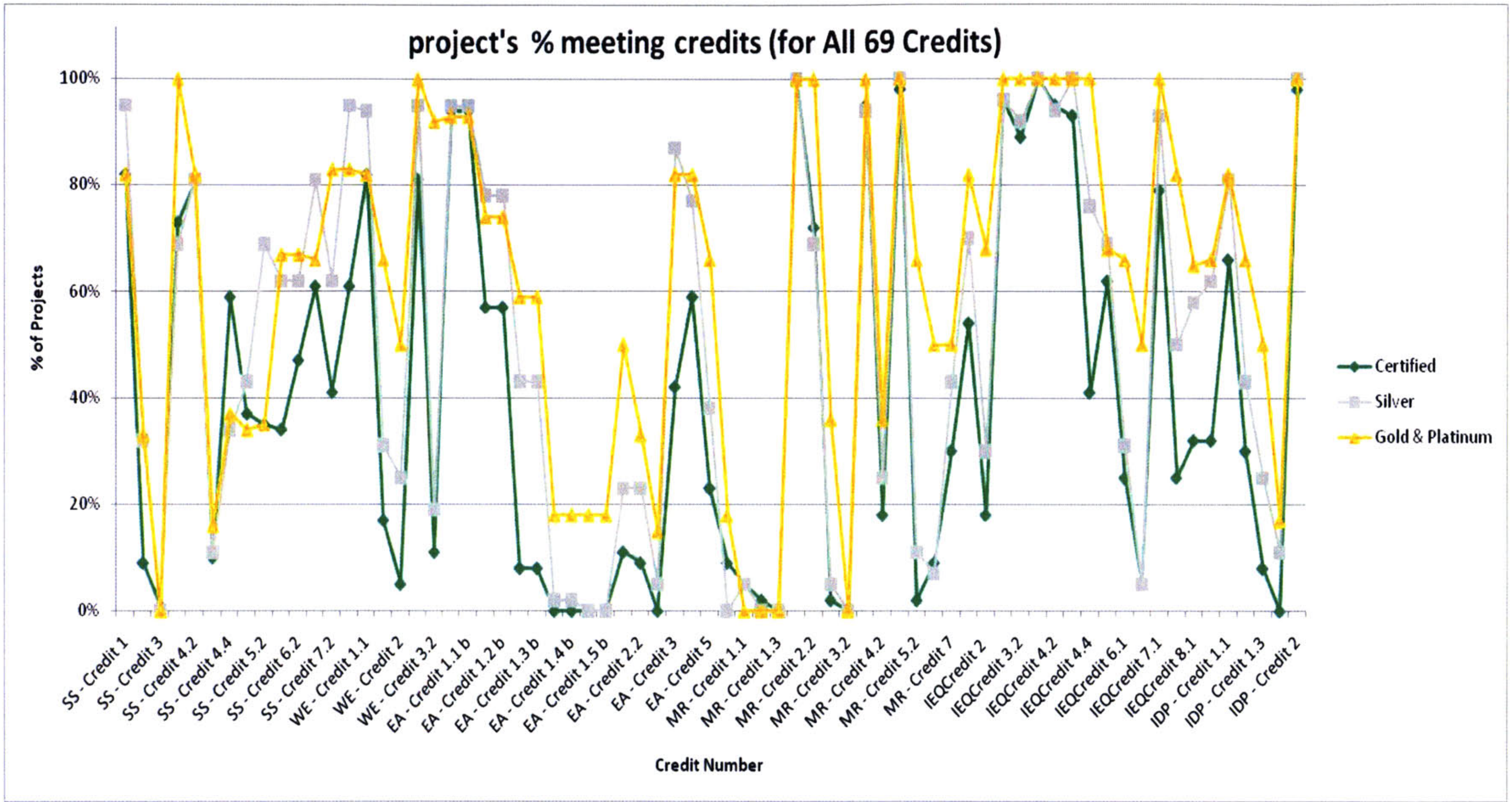


Figure 5.4: For all credits. % of projects meeting credit.

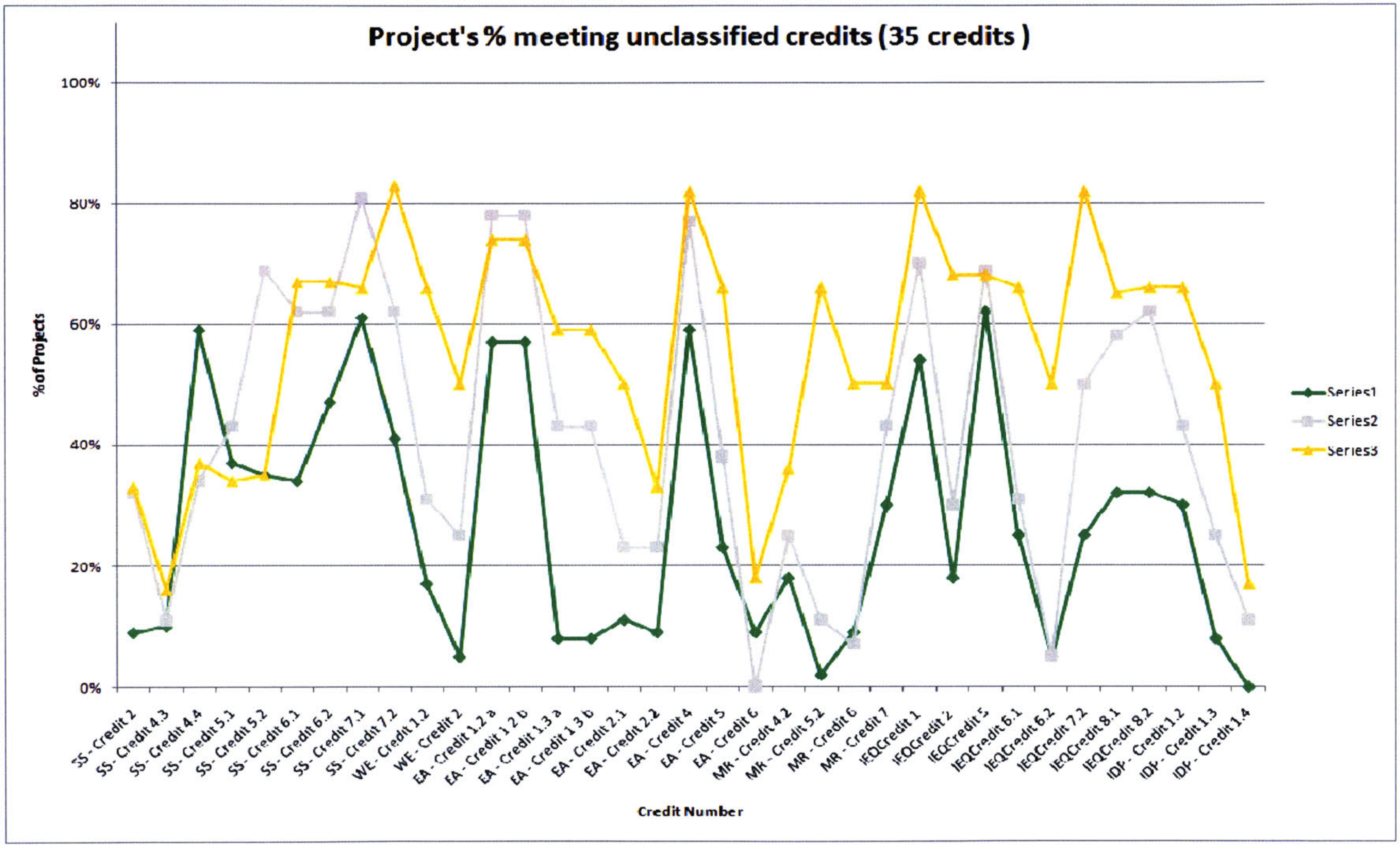
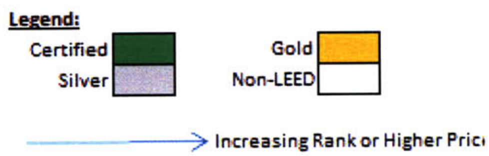


Figure 5.5: After excluding 'Easy' & 'Difficult'. % of projects meeting credit.

5.1.3 Cost Analysis of similar buildings:

In addition to the percentages study, Davis Langdon compared costs of different types of buildings seeking different level or even no LEED certification. Types, number of buildings and results are shown below as well as a subsequent graph summarizing the results:



Rank # 1 was attributed for the project with lowest cost and increased relatively

a) Academic Buildings:

- 60 Classroom buildings
- 17 Seeking LEED: 9 Certified; 6 Silver; 2 Gold
- 43 non-LEED

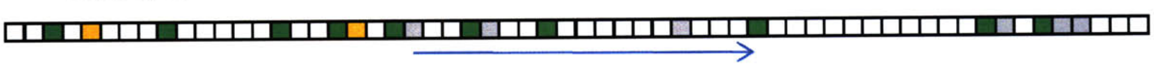
Ranges of cost per square foot varied from as low as $ 230/sf to as high as $ 590/sf.

Ranking was as follows:

Certified: 3, 9, 15, 18, 21, 25, 29, 40, 52, 55

Silver: 22, 26, 36, 53, 56, 57

Gold: 5, 19



b) Laboratory Buildings:

- 70 Laboratories
- 23 Seeking LEED: 17 Certified; 5 Silver; 1 Gold
- 47 non-LEED

Ranges of cost per square foot varied from as low as $ 210/sf to as high as $ 790/sf.

