Cost and Benefit of Energy Efficient Buildings

by

Wenying Zhang

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Signature of Author: ______________________
Department of Mechanical Engineering
5/12/2006

Certified by: ______________________
Leon R. Glicksman
Professor of Mechanical Engineering
Thesis Supervisor

Accepted by: ______________________
John H. Lienhard V
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee

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WENYING ZHANG

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ABSTRACT

A common misconception among developers and policy-makers is that "sustainable buildings" may not be financially justified. However, this report strives to show that building green is cost-effective and does make financial sense today. Though green buildings typically have a higher upfront cost compared to conventional constructions, they do offer benefits that simply built-to-code projects lack. These benefits include cost savings from reduced energy and water use, less waste production, diminished environmental and emissions costs, lower operations and maintenance costs, and enhanced occupant productivity and health. These values range from being fairly predictable (energy and water savings can be recorded over time) to relatively uncertain (productivity/health benefits are somewhat arbitrary and subjective).

Based on a 20-year Net Present Value analysis with a 5% real interest rate, a recent study by the California Sustainable Energy Task Force showed the total financial benefits of green design to be $\$50/ft^2$ - $\$75/ft^2$, depending on the building's level of LEED Certification. This number is over ten times bigger than the average 2% cost premium calculated for the 33 green buildings they analyzed—about $\$3\text{-}5/ft^2$ in California. Energy savings alone, from reduced energy demand and decreased peak load, was calculated to be $5.79, which already exceeds the cost premium. Conservative calculations based on a study on Norway building retrofits show that the cost of energy savings ranges from 1-4 ¢/kWh. Comparing this number to the cost of various modes of electricity generation, ranging from 3-80 ¢/kWh, it is clear that the cost of generating electricity greatly exceeds the cost of saving energy through energy efficient buildings. Thus, green buildings are cost effective and should be more widely adopted.

Thesis Supervisor: Leon Glicksman
Title: Professor of Mechanical Engineering

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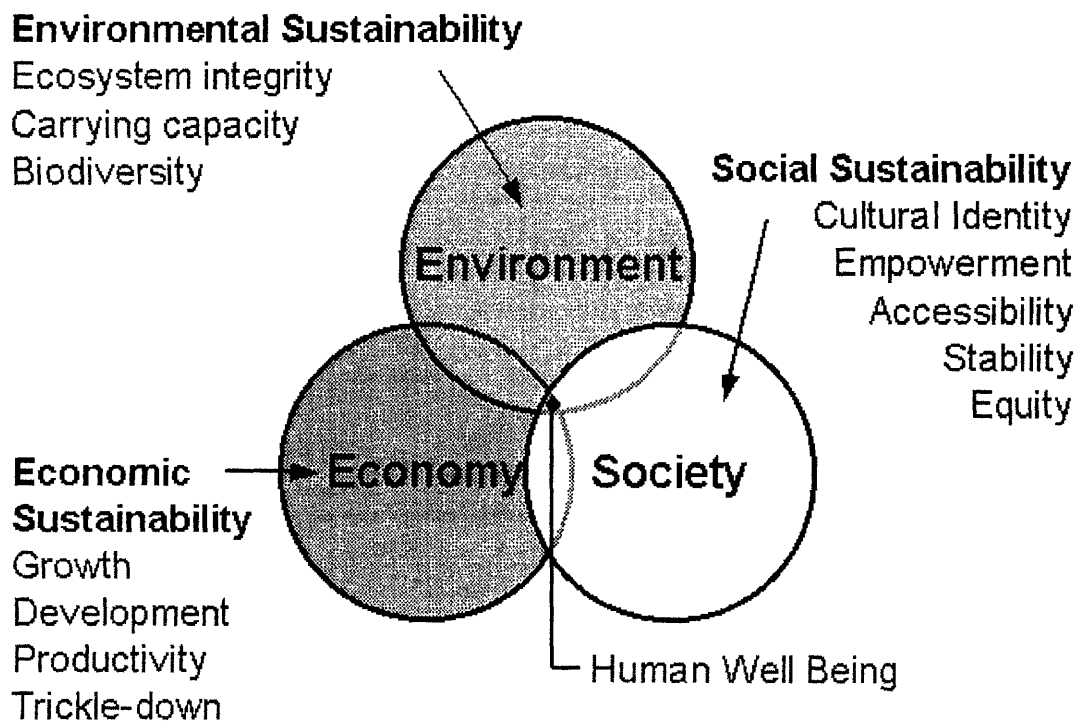
Introduction