Ranking was as follows:

Certified: 3, 16, 19, 30, 34, 35, 37, 39, 40, 41, 49, 50, 51, 52, 57, 59, 64

Silver: 22, 24, 33, 53, 66

Gold: 21

c) Library Buildings:

- 57 Libraries
- 25 Seeking LEED: 25 Certified; 0 Silver; 0 Gold
- 32 non-LEED

Ranges of cost per square foot varied from as low as $ 230/sf to as high as $ 505/sf.

Ranking was as follows:

Certified: 2, 4, 7, 12, 13, 15, 16, 17, 18, 19, 23, 26, 29, 30, 31, 32, 34, 35, 38, 45, 51, 52, 54, 55, 57

Silver: None

Gold: None

d) Community Centers:

- 18 Community Centers
- 9 Seeking LEED: 6 Certified; 3 Silver; 0 Gold
- 9 non-LEED

Ranges of cost per square foot varied from as low as $ 220/sf to as high as $ 450/sf.

Ranking was as follows:

Certified: 4, 5, 8, 10, 15, 16

Silver: 9, 11, 12

Gold: None

e) Ambulatory Care:

- 17 Community Centers
- 9 Seeking LEED: 8 Certified; 1 Silver; 0 Gold
- 8 non-LEED

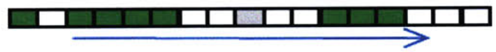
Ranges of cost per square foot varied from as low as $ 270/sf to as high as $ 580/sf.

Ranking was as follows:

Certified: 1, 3, 4, 5, 6, 12, 13, 14

Silver: 9,

Gold: None



Except for Library buildings, green building was never the highest cost. In the library case, the difference between the highest cost for a 'Certified' level building, and the second to last a 'Non-LEED' building was very small; even less than 1%. The green buildings cost, in general, was scattered between costs of non-LEED seeking buildings which implies there is no proof of additional cost associated with sustainable buildings. It is also important to note that the variance in each type was high; this is expected in the construction industry due to particularities of cases in factors such as technology used, specification levels, and quality of end product.

5.1.4 Conclusion:

In Langdon's research, the sample size available for the high level certification is small. In the first case, Gold and Platinum were mixed as 1 category, and in the second part there was no platinum building and only 3 gold cases. Thus, making strong conclusions about high certification level based on available data is not favorable. However, in the first part we were able to show that a large number of LEED credits are easily attainable, and only a small number difficult to do so. The second part builds on this conclusion, in that it shows that the cost of LEED seeking buildings are falling into the range of the cost of non-LEED buildings.

Some interesting conclusions can be drawn out of the previous analysis.

- From *Figure 5.4*, we can see that for Certified levels the majority of points fall in extremes; more than or equal to 80%, or less than 5%.
- Based on our classification approach in section 5.2.2; 23 credits are classified as easy. 26 is the minimum required to obtain a LEED certification, thus a 'Certified' level appears to be relatively easy to obtain.

- The highest certification level, Platinum, requires 52 points or can lose up to 17 of the total 69. Our classification in section 5.2.2 shows only 11 credits as difficult to obtain, suggesting that the Platinum certification is reasonably designed.

- Comparing the 6 categories in *Tables 5.1.1* to *5.1.6*; IEQ had on average for all 3 levels the highest percentage of projects meetings its credits.

- From *Tables 5.1.1* to *5.1.6*, comparing credits; we can note that large differences between percentages of projects meeting it exist.

- From *Figure 5.3*; for the 3 certification levels, if we add the number of credits in the more than 80% category to the number of credits less than 5% category result will be greater than or equal to 30 credits. Then, in most cases, designers/developers decide which and how many to seek out of the remaining 39 credits.

- From Section 5.2.3; we can conclude that it is possible to achieve, at low cost a high certification level, even Gold, by using simple approaches and avoiding adding green technologies.

- From section 5.2.3, we can observe that different types of buildings tended to focus on different categories.

- From section 5.2.3, we can say that there is no clear indication that Green Buildings have a cost impact.

- From sections 5.2.2 and 5.2.3, we can note that LEED Certification can be obtained without the need to change budgeted amount.

- From *Table 5.2*, we can notice patterns of meeting credits especially when looking at more than 60% of the projects: (Calculation details at end)
  For 'Certified' level, 76% of the Credits met are the same.
  For 'Silver' level, 93% of the Credits met are the same.
  For 'Gold & Platinum' level, 76% of the Credits are the same.

Pattern calculations are done by adding '# credits Met ≥ 80%' & '# credits Met]60%-80%[' shown in *Figure 5.2*; and then dividing result by the Average of the range of the Certification level. For example for Certified, number of credits in common in more than 60% of the projects is 22 = 15 + 7. The average for Certified level is 29 (0.5 * (26+32)) => 76% (22/29) of the credits are common on more than 60% of the projects.

5.2 General Services Administration (GSA)

5.2.1 Introduction

Part of the responsibilities of US GSA is to construct, manage, operate, maintain, and preserve governmental buildings. Being one of the largest building owners, GSA has its own standard; but the standard's objective is to ensure acceptable quality while minimizing costs. In February 2005, a study to determine the capital cost impact of LEED certifications on GSA buildings was prepared. Results of this study can feed directly into our research since our interest is in finding the marginal cost to achieve LEED certification. However, we need to make the assumption that the cost of a building following GSA standards is the same as cost of any non-LEED seeking one. Three sets of results in GSA-LEED cost study are relevant to our work:

- Credit cost Impact: shows impact on a 1 to 5 scale of each credit
- Scorecards for recent projects: shows credits pursued or being pursued on recent projects
- Evaluation Process: groups credits into different categories such as unlikely, low hanging fruits, etc.

Figure 5.2 is a schematic summary of these 3 studies.

Tables 5-3.1 to *5.3.6* below summarize results to be used in sections 5.3.2 & 5.3.3. In addition to providing necessary information on research and methodology these sections will further analyze the results. Then, in section 5.3.5, we will compare findings of the 3 studies and provide conclusions based on GSA study as a whole.

Legend used in tables:

Legend & Abbreviations:

N.P. :	Not Pursued
	Prerequisite: In order to claify for any level project shall meet it
x %	Cell has the following format whenever % is > 80%
x %	Cell has the following format whenever % is < 5%
x %	Represent the average for a certain Category
	Might cost up to 5

Sustainable Sites		Cost results	% Pursued
Prereq 1		2	
Credit 1	1	2	83%
Credit 2	1	2	70%
Credit 3	1	2	64%
Credit 4.1	1	2	91%
Credit 4.2	1	5	67%
Credit 4.3	1	3	11%
Credit 4.4	1	3	78%
Credit 5.1	1	2	80%
Credit 5.2	1	2	64%
Credit 6.1	1	2 or 5	60%
Credit 6.2	1	4	27%
Credit 7.1	1	2	67%
Credit 7.2	1	2 or 5	67%
Credit 8	1	2	63%
Average of SS			**64%**

Table 5.3.1: SS - Results of GSA Study (Source: GSA)

Water Efficiency		Cost results	% Pursued
Credit 1.1	1	2	91%
Credit 1.2	1	2	60%
Credit 2	1	NP	0%
Credit 3.1	1	1	44%
Credit 3.2	1	4	30%
Average of WE			45%

Table 5.3.2: WE - Results of GSA Study (Source: GSA)

Energy & Atmosphere		Cost results	% Pursued
Prereq 1	Required	1	
Prereq 2	Required	1	
Prereq 3	Required	1	
Credit 1	1-10		
Credit 1.1 a		2	90%
Credit 1.1 b		2	90%
Credit 1.2 a		2	71%
Credit 1.2 b		2 or 3	71%
Credit 1.3 a		4	30%
Credit 1.3 b		4 or 5	10%
Credit 1.4 a		5	9%
Credit 1.4 b		5	17%
Credit 1.5 a		5	8%
Credit 1.5 b		5	8%
Credit 2	1-3		
Credit 2.1		5	18%
Credit 2.2		5	8%
Credit 2.3		5	8%
Credit 3	1	3	67%
Credit 4	1	NP	86%
Credit 5	1	4	70%
Credit 6	1	NP	22%
Average of EA			40%

Table 5.3.3: EA - Results of GSA Study (Source: GSA)

Materials & Resources		Cost results	% Pursued
Prereq 1	Required	1	
Credit 1.1	1	2	42%
Credit 1.2	1	2	25%
Credit 1.3	1	NP	0%
Credit 2.1	1	2 or 3 or 4	75%
Credit 2.2	1	3	44%
Credit 3.1	1	NP	10%
Credit 3.2	1	NP	0%
Credit 4.1	1	2	88%
Credit 4.2	1	2 or 3 or 4	29%
Credit 5.1	1	2 or 4	80%
Credit 5.2	1	2	44%
Credit 6	1	NP	0%
Credit 7	1	4 or 5	44%
Average of MR			37%

Table 5.3.4: MR - Results of GSA Study (Source: GSA)

Indoor Environmental Quality		Cost results	% Pursued
Prereq 1	Required	1	
Prereq 2	Required	2 or 3	
Credit 1	1	4	80%
Credit 2	1	1 or 2	55%
Credit 3.1	1	3	100%
Credit 3.2	1	3	100%
Credit 4.1	1	2	91%
Credit 4.2	1	2	80%
Credit 4.3	1	1	91%
Credit 4.4	1	4 or 5	71%
Credit 5	1	2 or 3	67%
Credit 6.1	1	4 or 5	0%
Credit 6.2	1	1	0%
Credit 7.1	1	1 or 5	100%
Credit 7.2	1	1 or 2	73%
Credit 8.1	1	NP	63%
Credit 8.2	1	5	40%
Average of IEQ			67%

Table 5.3.5: IEQ - Results of GSA Study (Source: GSA)

Innovation & Design Process		Cost results	% Pursued
Credit 1.1	1	1	75%
Credit 1.2	1	2	50%
Credit 1.3	1	3	33%
Credit 1.4	1	5	29%
Credit 2	1	2	100%
Average of IDP			57%

Table 5.3.6: IDP - Results of GSA Study (Source: GSA)

5.2.2 Credit Cost Impact

In response to government incentive 'Efficient Energy Management', and in order for project managers to correctly budget for their jobs, a credit cost impact was prepared. GSA selected 2 types of buildings: New Mid-rise federal Courthouse; and Office Building Modernization. The selection was based on planned capital projects over the next 5 to 10 years. Design was developed for research purposes only, and not for implementation; however, these designs significantly reflect current and future projects designs. Six scenarios for each of the 2 types were developed; *Figure 5.6* summarizes these scenarios:

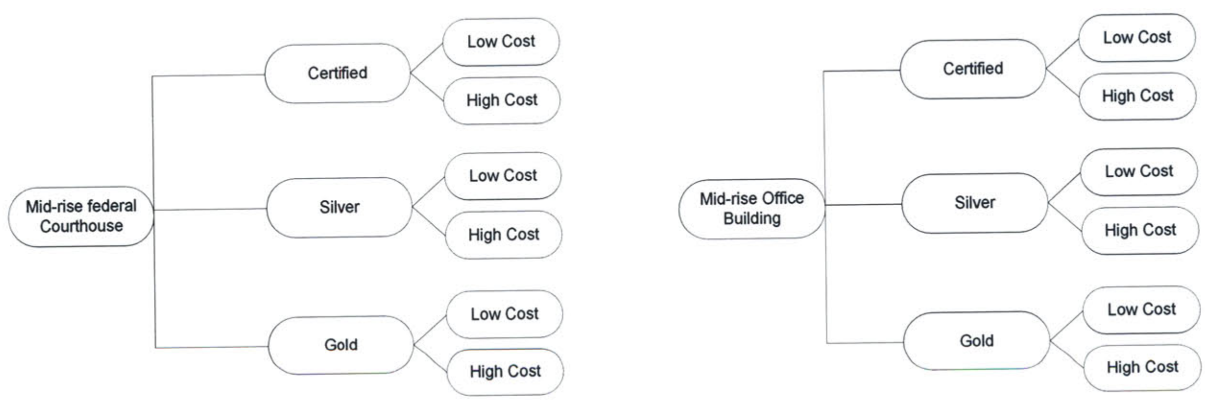


Figure 5.6: Summary of GSA Study

On a scale of 1 to 5 each credit was classified, each category stands for:

- 1: GSA mandate (no cost)
- 2: No cost Potential Cost Decrease
- 3: Low Cost (< $50K)

- 4: Moderate Cost ($50K-$150K)
- 5: High Cost (>$150K)

Since our main concern in this paper is to analyze all economics of green buildings as a whole; we summarized results of *Tables 5.3.1 to 5.3.6* in *Table 5.4* below. Then, in the lower part of *Table 5.4*, based on description provided by GSA, we grouped low or no cost items in a category and in another one grouped the moderate and high cost items.

	Incl. Prereq	Prereq.	Optional
# of Credits With Cost Impact 1=	9	5	4
# of Credits With Cost Impact 2=	22	1	21
# of Credits With Cost Impact 3=	7		7
# of Credits With Cost Impact 4=	5		5
# of Credits With Cost Impact 5=	10		10
# of Credits With Cost Impact 1 or 2=	2		2
# of Credits With Cost Impact 1 or 5=	1		1
# of Credits With Cost Impact 2 or 3=	3	1	2
# of Credits With Cost Impact 2 or 4=	1		1
# of Credits With Cost Impact 2 or 5=	2		2
# of Credits With Cost Impact 4 or 5=	4		4
# of Credits With Cost Impact 2 or 3 or 4=	2		2
# of Credits With Cost Impact NP=	8		8
Low or No Premium (1, 2, 3, or Comb)=	43	7	36
Moderate or Highh (4, 5, or Comb)=	19	0	19

Table 5.4: Number of credits per category

What also should strike our attention, is the fact the 36 credits (excluding prerequisites: 43-7) have low or no premium. These 36 points classify the project in the upper half of Silver certification level. Going into more detail, from the upper part of table we can see that 7 out of the 36 are in category 3, and 2 others can be in either 2 or 3. We will run through an example to have a better feel of the implications of the results. We will first assume that all 36 credits are applicable to our example, but in reality this is not always true. Then, taking the worst case scenario, which means assuming that cost was $50K (upper bound for category 3) and the 2 credits with uncertain impact turn out to be I category 3, total cost impact will be $450K. Average gross area of studied building is 280,000 ft^2 assuming a construction cost of 350 $/ft2 (GSA,2009), the maximum cost that might be incurred to obtain 36 credits would be about

0.46% of the total project cost (0.46% = 450,000 / (280,000 * 350)). Similar scenarios can be assumed to find out the average for reaching Gold and Platinum.

5.2.3 Scorecard of Recent Projects

A summary of scorecards for 12 other projects under construction, or completed projects, was also provided in the study; and the results are included in *Tables 5.3.1* to *5.3.6*. Since some of the buildings were still under execution when the study was prepared, the qualification status of some credits were still unclear. Because of this uncertainty, we were unable to split results by certification level similar to what was done in Langdon's study. For example, the ATF project has a variance of 28 credits which means that project can obtain any of the 4 classification levels. The following list will provide project type, location, total number of met credits, and uncertain credits respectively: Courthouse, Youngstown, 27 & 5 uncertain

- SSA, Woodlawn, 26 & 6 uncertain (renovation)
- Child care (Woodlawn)28 & 6 uncertain
- EPA technology center, Kansas city, 18 & 28 uncertain
- MLK federal building, Atlanta, 24 & 22 uncertain
- federal building, Moorhead, 25 & 8 uncertain
- courthouse, Little Rock, 25 & 16 uncertain
- Federal Building, San Francisco, 45 & 8 uncertain
- ATF headquarters, Washington DC, 29 & 28 uncertain
- Patent and trademark office, Alexandria, 11& 18 uncertain
- Laboratory, Chelmsford, 26 & 5 uncertain
- Federal Campus, OKC, 26 & 0

In our analysis we excluded uncertain results from our calculations. For example, for a particular credit if the available data showed qualification status uncertainty for 2 projects, when calculating percentage of project which met credit, we only used the 10 certain results. We made another modification to GSA analysis; GSA considered only credits of relevance to their particular projects, as for us we included all met credits.

After calculating percentage of projects meeting credits, we classified the last in categories as shown in *Figure 5.7*.

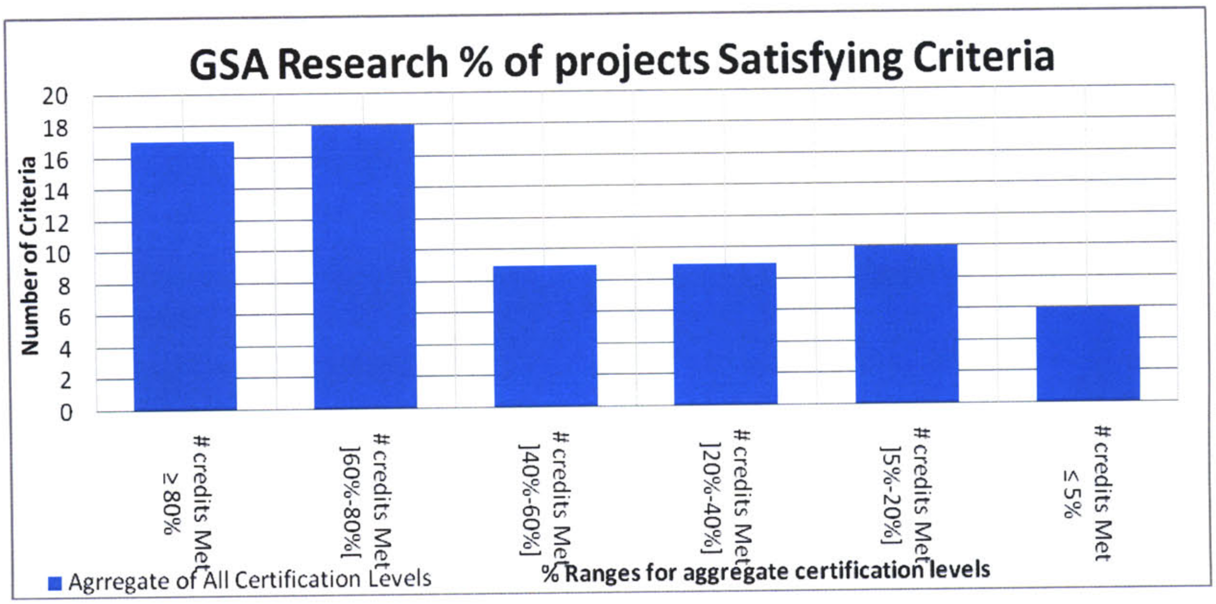


Figure 5.7: Ranges of %s for an aggregate of certification levels. Note:]x,y] ,means x value excluded from range, y value included in range.