"Sustainable development is development which meets the needs of the present without compromising the ability of future generation to meet their own needs."[1] There are three dimensions of sustainability: environmental, social and economic sustainability. Each has its own impact on Earth and its inhabitants. For example, environmental sustainability focuses on leaving the Earth in as good or better shape for the future generations. Human activities should not deplete natural resources or degrade the natural environment. This could be achieved by reducing waste and emissions, using renewable materials and eliminating toxic substances. Social dimensions of sustainability focus on improving worker's health and safety, and benefiting disadvantaged groups, such as the disabled. Economically, it is encouraged to create new markets, reduce cost through efficiency improvements and decrease energy and raw material inputs.

[1] World Commission on Environment and Development, Our Common Future, pp. 4, Oxford University Press, New York, 1987.

The graph below shows a breakdown of the three dimensions of sustainability and their contribution to the well-being of mankind:



Graph 1: The three dimensions of sustainability[2].

Architecture provides a lot of problems to sustainability since construction projects tend to use a lot of resources and produce a large amount of pollutants. Sustainable construction is defined as "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles."[3] Sustainable buildings aim to decrease their impact on the environment through energy and resource efficiency. It includes enhancing the natural environment and minimizing non-renewable resource consumption and the use of toxins.

[2] http://www.arch.hku.hk/research/BEER/sustain.htm
[3] http://www.arch.hku.hk/research/BEER/sustain.htm

The five principles of an environmental architecture are:[4]

- Healthful Interior Environment—all possible measures are taken to ensure that materials and building systems do not emit toxic substances into the interior atmosphere.
- Energy Efficiency—all possible measures are taken to ensure that the building uses minimal energy. Cooling, heating and lighting systems use methods and products that conserve energy use.
- Ecologically Benign Materials—all possible measures are taken to use building materials that minimize environmental damages.
- Environmental Form—all possible measures are taken to relate the form of the design to the site, the region and the climate. Accommodations are made for recycling and energy efficiency. Measures are taken to relate the form of building to a harmonious relationship between the inhabitants and nature.
- Good Design—all possible measures are taken to achieve an efficient, long lasting relationship of use areas, circulation, building form, mechanical systems and construction technology.

According to an OECD project, "Sustainable building" can be defined as those buildings that have minimum adverse impacts on the built and natural environment, in terms of the buildings themselves, their surroundings and the broader regional and global setting[5]. Sustainable buildings strive for integral quality (including economic, social and environmental performance). A high priority is placed on health, environmental and

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[4] Thomas A. Fisher, AIA, November, 1992.
[5] www.oecd.org/env/efficiency/susbuild.htm

resource conservation performance over the life-cycle of the building. These new priorities expand upon and complement the conventional building design concerns, which include economy, utility, durability, texture, scale, and light. Natural resources should be used rationally and the building stock should be managed appropriately; this will contribute to saving resources, reducing energy consumption, and improving environmental quality.

The Rocky Mountain Institute outlines several elements for sustainable design. One element is to plan and design thoroughly from the beginning since early decisions have the greatest impact on energy efficiency, daylighting, and natural cooling. They believe sustainable design is more of a philosophy of building than a prescriptive building style; these buildings also do not necessarily cost more, nor are they more complicated than traditional construction. Sustainable design begins with a clear understanding of the place. For example, knowing the environment well can help design solar orientations and help preserve the surrounding nature. Following the lead of nature, which has no waste products since the byproduct of one organism becomes the food for another, sustainable designs attempt to engage processes that regenerate rather than deplete nature. This can be achieved by understanding the environmental impact by evaluating the site, the energy and toxicity of the materials, and the energy efficiency of design, materials and construction techniques. Sustainable design must also take into consideration the wide range of cultures, races, religions and habits of the people who are going to be using and inhabiting the built environment. Integrated design, where each component is considered part of a greater whole, is critical to successful sustainable design.[6]

Most green buildings are high-quality buildings; they last longer, cost less to operate and maintain, and provide greater comfort for the occupants. There is no universally accepted way to compare these diverse green attributes, such as improved human health, reduced air and water pollution. Different projects balance various dimensions of "greenness" through a subjective weighting. For example, Green Globes, a US online assessment tool for benchmarking the greenness of building performance, attributes 34% of the weighting of building greenness to energy use, which is more than the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) Rating System's 29%[7].