Easy Credits or credits met more than or equal to 80% are:

- SS (3 out of 14): Credit 1; Credit 4.1; Credit 5.1
- WE (1 out of 5): Credit 1.1
- E&A (3 out of 17): Credit 1.1a; Credit 1.1b; Credit 4
- M&R (2 out of 13): Credit 4.1; 5.1
- IEQ (7 out of 15): Credit 1; Credit 3.1; Credit 3.2; Credit 4.1; Credit 4.2; Credit 4.3; Credit 7.1

- IDP (1 out of 5): Credit 2

As for the difficult credits, or the one met less than 5% are:

- WE (1 out of 5): Credit 2.0
- M&R (3 out of 13): Credit 1.3; Credit 3.2; Credit 6.0
- IEQ (2 out of 15): Credit 6.1; Credit 6.2

5.2.4 Evaluation Process

GSA also distributed credits into different categories; we have selected some of them which are similar to discussions we had earlier.

GSA considered 14 out of the 69 credits "Unlikely" or "Not Applicable". First let's identify these credits and then try to understand why a close to 20% of the LEED credits were considered as inapplicable for a typical design of one of the largest building developers. Credits are:

- SS (2 out of 14): Credit 4.3; Credit 4.4
- WE (1 out of 5): Credit 2
- E&A (4 out of 17): Credit 2.2; Credit 2.3; Credit 4; Credit 6
- M&R (6 out of 13): Credit 1.1; Credit 1.2; Credit 1.3; Credit 3.1; Credit 3.2; Credit 6
- IEQ (1 out of 15): Credit 6.1

Sustainable site requirements classified here do not add direct value to the building and are driven by other factors. They relate to parking capacity and providing ZEV's which in case of governmental building might just not be feasible. Credits in remaining categories have also similar constraints where implementing them on such building types is either not practical, or cannot be economically justified. The most critical section is Material and Resources, where almost half of the credits can't be met. As mentioned, 3 of them are applicable to existing buildings only, and the remaining 3 depend on material availability in market.

In sum, due to the way LEED standards are designed, developers are losing opportunities to target more cases, or sometimes losing interest in doing so.

Another relevant set was 'high design impact credits' which included 20 credits. This might be seen as a difficult as well as costly credit. It needs to be considered at the early stages and might change drawings, specifications, or multiple elements of the design at a time. In general, additional soft and in hard cost will be incurred to meet the requirements. These credits are:

- SS (3 out of 14): Credit 5.1; Credit 5.2; Credit 6.1
- WE (2 out of 5): Credit 1.1; Credit 1.2
- E&A (9 out of 17): Credit 1.2a; Credit 1.2b; Credit 1.3a; Credit 1.3b; Credit 1.4a; Credit 1.4b; Credit 1.5a; Credit 1.5b; Credit 2.1
- IEQ (5 out of 15): Credit 2; Credit 6.2; Credit 7.1; Credit 8.1; Credit 8.2
- IDP (1 out of 5): Credit 1.1

5.2.5 Conclusion

After presenting and separately analyzing each of the 3 studies, we will now simultaneously look at them and draw conclusions. The sample size of the GSA study is small; but still can be used to help in understanding and evaluating the impact of LEED standards.

- Most LEED prerequisites are GSA mandates. In fact, from *Table 5.4*, we see that 5 out of the 7 are mandated, and the remaining 2 have no cost impact.
- From *Tables 5.3.1* to *5.3.6*, we can notice a correlation (negative) between Cost and percentage pursued.
- Energy and Atmosphere credits tend to be the toughest credits. From section 5.3.4 we can notice that 9 out of the 20 'High Design Impact' credit are E&A. Similar conclusions can be made from sections 5.3.2 & 5.3.3.
- From section 5.3.4 and Chapter 4; we can say that credits classified as 'High design impact' but with no associated hard costs are still frequently met by projects. Thus, the relation between 'High Design Impact' and qualification status is not causality.
- Qualification patterns can be identified. From *Figure 5.7*, about 50% of the credits are met more than 60% of the times.

- About 20% of the credits are not applicable to the largest building owner/developer. Section 5.3.4.

- IEQ credits are the most commonly earned credits. In fact, the average of the category (*Tables 5.3.1* to *5.3.6*) is higher than the remaining 5. And in section 5.3.4, about 50% of the credits met more than 80% are IEQ credits.

- 6 Credits only were met less than 5% or classified as difficult based on percentage criteria. This leaves a margin of up to 11 other credits for projects to be certified as Platinum.

- From *Table 5.4*; 19 credits are classified as moderate to high cost; this implies that obtaining high certification levels will accrue costs.

- Based on *Table 5.4*, 36 credits have no or low cost impact. These credits give projects a 'Silver' certification level and make them only 3 points away from 'Gold'. However, not all credits are attainable. For example, MR Credit 1.1 is classified as one without cost impact but it is only applicable to existing building.

- From *Tables 5.3.1* to *5.3.1*; we can notice that a credit can have no cost at all or can cost more than $ 150K .

5.3 Conclusion

In this chapter we presented work on cost impact of green buildings done by Davis Langdon and by GSA. We looked at: the percentages of projects meeting credit; by the overall cost study; by the additional cost study; and by the different suggested categories. After seeing the results of both organizations, we can say that: difficulty, cost to meet, and applicability differences exist between the 69 equally weighed optional credits.

The data used in this chapter is on projects geographically scattered; in the next chapter we will look at few cases but fix this variable and evaluate the impact. Also, in chapter 6 we will try to reflect on particularities of projects.

Chapter 6

Case Studies

6.0 Introduction

In order to minimize variances caused by differing geographies, we will next examine three buildings all in the same geographical region. This chapter will present a LEED scorecard for 3 projects in their Boston, Massachusetts area, discuss their results, and summarize lessons learned. The three buildings we considered are:

- MIT Sloan School Building: E62, Cambridge, MA
- Macallen building, Boston, MA
- Artist For Humanity building (AFH), Boston, MA

Data concerning the MIT Sloan's building was obtained from the MIT 'Department of Facilities Engineering' (MITFac,2009); while Macallen and AFH data were obtained from case studies available on LEED's (USGBC,2009) website. All three buildings are new; two are completed while the MIT Sloan building is still under construction. Aside from the fact that these three buildings are located in/near the Boston metropolitan area, the differences between the buildings are significant; this should enrich our analysis by making visible the impact of specific variances. It's interesting to note that even the motivation of building green is not the same; MIT has a commitment to "become a leader in environmentally responsible operations, development of new and renewed facilities, and education (Environment at MIT)'" MIT requires a minimum silver LEED certification. On the other hand, the Macallen project was designed to market a "green lifestyle" in order to increase profit. The AFH decision to build green was motivated by youth in the neighborhood striving for self sufficiency and believing that a green building embodied this idea. Other differences between the projects are numerous: the built-up area; financing; building operations, maintenance; occupancy type (student, owner, individuals); client involvement in different phases of projects; and others.

6.1 Sloan Building - Project Description

Pic 6.1 Sloan Building MIT, E62-Planned completion Date 2010 (Source: MITNews)

Feeling the need to address world's energy problem, MIT is aggressively researching methods to optimize energy use. In this effort, the institution has begun to implement some of the research and create a campus that is more environmentally friendly.

The new Sloan building E62 is approximately 215,000 ft^2, and is designed to have classrooms, offices, study, dining, and lounge areas. The Sloan building is currently meeting 47 credits qualifying it as Gold, but it might still earn 6 additional ones and obtain Platinum level.

6.2 The Macallen Building - Project Description

Pic 6.2: Macallen Building, Boston (Source: Archrecord)

With an objective of producing benefits to all parties involved in the job, Pappas Properties, a for-profit organization developed the Macallen building. For developers, architects and engineers, higher margins were expected because of the additional luxury, better environment, and potential savings offered by the building. The initial investment by residents is expected to be offset by the operational savings created by the more efficient building design. The building is designed to save about 600,000 gallons of water per year, and to use 30% less electricity than a code-built one.

Consisting of 140 condominiums, a built-up area of 350,000ft^2, and located in an industrial area, the Macallen building project encountered a number of challenges, particularly air and noise pollution. Completed in 2007, the Macallen building earned a gold certification level with a total of 41 points. The building cost excluding land was about \$200 /ft^2. This cost tend to be on the high side for a building completed in 2007, however it condominiums were sold on average 10% above market price.

6.3 Artists For Humanity Building – Project Description

Pic 6.3 AFH Headquarters, Boston (Source: Buildinggreen)

The AFH building is located in the heart of Boston and serves as the headquarters for a nonprofit organization with a mission to bridge economic, racial, social divisions and provide keys to self-sufficiency to underserved youth through employment in the arts. Despite significant budget restrictions, the AFH founder wanted to attain high certification levels not only to make use of the savings, but also to educate and offer public awareness of sustainable building.

The building was completed in September 2004, and earned platinum level with 53 points. With a Built-up area of 23,500 ft^2, the construction cost of AFH headquarters were around \$183 /ft^2 excluding land, but including all systems installed to optimize energy use. The systems and strategies used for better performance the elimination of mechanical cooling, high level of daylight penetration, dimming and automatic shutoff lighting system, reduction of energy losses by improving envelope efficiency and air sealing, and photovoltaic (PV) system. Most of these systems have an impact on either the shape of the building, its orientation, materials used, or other major design factors. However, since these were considered and designed for in the early stages the cost impact was minimized. Expectations are that

- water savings will be as high as 30%
- PV system is expected to generate 156% of the electrical energy required which represents 32% of the total energy required. The additional power produced will be sold back to the grid and should pay for the remaining energy cost.

6.4 LEED Scorecards for all 3 projects

Following this brief description of every project, we will now present and compare their scorecards, analyzing and commenting on results whenever possible. As mentioned earlier, the MIT building is currently under execution, and that is why 6 credits are still uncertain. In comparison tables below (*Tables 6.1.1 to 6.1.6*), at the end of each category we calculated the average number of credits met. For the Sloan building we excluded all 'Maybe' credits when calculating averages. Next to the project results, we added three columns to show commonality between results.

Sustainable Site Category:

Beginning with sustainable sites, this category mainly deals with issues outside the building such as land, transportation, and surrounding community. Comparison for SS category is provided in *Table 6.1.1*.

SS		MIT Sloan Gold	Macallen Gold	AFH Platinum	Common(Yes/No) GD: Sloan & Mac.	Common(Yes/No) Gd Sloan & PT AFH	Common(Yes/No) All 3 of Them
Prereq 1							
Credit 1	1	Yes	Yes	Yes	1	1	1
Credit 2	1	Yes	Yes	Yes	1	1	1
Credit 3	1	Yes	No	Yes	0	1	0
Credit 4.1	1	Yes	Yes	Yes	1	1	1
Credit 4.2	1	Yes	Yes	Yes	1	1	1
Credit 4.3	1	Yes	Yes	No	1	0	0
Credit 4.4	1	Yes	Yes	Yes	1	1	1
Credit 5.1	1	No	No	No	1	1	1
Credit 5.2	1	Yes	No	No	0	0	0
Credit 6.1	1	No	Yes	No	0	1	0
Credit 6.2	1	Yes	No	Yes	0	1	0
Credit 7.1	1	Yes	Yes	Yes	1	1	1
Credit 7.2	1	Yes	Yes	Yes	1	1	1
Credit 8	1	Maybe	Yes	Yes	0	0	0
Average SS		85%	71%	71%			
		Total # of Common Credits=			9	11	8
		% of Common Cred. out of Poss. Cred			69%	85%	62%

Table 6.1.1: SS - Comparison Sloan, Macallen, & AFH

Looking at the averages of the section, we can see that the Macallen building which met about 59% of the total 69 credits (41/69) and AFH which met up to 76% of the total credits (53/69), have the same average percentage in SS. The MIT project met 85%; much more then both of them, and much more than its own overall average of 68%. The point we are trying to emphasize here is that no matter what level developers are targeting, classifying for some of the requirements are driven by external factors such as strategy. As an example, credit 4.3 related to zero emission vehicles (ZEV) was met by the 2 gold projects and not by the platinum one. It is clear that this credit will not affect building operation. Another observation is the fact that all of the projects did not obtain credit 5.1, let us doubt in applicability of this credit. Then we noticed that 5.2 was met by MIT only, Credit 5.2 is about open space, a possible explanation for the Macallen building is that the objective was to maximize profit and sell as much as possible without losing open spaces; as for AFH project it might be that due to the limited lot size and need for space, this credit was not feasible. In the case of MIT, it is a big campus with a lot of green areas and open spaces for students to enjoy outdoor life; this credit is to some extent embedded in their principles.

Water Efficiency Category:

As for water efficiency, which represents major concerns in today's world, a more logical pattern can be seen in *Table 6.1.2*, where higher certification levels qualified for more credits.

WE		MIT Gold	Macallen Gold	AFH Platinum	Common Sloan & Web.	Common(Yes/No) Gd Sloan & PT Web	Common(Yes/No) All 3 of Them
Credit 1.1	1	Yes	Yes	Yes	1	1	1
Credit 1.2	1	No	Yes	Yes	0	0	0
Credit 2	1	No	No	No	1	1	1
Credit 3.1	1	Yes	Yes	Yes	1	1	1
Credit 3.2	1	Yes	No	Yes	0	1	0
Average WE		60%	60%	80%			
		Total # of Common Credits=			3	4	3
		% of Common Cred. out of Poss. Cred			60%	80%	60%

Table 6.1.2: WE - Comparison Sloan, Macallen, & AFH

In this category there are two points which represent higher levels for two others. All three projects obtained the lower level points. Sloan obtained the higher the water use point, unlike Macallen which took the irrigation one. AFH on the other hand obtained the higher level for water use and irrigation. Each project followed a different strategy; Macallen used recycled graywater for irrigation and this is not practical to MIT due to many reasons such as area to be irrigated, or because E62 is a part of the campus and not a standalone building like the remaining two. None of the projects qualifies for the waste water credits, which is apparently more difficult or less beneficial.

Energy & Atmosphere Category:

Next is the energy and atmosphere category which has the highest share in LEED standards. In *Table 6.1.3* we can see the difference in results between different projects; in fact percentages ranged from 24% to 100%.

From the table we can see that the Macallen building scored very low in this category, and out of the 10 credits in credit 1. series it obtained only 1 point. After a June 2007, meeting at least 2 credits in the 1. series, became a mandatory requirement. On the other extreme, the AFR project met 100% of the credits; in our opinion the difference in motivation between these 2 developers and size of projects had a major influence on the percentage met. Increasing levels of energy performance relative to other credits require large up-front investments; however these investments will imply savings on operational cost. In contradiction with Sloan and AFR, the developer of the Macallen building is not the end user and therefore did not stand to benefit financially from future savings in this area.

E&A		MIT Gold	Macallen Gold	AFH Platinum	Common(Yes/No) GD: Sloan & Web.	Common(Yes/No) Gd Sloan & PT Web	Common(Yes/No) All 3 of Them
Prereq 1	Required						
Prereq 2	Required						
Prereq 3	Required						
Credit 1	1-10						
		Yes	Yes	Yes	1	1	1
		Yes	No	Yes	0	1	0
		Yes	No	Yes	0	1	0
		Yes	No	Yes	0	1	0
		Yes	No	Yes	0	1	0
		Yes	No	Yes	0	1	0
		Yes	No	Yes	0	1	0
		Maybe	No	Yes	0	0	0
		Maybe	No	Yes	0	0	0
		No	No	Yes	1	0	0
Credit 2	1-3				0	0	0
		No	No	Yes	1	0	0
		No	No	Yes	1	0	0
		No	No	Yes	1	0	0
Credit 3	1	Yes	Yes	Yes	1	1	1
Credit 4	1	Yes	Yes	Yes	1	1	1
Credit 5	1	Yes	No	Yes	0	1	0
Credit 6	1	Maybe	Yes	Yes	0	0	0
	Average of E&A	71%	24%	100%			
		Total # of Common Credits=			7	10	3
		% of Common Cred. out of Poss. Cred			50%	71%	21%

Table 6.1.3: EA - Comparison Sloan, Macallen, & AFH

We also see in *Table 6.1.3* that the three credits related to renewable energy (credit 2) were only met by AFH. In general this is rarely seen, however in this case the size of the project and the motivation to educate the public and create self-sufficiency created the conditions under which developers were willing to meet this credit.

Material & Resources Category:

The category in which the three projects scored the lowest is the material and resources category. *Table 6.1.4* below shows the results. For 5 out of the 13 points shown in table, it is clear why results are the same. All 3 projects are new and this prevented them from obtaining the building-reuse credit, and the other related to construction waste, these are required by the city.

M&R		MIT Gold	Macallen Gold	AFH Platinum	Common(Yes/No) GD: Sloan & Web.	Common(Yes/No) Gd Sloan & PT Web	Common(Yes/No) All 3 of Them
Prereq 1	Required						
Credit 1.1	1	No	No	No	1	1	1
Credit 1.2	1	No	No	No	1	1	1
Credit 1.3	1	No	No	No	1	1	1
Credit 2.1	1	Yes	Yes	Yes	1	1	1
Credit 2.2	1	Yes	Yes	Yes	1	1	1
Credit 3.1	1	No	No	No	1	1	1
Credit 3.2	1	No	No	No	1	1	1
Credit 4.1	1	Yes	Yes	Yes	1	1	1
Credit 4.2	1	Yes	Yes	Yes	1	1	1
Credit 5.1	1	Yes	Yes	No	1	0	0
Credit 5.2	1	Maybe	No	No	0	0	0
Credit 6	1	No	Yes	No	0	1	0
Credit 7	1	Maybe	Yes	Yes	0	0	0
Average M&R		45%	54%	38%			
		Total # of Common Credits=			10	10	9
		% of Common Cred. out of Poss. Cred			91%	91%	82%

Table 6.1.4: MR - Comparison Sloan, Macallen, & AFH

Indoor Environmental Quality Category:

What first struck our attention when looking at *Table 6.1.5*; is the fact that all credits were at least met by 1 of the three projects. All 3 projects scored high on this category;

IEQ		MIT Gold	Macallen Gold	AFH Platinum	Common(Yes/No) GD: Sloan & Web.	Common(Yes/No) Gd Sloan & PT Web	Common(Yes/No) All 3 of Them
Prereq 1	Required						
Prereq 2	Required						
Credit 1	1	Yes	Yes	No	1	0	0
Credit 2	1	Yes	Yes	No	1	0	0
Credit 3.1	1	Yes	Yes	Yes	1	1	1
Credit 3.2	1	Yes	Yes	Yes	1	1	1
Credit 4.1	1	Yes	Yes	Yes	1	1	1
Credit 4.2	1	Yes	Yes	Yes	1	1	1
Credit 4.3	1	Yes	Yes	Yes	1	1	1
Credit 4.4	1	Yes	Yes	Yes	1	1	1
Credit 5	1	Yes	No	Yes	0	1	0
Credit 6.1	1	Yes	Yes	Yes	1	1	1
Credit 6.2	1	Yes	Yes	Yes	1	1	1
Credit 7.1	1	Yes	Yes	Yes	1	1	1
Credit 7.2	1	Yes	Yes	No	1	0	0
Credit 8.1	1	No	No	Yes	1	0	0
Credit 8.2	1	No	Yes	Yes	0	0	0
Average IEQ		87%	87%	80%			
		Total # of Common Credits=			13	10	9
		% of Common Cred. out of Poss. Cred			87%	67%	60%