Over the last few years, the green building movement has gained tremendous momentum. USGBC, a national non-profit organization, has grown tremendously. Its LEED rating system has been widely embraced both nationally and internationally as the green building design standard. Public and private sectors, such as Los Angeles, Seattle, the Department of the Navy, and the state of Massachusetts, have all adopted the green building policies and cleaner energy standards.

The USGBC's LEED system is useful for measuring the level of sustainability in a building using accepted standards and methodologies; cost and quantities are used as determinants. The LEED rating system is a "voluntary, consensus-based national

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[6] www.arch.hku.hk/research/BEER/sustain.htm
[7] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

standard for developing high-performance, sustainable buildings."[8] It comprises of 7 prerequisites and 69 elective points, grouped into 6 categories:

- Sustainable sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation and Design Process

A building earns points for meeting specific requirements in each category. For example, a point is awarded if there are provisions of bike racks and showers under the "sustainable sites" category; points can be earned if the building utilizes renewable and reuse material under the "material and resources" category.[9] There are different costs associated with meeting each of the four levels of LEED certification:

- LEED Certified 26-32 points
- LEED Silver 33-38 points
- LEED Gold 39-51 points
- LEED Platinum 52+ points

The highest levels of certification, Gold and Platinum, require a high level of commitment from both the project owner and the building designers; it forces them to push the boundaries of sustainability and create highly efficient, sustainable buildings to serve as an example for others.

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[8] LEED http://www.usgbc.org/leed/leed_main.asp

[9] Matthiessen, Lisa Fay and Peter Morris. "Costing Green: A Comprehensive Cost Database and Budgeting Methodology." Davis Langdon: Santa Monica, CA , July 2004.

At the end of 2000, about 8 million square feet of buildings were undergoing LEED certification. This number increased to over 100 million by the beginning of 2003. As of December 2002, of all new construction projects in the United States, an estimated 3% had applied for LEED certification; in addition, many buildings use LEED as a design tool without going through the certification process[10].

Massachusetts is a leading state in the rapidly growing green building movement. For example, the Genzyme building in Cambridge is a world-class green building; it utilizes advanced daylighting and thermal technologies. It also has a photovoltaic installation on top of the roof that has a combined heliostat and reflective panel system to direct sunlight into the 8 story building. Its openness, natural lighting combined with a green décor help to give the occupants have a general feeling of comfort while being inside this building. Below is a picture which shows the open interior:

Picture 1: Interior of the Genzyme building in Cambridge, MA.[11]

[10] US Green Building Council, Urban Land Institute and The Real Estate Roundtable. "Making the Business Case for High Performance Green Buildings." 2002.
[11] Gregory H. Kats. "Green Building Costs and Financial Benefits". Massachusetts Technology Collaborative, 2003.

The first question often asked about sustainable design is "how much more does 'green' cost?" The "cost" of green buildings is uncertain since there is a lack of accurate and thorough information concerning the financials. Buildings have traditionally been viewed as a relatively stable sector of the economy experiencing little change in technology or resource consumption patterns. There is a widespread perception that green buildings may not be justified from a cost perspective; this has been a large obstacle to the adoption of green design.

While it is true that sustainable buildings generally do have a bigger upfront cost than standard constructions, they provide various health, environmental, and financial benefits that conventional buildings do not. Sustainable buildings are cost effective by reducing operations and maintenance costs as well as the utility bill. They use key resources like energy, water, mineral, and land much more efficiently than buildings that are simply built to code. As a result of better natural lighting and cleaner air, green buildings also create healthier work and living environments. Great improvements can be observed on students and employees' health and productivity. When evaluated over the green buildings' entire lifetime, these benefits greatly exceeded any additional upfront costs.

The cost and benefit of green buildings should be analyzed from every aspect—manufacturing, operations & maintenance cost, user productivity, health and energy improvements. There are several factors that influence the cost of sustainable design. They include, but are not limited to: demographic location, bidding climate and culture, local building standards, climates, project intent, size of building and timing.[12] What surprises many people unfamiliar with this design movement is that green buildings often

[12] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003

cost little or no more to build than conventional designs. Commitment to better performance, close teamwork throughout the design process, openness to new approaches, and information on how these are best applied are more important than a large construction budget[13]. There are many projects that achieve the sustainable design within their initial budget or with very small supplemental funding. However, there is no one right answer regarding exactly how much a green building actually cost. Each building is unique; benchmarking with other comparable projects is useful and informative, but not predictive. The cost of sustainable design for a particular building should be calculated according to that building's specific requirements and circumstance.

There are several studies that attempted to address this issue of cost and benefit:

- In October 2002, the David and Lucille Packard Foundation released their Sustainability Matrix and Sustainability Report, which was developed for a new 90,000 square foot office facility. The study found that with each increasing level of sustainability, short-term costs increased, but long-term costs decreased significantly.[14]
- An older study conducted by Xenergy for the City of Portland identified a 15% lifecycle savings associated with retrofitting three standard buildings to be LEED certified.

However, the most comprehensive study to date was conducted by the California's Sustainable Building Task Force, in October of 2003. Led by Capital E, the Report was prepared in partnership with the US Green Building Council and California's Sustainable Building Task Force for 40+ California state agencies. Their study confirmed that a

[13] http://www.arch.hku.hk/research/BEER/sustain.htm
[14] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

minimal increase in upfront costs of about 2% would result in life cycle savings of 20% of total construction costs, which is more than ten times the initial investment[15].

Motivation

Shelter is one of the most important human needs. Though in some developing countries people still live in caves or huts, people in the developed world are used to living in comfortable homes and working in offices that provide sufficient heating, air-conditioning and lighting. In fact, buildings consume about 1/3 of the total energy and more than ½ of total electricity for countries in the Organization for Economic Cooperation and Development (OECD)[16]. For the United States in particular, buildings consume 70% of the nation's electricity and a large portion of materials, water and waste used and generated in the economy.[17] Thus, in a world with an increasing concern on energy preservation, it is important to analyze the building sector extensively and figure out ways to conserve energy usage and calculate the cost of these energy savings. However, there are no solid on how much a conventional building would have cost if it were built green to be energy efficient; likewise, most green buildings do not have data on what it would have cost if it were built as a conventional building. Due to this lack of concrete data, people often have reservations regarding the initial investment to retrofit a building or to start building green from the beginning; it is a common misconception that buying more energy to meet the increasing demand is more cost effective than putting in

[15] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[16] Tester, Drake, Driscoll, Golay, and Peters. "Sustainable Energy: Choosing Among Options." Cambridge, MA: The MIT Press, 2005. Page 778.
[17] Gregory H. Kats. "Green Building Costs and Financial Benefits". Massachusetts Technology Collaborative, 2003.

an initial investment to build more efficient building and thus decreasing the amount of energy needed. However, this paper aims to show the contrary—it is cost-effective to build green; the initial green premium will be returned in the form of energy savings through the lifecycle of a building. Comparing the cost of energy savings to the cost of electricity generation, it will be shown that the cost of energy savings is far less than the actual electricity cost.