Table 6.1.5: IEQ - Comparison Sloan, Macallen, & AFH

Innovation & Design Process Category:

IDP		MIT Gold	Macallen Gold	AFH Platinum	Common(Yes/No) GD: Sloan & Web.	Common(Yes/No) Gd Sloan & PT Web	Common(Yes/No) All 3 of Them
Credit 1.1	1	Yes	Yes	Yes	1	1	1
Credit 1.2	1	Yes	Yes	Yes	1	1	1
Credit 1.3	1	Yes	No	Yes	0	1	0
Credit 1.4	1	Yes	Yes	Yes	1	1	1
Credit 2	1	Yes	Yes	Yes	1	1	1
Average IDP		100%	80%	100%			
Total # of Common Credits=					4	5	4
% of Common Cred. out of Poss. Cred					80%	100%	80%

Table 6.1.6: IDP - Comparison Sloan, Macallen, & AFH

As for the last part which rewards innovations and/or performance beyond those required by the standard, both MIT and AFR obtained all 5 credits, while the Macallen project obtained four credits. *Table 6.1.6* summarizes results. We will not discuss further this category because of the different possible ways to obtain credits, for example IDP 1.2 for AFH was granted for their Innovative elevator while Macallen earned the 1.2 credit for their 'Non chemical Water Treatment'.

Finally, in *Tables 6.1.1* through *6.1.6*, we have seen that higher commonality ratios excluding IDP were in MR between all 3 of them (91%), IEQ between Sloan and Macallen (87%), and SS between Sloan and AFH (85%). Ranges of commonality values varied between 21% and 91%; lowest commonality was in energy and atmosphere where cost of credits is higher than other categories. As for the highest commonality ratio, it was for the MR category, where the average score of all 3 projects is the lowest. In other words, the highest agreement between the three projects occurred on difficult credits.

We will now summarize averages of each category and overall average in *Figure 6.1* below.

The different strategy of the Macallen building and the over-performance of the AFR bulding in the Energy and Atmosphere category are obvious in the graph below. AFR again over-performed Sloan & Macallen in Water Efficiency. In the remaining three categories the results of all the projects were close to each other. The variances of the Macallen building are the largest; in our opinion they scored high in IEQ to compensate for EA, because IEQ credits are more attractive and visible to perspective buyers.

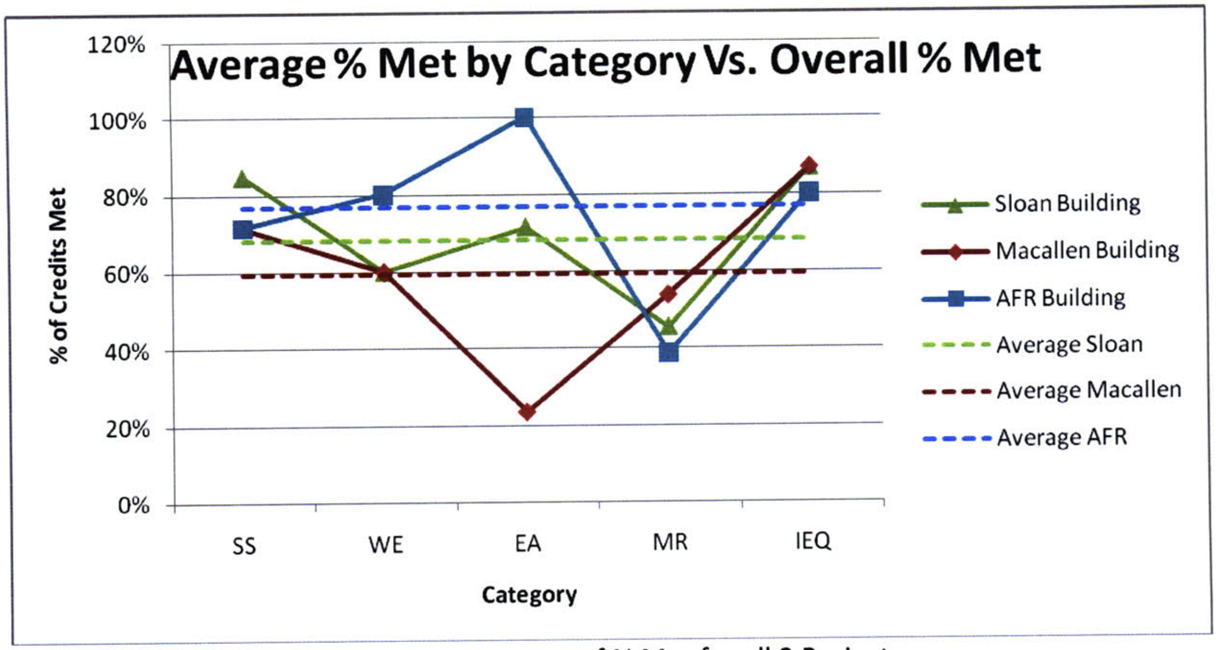


Figure 6.1: Summary of % Met for all 3 Projects

6.5 Lessons Learned & Conclusions

Projects with different scales and types of buildings were presented in this chapter; we highlighted commonalities and differences and provided explanations when possible. Major lessons learned from these case studies are:

- Sustainable building can be executed within budgets
- Evaluation of life cycle cost of systems might lead to installation of expensive systems
- Early decision of building green will result in large savings
- Involvement of all parties and their collaboration will facilitate the job in particular when it starts early in the design phase
- In case of use of sophisticated systems, maintenance teams need to be appropriately trained
- Set clear and appropriate green strategies early in design phase in order to maximize benefits to the environment as well as the investor.

Chapter 7

Heuristics / Conclusions

7.0 Introduction

This concluding chapter provides a holistic view of the thesis. We will discuss similarities and contradictions between presented analyses. Chapter 4 was a breakdown of LEED standard requirements, analysis and evaluation of credit's impact based on intensive readings of valuable resources and feedback from people in the industry. Then, in chapters 5 and 6, we looked at different studies and research, analyzed and evaluated impact of standard according to each of them separately. In these chapters, we referred to chapter 4 only few times and that was whenever study data wasn't enough to support the conclusion. *Figure 7.1* below represents the flow of information from chapter four to chapter seven.

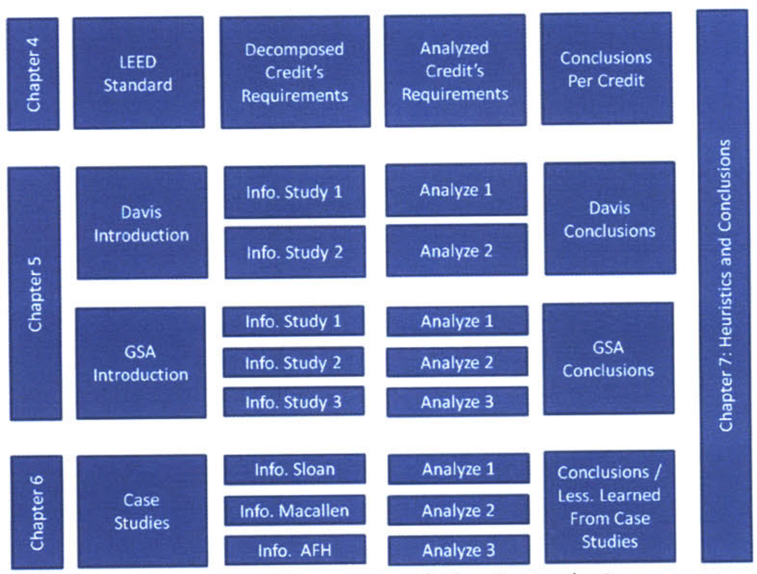


Figure 7.1: Summary of Thesis Analysis

As shown in this figure, while conclusions have been made in different parts based on the information it contains; the next section will present the major heuristics resulting from the complete work presented.

7.1 Heuristics on LEED

A major take away from this research project is that there are numerous factors affecting difficulty of achieving, cost, and benefits of LEED credits. In addition to that, the correlation between credits and the large number of combinations to qualify for LEED certification levels, make it unreasonable to generalize about the incremental cost for any certification level. However, some key findings were determined as a result of our work. They are summarized below as heuristics following their explanation and proof.

In all our analysis earlier we deduced that there is a large variance in incremental costs associated with seeking a LEED credit. This cost varies from very low or no additional cost to cost of changing major building's systems. Proofs as well as detailed discussions can be found:

- The credit by credit analysis, where requirements were elaborated and impact was discussed – Chapter 4
- Both studies performed by 'Davis Langdon' – Chapter 5, Section 5.2
- The three studies performed by GSA - Chapter 5, Section 5.3
- Three case studies in greater Boston area – Chapter 6

In fact, taking the credits met more than 80% in Langdon's study for silver certification level, comparing them to cost analyzed by 'GSA', we can see that in most of the cases results were consistent. Analysis done in chapter 4, suggested that there is no or low cost required to meet these conditions. Then, looking at the Sloan building and the other two case studies discussed; almost all selected credits were met by each of the three projects. Therefore we can say that these credits are met by most projects.

A contradiction between the GSA evaluation and the remaining studies is Credit 4.2 highlighted below. To understand these differences, we will first give LEED's credit description: "Alternative Transportation, Bicycle Storage & Changing Rooms" (USGBC,2009). Unlike other presented studies; GSA concentrates on governmental projects with high number of occupants. A possible explanation for GSA classification is; since the credit is a function of number of occupants, it becomes capital intensive to qualify for it. Thus, contradiction mainly results from the difference of types of buildings.

Table 7.1 shows the results of Davis and GSA studies for the eighteen selected credits, their qualification status for the three case studies, and summarizes their associate hard and soft costs based on the analysis performed in chapter 4.

Credit Reference	Davis Certified	GSA	MIT Sloan	LEED Gold	LEED Platinum	Analysis Hard cost	Analysis Soft cost
Sustainable Sites							
Credit 1	95%	2	Yes	Yes	Yes	No	No
Credit 4.2	81%	5	Yes	Yes	Yes	Varies	Low
Credit 7.1	81%	2	Yes	Yes	Yes	Varies	Low
Credit 8	95%	2	Maybe	Yes	Yes	No/Savings	Medium
Water Efficiency							
Credit 1.1	94%	2	Yes	Yes	Yes	Varies	Varies
Credit 3.1	95%	1	Yes	Yes	Yes	Low	No
Energy & Atmosphere							
Credit 1.1a	95%	1 or 2	Yes	Yes	Yes	Low	Low
Credit 1.1b	95%	1 or 2	Yes	No	Yes	Low	Low
Credit 3	87%	3	Yes	Yes	Yes	No	Low
Materials & Resources							
Credit 2.1	100%	2 or 3 or 4	Yes	Yes	Yes	Low	Low
Credit 4.1	94%	2	Yes	Yes	Yes	Low	Low
Credit 5.1	100%	2 or 4	Yes	Yes	No	Low	No
Indoor Environmental Quality							
Credit 3.1	96%	3	Yes	Yes	Yes	Low	No
Credit 3.2	92%	3	Yes	Yes	Yes	Low	No
Credit 4.1	100%	2	Yes	Yes	Yes	Very Low	Very Low
Credit 4.2	94%	2	Yes	Yes	Yes	Very Low	Very Low
Credit 4.3	100%	1	Yes	Yes	Yes	Very Low	Very Low
Credit 7.1	93%	1 or 5	Yes	Yes	Yes	Varies	No

Table 7.1: Low Cost Credits

Results in above table are consistent in most cases; and whenever contradictions arise, a possible logical explanation can be found. As a result, we are concluding that multiple credits can be grouped as low cost or easy to obtain.

For the other extreme; same studies also showed that a group of credits tend to be very expensive and difficult to meet. We will take from Langdon's study, the item met by less than 5% of the projects. *Table 7.2* below includes same information as *Table 7.1* but for then fourteen costly or difficult to obtain credits. Items highlighted in red were excluded from our analysis because we limited our study to new buildings and these credits are only applicable to existing structures. Before further analysis, it is worth clarifying some differences between Davis and GSA:

- Government tends to build on brownfields regardless of LEED requirements.
- GSA works on many renovation projects. Reusing is included in their designs whether they are seeking green building certification or not.

These two points might be a good explanation of the contradictions shown in *Table 7.2*. For example, SS credit 3 is the 'Brownfield Development' which is part of GSA standards. SS credit 3 is classified by GSA as no cost, although the cost incurred to meet it might be high, that fact is negated because the government frequently builds on contaminated sites (regardless of LEED requirements).The same explanation can be attributed to IEQ credit 6.2.

Material Reuse credits 3.1 and 3.2, also strike our attention. Based on requirements, obtaining them does not look costly. However, almost none of the projects analyzed qualified for them, thus it might be a problem with availability or some other ambiguous factors.

With the exception of the platinum building, a high scoring project meant to be a source of learning, the majority of case studies did not meet the credits. So meeting these credits does not justify that they are not costly or difficult.

Credit Reference	Davis Certified	GSA	MIT Sloan	LEED Gold	LEED Platinum	Analysis Hard cost	Analysis Soft cost
Sustainable Sites							
Credit 3	0%	2	Yes	No	Yes	Can be High	Can be High
Energy & Atmosphere							
Credit 1.4a	2%	5	Yes	No	Yes	High	High
Credit 1.4b	2%	5	Maybe	No	Yes	Very High	Very High
Credit 1.5a	0%	5	Maybe	No	Yes	Very High	Very High
Credit 1.5b	0%	5	No	No	Yes	Very High	Very High
Credit 2.3	5%	5	No	No	Yes	High	High
Credit 6	0%	NP	Maybe	Yes	Yes	High	High
Materials & Resources							
Credit 1.1	5%	2	No	No	No	-	-
Credit 1.2	0%	2	No	No	No	-	-
Credit 1.3	0%	NP	No	No	No	-	-
Credit 3.1	5%	NP	No	No	No	Medium	No
Credit 3.2	0%	NP	No	No	No	Medium	No
Credit 6	7%	NP	No	Yes	No	Low	Low
Indoor Environmental Quality							
Credit 6.2	5%	1	Yes	Yes	Yes	High	Low

Table 7.2 High Cost Credits

In sum, even though any credit grants one point only; the above two tables and discussions proved that its costs and/or difficulty might be very different, thus:

Heuristic #1: Cost impact/difficulty of LEED credits vary significantly.

Some of the LEED credits are designed to minimize emissions resulting from the building itself. Others are designed from a higher perspective by taking into consideration the indirect emissions such as these resulting from transportation to and from the building. It is clear that in case a building qualifies for alternative transportation credit, it doesn't mean that the building itself is more environmentally friendly. On the other hand, in order to obtain more energy efficiency credit better building performance is a must.

In addition to types of environmental impact (direct or indirect), large differences in duration of impact of credit exist. Impact of some is restricted to a specific period of time while others remain during the full life of the project. Case in point, impact of energy performance credit is over the life cycle of a project, but impact of construction waste management credit is over a much shorter period. Both type and duration affect the magnitude of a building's environmental impact. And even when both are the same, the magnitude of the environmental impact can still be very different because it is a function of several factors. For example, comparing energy and water credits; a 30% reduction of water use is rewarded by two credits similarly to 20% of energy savings. Their environmental impact varies with the generation source type; therefore it is rare that two credits earned in energy use will have the same impact as two in water use.

These possible differences in impact lead to a conclusion that it is not always true that a building which has obtained more points will perform better. In sum, to compare the environmental footprint of buildings with LEED certification, it is necessary to evaluate based on the type of credits obtained and not only based on the total number of credits. Therefore:

Heuristic #2: Environmental impact of LEED credits differs significantly

As soon as developers decide on a project's geographic location; they have committed themselves to certain conditions resulting from the project's context. These conditions have an impact on a project's behavior and include:

- Weather conditions
- Availability of resources near the project
- Costs of materials, labor, and energy cost
- Project's proximity to basic services
- Site characteristics such as type

The impact of geographic location on LEED credits can even be causality, where designers after site selection cannot do anything to meet a certain criterion. Brownfield, transportation, and other sustainable credits work as good examples of such cases. From a financial perspective, energy prices, cost of materials and equipment, heating and cooling requirements, and several other factors widely vary with geographic location and significantly modify the attractiveness of green investments. For example, the higher the utilities unit rate are the more incentivized individuals are to save use of energy. This can be expressed as:

Heuristic #3: Project's geographic location affects the benefits/difficulty of meeting certain credits

Few of the LEED credits are stated as a function of building occupants. An example of that would be the parking requirements. Occupancy level of a residential building is different than that of an office building similarly for any other type. Building type also affect the space requirements and specifications. Clearly these differences will change credit's cost impact. An example of dependency on type can be seen from the contradiction in the financial evaluation summarized in *Tables 7.1 & 7.2.* A logical explanation of why results were not similar is because of the difference between the building types constructed by both organizations. The generated heuristic would be:

Heuristic #4: Cost Impact of credits vary with building's type

Chapter 4 of this study looked at LEED standard as a set of credits or requirements. However; it is important to mention that there are relationships between many of these credits. A good example would be the daylight credit and energy efficiency. If a project is properly oriented with well designed openings than this energy required for lighting, heating and cooling is expected to be lower. Similarly, there is a correlation between heat islands whether roof or non-roof and energy requirements. Several other examples of correlations exist, and if designs are prepared from a holistic approach making use of such correlation, better building performance will result. By starting with the objective of building green early in a project's life cycle, designers can better understand and make more use of dependencies since none of the design variables have been fixed yet. Additionally, decisions would be more influential and without the need for rework. In fact, submissions of most credits can be done as early as in the design phase, thus if changes are required their costs would be restricted to soft costs and hence:

Heuristic #5: Earlier consideration of green building initiatives yield lower life-cycle costs

When restricting the analysis to emissions directly resulting from the building, not all LEED credits would look beneficial. However, this conclusion does not hold true when comparing the greenhouse gases emissions before and after construction. The differences between pre and post construction in this case are a result of the indirect emissions caused by buildings. A typical example would be transportation credits. Chapter 4 of this document provides more discussions on credit's effect. What should be remembered is:

Heuristic #6: Every credit whether directly or indirectly has a positive impact on the environment

Earlier in this section, we have concluded that not all credits are created equal. This covered different perspectives including cost of qualifying for a credit and environmental impact. Some credits are capital intensive with large savings on operational cost whole others the opposite. In the first case, the payback period can still be as short as five years. Based on that we notice that the financial relevance of a credit to a developer depends on whether or not they will be operating the building. For example, Macallen building with 'Gold' certification, the case discussed in chapter 6 which met in total about 60% of the credits, met only 24% of the credits in energy and atmosphere category (More details in *Figure 6.1*).