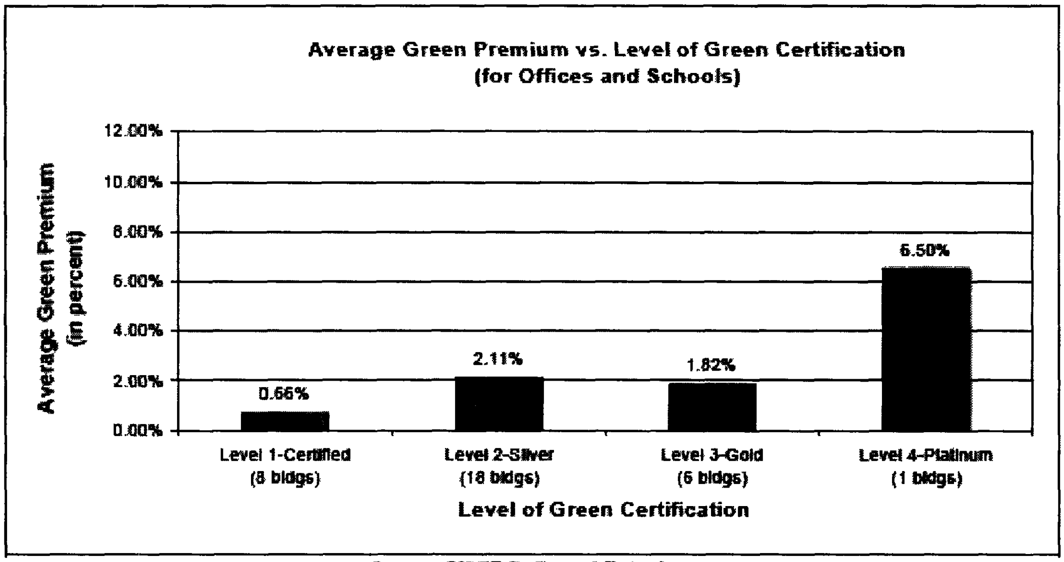
Cost of Green Buildings

In order to determine the cost premium of green buildings, the California's Sustainable Task Force contacted several dozen building representatives and architects to secure the cost of 33 green buildings from California and compared those to the cost of conventional designs for the same buildings.

It was discovered that on average, the premium for green buildings is about 2%. The eight rated Bronze level buildings had an average cost premium of less than 1%. Eighteen Silver-level buildings averaged a 2.1% cost premium. The six Gold buildings had an average premium of 1.8%, and the one Platinum building was at 6.5%. The average reported cost premium for all 33 buildings is somewhat less than 2%, or \$3-5/ft^2, which is significantly lower than commonly perceived.[18]

[18] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

The Figure below shows a graphical representation of the cost premium for each of the four different certification levels:



Source: USGBC, Capital E Analysis

Figure 2: Average green premium for different levels of LEED certifications.

According to the study, the majority of cost premiums were a result of the increased architectural and engineering design time needed to integrate sustainable building practices into projects. The author is later quoted to say, "the thing about green buildings is that they are much more cost effective if you do them as a whole rather than piecemeal. The key is to start very early, include everyone, and have senior management take the lead responsibility on greening."[19]

The cost of green design has indeed dropped in the last few years as the number of green buildings rose. The trend of declining costs associated with increased experience can be observed through Portland's three reported and completed LEED

[19] http://www.buildings.com/Articles/detailBuildings.asp?ArticleID=3029

Silver buildings, which were finished in 1995, 1997, and 2000. They incurred cost premiums of 2%, 1% and 0% respectively. Also, the cost of LEED Silver buildings has dropped from 3-4% several years ago to 1-2% in Seattle[20].

Another study by Lisa Fay Matthiessen and Peter Morris of Davis Langdon in 2004 notes that the cost per square foot for buildings seeking basic LEED certification - not the Bronze, Silver, Gold, or Platinum levels - falls into the existing range of costs for buildings of a similar program type.[21] The study notes that one of the most common methods used to establish the cost of green has been to compare final construction costs to the project's established budget. They compared the construction costs of 138 buildings where LEED certification was a primary goal for 45 building to those 93 buildings where LEED certification was not considered. At the same time, they studies whether or not the budget increased to accommodate the sustainable elements or if the elements were incorporated into the design using the original funding. Comparing the cost per square foot for all the buildings, the cost for LEED seeking buildings were scattered throughout the range of cost for all the buildings, with no apparent pattern of distribution. They performed a statistical test, which showed that there is no statistically significant difference between the non-LEED and LEED buildings. The standard deviation was high since there is a large variation of building costs. Thus, they concluded that there are high and low cost LEED buildings as well as non-LEED; as a result of the large variation, comparing the average cost per square foot for one set of buildings to another does not provide any meaningful information. At the same time,

[20] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[21] Matthiessen, Lisa Fay and Peter Morris. "Costing Green: A Comprehensive Cost Database and Budgeting Methodology." Davis Langdon: Santa Monica, CA , July 2004.

researchers found that more than half of the LEED projects had original budgets set without regard to sustainable design, yet received no supplemental funds to support sustainable goals. Of those buildings that received extra funding, the supplement was usually provided only for specific enhancements or requirements, such as photovoltaic systems; these supplemental funding ranged between 0 and 3 percent of the initial budget.[22]

Another study on the cost of green buildings was undertaken by New Ecology and the Tellus Institute in 2005. It is comprised of 16 case studies of affordable housing projects from around the country. The green projects reviewed in the report had a total development cost that ranged from 18% below to 9% above the costs for comparable conventional affordable housing. On average, the sixteen case studies showed a green premium of 2.42% in total development costs, which was largely due to the increased construction cost as opposed to extra design costs.[23]

Studies above have shown that the green premium ranges from 0 to 2%. There is a large variation in the cost due to various factors, such as the actual design, extra enhancements or requirements, location, and the time when adding these green attributes. Nonetheless, even 2% premium is a lot lower than commonly perceived, and it is shown later in the report that this extra cost will be compensated for through energy conservations.

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[22] Matthiessen, Lisa Fay and Peter Morris. "Costing Green: A Comprehensive Cost Database and Budgeting Methodology." Davis Langdon: Santa Monica, CA , July 2004.
[23] http://www.newecology.org/cb%20description.htm

Benefits of Green Buildings

It is generally recognized that buildings consume a large portion of water, wood, energy, and other resources; in particular, buildings consume 70% of the nation's electricity.[24] At the same time, US buildings alone are responsible for more CO2 emissions than any other country in the world except China.[25] Green buildings provide financial benefits that conventional buildings do not. These benefits include energy and water savings, reduced waste, improved indoor environmental quality, greater employee comfort/productivity, reduced employee health costs and lower operations and maintenance cost. Building green is cost effective, and it offers a promising way to help address a range of challenges facing the world—by reducing energy demand and electricity and gas prices, for example.

Net Present Value

Green buildings may cost more to build than conventional buildings, especially when incorporating more advanced technologies and higher levels of sustainability. However, they also offer significant cost savings over time. In order to answer the question: Does it make financial and economic sense to build a green building? The current value of green buildings and the value of savings through energy reduction need to be calculated on a net present value (NPV) basis. NPV reflects a stream of current and future benefits and costs, and presents the value in today's dollars.[26]

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[24] Gregory H. Kats. "Green Building Costs and Financial Benefits". Massachusetts Technology Collaborative, 2003.
[25] http://www.iisd.ca/climate-l/Climate-L_News_14.txt
[26] http://www.investorwords.com/cgi-bin/getword.cgi?3257

Net present value can be calculated using the following formula:

$$NPV = \sum_{i=1}^{n} \frac{values_i}{(1+rate)^i}, \tag{1}$$

where rate is the interest rate per time period (usually assumed to be 5% real), n is the number of time periods (assumed lifetime of buildings), and values are the constant sized payment paid or financial benefits gained each time period. This provides a calculation of the value in today's dollars for the stream of a certain number of years of financial benefits discounted by the 5% real interest rate. In order to calculate the net present value of the entire investment, the initial green cost premium need to be subtracted from the stream of future discounted financial benefits.

Buildings typically operate for over 25 years. A recent report for the Packard Foundation shows building life increasing with increasing levels of greenness. According to the Packard study, a conventional building is expected to last 40 years, a LEED Silver level building for 60 years and Gold or Platinum level buildings even longer.[27] In buildings, different energy systems and technologies last for different lengths of time. Thus, assuming a 25-year lifetime in this report is a conservative estimate.

Like the California Analysis, this report also assumes that costs as well as benefits rise at the same rate of inflation (assumed to be 2%); and so present value calculations are made on the basis of a conservative real 5% discount rate without any inflation effects. This is an oversimplification since energy costs are relatively volatile.

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[27] "Building For Sustainability Report: Six Scenarios for The David and Lucile Packard Foundation." Los Altos Project, October 2002.