In sum, because of the differences in the cost/benefit structure of LEED credits and in the developer's utility function, the expected value of a credit differs significantly. This can be summarized by:

Heuristic #7: Developer's objective function affects credits sought

Better building performance is closely related to operational cost. As a result, when comparing two buildings, in general the one which obtained more LEED credits is expected to have lower operational costs. Our findings proved that this perception is incorrect. One of the reasons is that some credits don't have a direct impact. For example, most of the credits in the 'Sustainable Sites' category don't lead to any operational cost savings. Additionally, several of the heuristics in this section complement this conclusion leading to:

Heuristic #8: Operational cost savings do not increase linearly with number of obtained credits

Throughout our analysis we have seen that reducing a building's environmental footprint can be achieved at low or no cost. We also acknowledged that some LEED credits are costly. However, environmental impact can be reduced even without obtaining these credits.

LEED-NC v2.1 Project	LEED-NC Certification Level	Building Size [SF]	Year Completed	Construction Cost [$/SF]	LEED Cost Premium [$/SF]	NPV Energy Cost Savings [$/SF]	Net LEED Savings [$/SF]
Aspen Skiing Company Snowmass Golf Clubhouse	Silver	10,000	2005	$370	($20.00)	no data	
CH2M Hill North Building	Certified	112,600	2003	$156	($1 90)	$4 30	$2 40
CH2M Hill South Building	Certified	112,600	2002	$156	($1 90)	$4.30	$2.40
CH2M Hill West Building	Certified	164,500	2003	$156	($1.90)	$4.30	$2.40
City of Boulder N. Boulder Rec. Center	Silver	62,000	2002	$188	($8 70)	$10.40	$1.70
City of Fort Collins Vehicle Storage	Certified	15,250	2005	$129	($8 20)	$6.70	($1.50)
Colorado College Tutt Science Center	Certified	54,123	2004	$200	($9 20)	no data	
Colorado Dept of Labor & Employment Addition	Certified	40,000	2004	$100	($3.30)	$2.30	($1.00)
Pikes Peak Regional Development Center	Silver	111,758	2005	$112	($0 90)	$5 10	$4 20
Poudre School District Fossil Ridge HS	Silver	288,685	2004	$122	($1.00)	$4.00	$3.00
University of Denver Law Building	Gold	210,000	2003	$230	($0 70)	$3.50	$2.80

NPV calculation assumes 6% discount rate over 20 years

Table 7.3: Costs and benefits of commissioning LEED-NC buildings
Peter C. D'Antonio 5/2007

In addition to our analysis in chapters 4, 5, and 6, *Table 7.3* above summarizes results of a research by Rebuild Colorado, a program of the Governor's Office of Energy Management and Conservation. The findings were that capital investment ranged between 1% and 6%. And in the majority of the cases over a project life cycle of 20 years benefits were larger than invested amount. As a conclusion:

Heuristic #9: Green construction does not always imply high capital investment

In each of the studies presented in chapter 5 sections 5.2 and 5.3 we determined a set of credits easy to meet. We will first select from Langdon's study the credits which are met more than 80% of the cases. Then, out of the credits, the ones which in the GSA study were met more than 80% of the cases and/or have a cost impact of 1 or 2 were assumed to be easy and/or inexpensive to meet.

		Davis	GSA	
		% Met (Avg)	% Met	Expected Cost
Sustainable Sites				
Credit 1	1	86%	83%	2
Credit 4.1	1	81%	91%	2
Credit 8	1	80%	63%	2
Water Efficiency				
Credit 1.1	1	86%	91%	2
Credit 3.1	1	92%	44%	1
Energy & Atmosphere				
Credit 1.1a	1	94%	90%	2
Credit 1.1b	1	94%	90%	2
Materials & Resources				
Credit 4.1	1	96%	88%	2
Credit 5.1	1	99%	80%	2 or 4
Indoor Environmental Quality				
Credit 3.1	1	97%	100%	3
Credit 3.2	1	94%	100%	3
Credit 4.1	1	100%	91%	2
Credit 4.2	1	96%	80%	2
Credit 4.3	1	98%	91%	1
Credit 7.1	1	91%	100%	1 or 5
Innovation & Design Process				
Credit 1.1	1	76%	75%	1
Credit 2	1	99%	100%	1

Table: 7.4 Common Easy Credits Davis & GSA

Table 7.4 shows the 17 credits selected by both studies to be easy or frequently met by projects; implying that:

Heuristic #10: At least 25% of LEED credits are easy to obtain

In addition to easy credits, we also determined the difficult to obtain ones. A credit which was met less than 5% in Davis' study and in GSA and/or with cost of 5 was deemed to be difficult.

		Davis	GSA	
		% Met (Avg)	% Met	Expected Cost
Energy & Atmosphere				
Credit 1.4a	1	7%	9%	5
Credit 1.4b	1	7%	17%	5
Credit 1.5a	1	6%	8%	5
Credit 1.5b	1	6%	8%	5
Credit 2.3	1	6%	8%	5
Materials & Resources				
Credit 1.3	1	0%	0%	NP
Credit 3.2	1	0%	0%	NP

Table 7.5: Common Difficult Credits Davis & GSA

Based on our comparison criteria results were consistent for 7 credits shown in *Table 7.5*. In sum, since these credits have been rarely met we can say:

Heuristic #11: At least 10% of LEED credits are difficult to obtain

In Chapter 4 we have seen that some credits are only applicable to existing buildings. We have also noticed that applicability depends on whether the area is rural or urban. Then chapter 5 showed that about 20% of the credits were not applicable to GSA the largest building owner in the US. These facts lead to a conclusion that:

Heuristic #12: Not all credits are applicable for all projects

Gaming LEED standard; or in other words obtaining more credits without really reducing the building's environmental footprint is possible. A good proof of that would be the aggregation of other heuristics like 'Not all LEED Credits are created equal' or 'Operational cost savings do not change linearly with number of obtained credits'. The real benefits are in minimizing the environmental impact regardless of which certification level the building obtains. Thus, LEED standard should only be a guide or a mean to reach this goal. This generates the following heuristic:

Heuristic #13: Designers should concentrate on a building's performance not on classification levels

Cost premium of green buildings is dependent on exposure level and adaptability. Soft costs for example, are expected to reduce with time because of more familiarity with the standard requirements. Same for hard costs, where factors such as technology, competition in the market, economies of scale and scope, are expected to drive costs down when demand increases. Additionally, with more experience, better design and construction processes will be learned reducing the required premium of green buildings. Hence the heuristic:

Heuristic #14: Green buildings premium cost decrease over time

7.2 Conclusion

The objective of this paper is to provide a comprehensive understanding of green buildings as classified by LEED standard. Standard selection and overview of other standards are elaborated in chapter 3. This document focuses on identifying the potential benefits, and discussing the costs that might incur in order to build greener. During our study we were unable to analyze cost impact of LEED version 3 because no data was available since no project was completed yet following the latest version. However, most of the discussions and conclusions performed on Version 2.2 are still applicable on the new version since minor changes were made to the 69 credits of the previous version. But; some of the issues raised in this document were improved, proving their relevance. An example would be the scoring system which has more points in version 3 to increase emphasis on energy and efficiency credits, and reduce impact of external factors or the consequences of 'one size fits all'. Another major change in the newer version is the effort from USGBC to lessen the geographic location impact by providing credits particular to zones. *Table 7.6* compares the weighing system (number of credits in each category and the category share of the total score) of the older version to that of the latest one.

	LEED-NC v2.2		LEED-v3 (2009)	
	# of Credits	% of Total Cr.	# of Credits	% of Total Cr.
Sustainable Sites	14	20%	26	25%
Water Efficiency	5	7%	10	9%
Energy & Atmosphere	17	25%	35	33%
Materials & Resources	13	19%	14	13%
Indoor Environmental Quality	15	22%	15	14%
Innovation in Design	5	7%	6	6%

Table 7.6: Comparison of Scoring LEED-NC v2.2 & LEED-v3

Yet, Version 3 did not respond to all critiques, for example the two mostly criticized credits, which are the bike rack and the brownfield credits, remained intact in the new version.

As for the impact evaluation part, in our literature review, we discussed the difficulty of determining the exact incremental costs of green buildings, and the scarcity of data available at present accurately capturing their financial impact. We also mentioned tools currently under development which will facilitate measuring the impact and improving the quality of the data. In this research, to minimize errors from current status, we looked at multiple studies then made high level conclusions whenever results of different organizations converged. In this study we did not evaluate non-financial benefits such as health improvement. A potential area of research for later work would be to evaluate in details using better tools the financial impact of the new USGBC version, and to quantify non-financial benefits. Challenges of the new work would be to have the right tools for the financial impact and to find the proper utility function for all non-financial benefits.

Finally, climate change is a complex issue made up of multiple sub-issues such as impact from construction, impact from transportation. Climate change impacts are already evident. Regardless of the human responsibility share of these changes, it is important to take immediate actions. Building green is simply the strategy of optimizing use of resources in all project phases. LEED and other standards are not perfect but provide good guidance for sustainable building.

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