Energy

It is widely recognized that energy efficiency improves greatly through building green, which in turn reduces the cost of building operations. Green building energy savings come primarily from reduced electricity purchases and secondarily from reduced peak energy demand. A review of 60 LEED rated buildings throughout the US demonstrates that green buildings, compared to conventional buildings, are[28]:

- On average 25-30% more energy efficient
- Characterized by even lower electricity peak consumption
- More likely to have on-site renewable energy generation
- More likely to purchase grid power generated from renewable energy sources

The figure below, taken from the California Sustainable Taskforce Study, shows a detailed breakdown of efficiency improvements and onsite renewable energy production for each of the four certification levels[29]:

Figure 2
Reduced Energy Use in Green Buildings as Compared with Conventional Buildings

	Certified	Silver	Gold	Average
Energy Efficiency (above standard code)	18%	30%	37%	28%
On-Site Renewable Energy	0%	0%	4%	2%
Green Power	10%	0%	7%	6%
Total	28%	30%	48%	36%

Source: USGBC, Capital E Analysis

Figure 3: Reduced energy use for buildings of different LEED certification levels.

[28] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[29] Gregory H. Kats. "Green Building Costs and Financial Benefits". Massachusetts Technology Collaborative, 2003.

The financial benefits of 30% reduced consumption at an electricity price of \$0.08/kWh are about $\$0.30/ft^2/yr$, with a 20-year NPV of over $\$5/ft^2$, which is already equal to or exceed the average additional 2% green premium as stated earlier in the Cost section[30]. Actual savings for a 100,000 ft^2 state office building in Massachusetts, worth \$60,000 per year, with a 20-year present value of expected energy savings at a 5% real discount rate, is worth about three quarters of a million dollars; this is calculated using the fact that the average annual cost of energy in Massachusetts buildings is approximately $\$2.00/ft^2$.[31]

Interactions between competing building systems, such as lighting vs. cooling, and fresh air vs. humidity control, are analyzed simultaneously; this allows the designers to reduce peak power demand by downsizing air conditioning and lighting loads while providing a comfortable indoor environment. For much of the US, air conditioning uses the most energy during peak load. The largest and third largest electricity demands, respectively, in California during a typical 50,000 MW peak load period are commercial air conditioning – representing 15% of peak load, and commercial lighting – representing 11% of peak load.[32]

The California study evaluated the LEED certification documents for over a dozen buildings, and it revealed that an approximate average reduction in energy use of 30%, but an average peak reduction of about 40%.[33] Though limited, this data set nonetheless indicates that peak demand reduction in green buildings is significant. Thus,

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[30] Gregory H. Kats. "Green Building Costs and Financial Benefits". Massachusetts Technology Collaborative, 2003.

[31] Gregory H. Kats. "Green Building Costs and Financial Benefits". Massachusetts Technology Collaborative, 2003

[32] John Wilson, Art Rosenfeld and Mike Jaske, "Using Demand Responsive Loads to Meet California's Reliability Needs."
http://www.energy.ca.gov/papers/2002-08-18_aceee_presentations/PANEL-05_WILSON.PDF.

[33] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003

the benefits of reduced consumption are largest during periods of peak power consumption. These benefits include: avoided congestion costs, reduced power quality and reliability problems, reduced pollution, and avoided capacity and transmissions and distribution (T&D) costs.[34] Therefore, energy benefits of green buildings need to be quantified not only based on reduced energy use but also on reduced peak electricity demand.

The most recent, robust data on the value of peak reduction in decreasing T&D, congestion, and related costs is ten to twelve years old. These studies calculated the value of reduced peak demand due to on-site electricity generation for eleven utility studies, including four in California. They showed an average T&D-related peak reduction value of $600 per kW.[35]

The California Analysis approximates the value of peak demand reduction in the following two ways:

- Based on California state building experience, a 10% reduction in peak demand for one million square feet of state prisons, hospitals or office buildings amounts to 200 kW, or about $24,000 per year, which works out to be $0.024/ ft^2 per year.[36]
- The annual savings from lowered peak power consumption can also be estimated based on the fact that each square feet in state buildings use 10 kWh per year, and the difference in cost between average and peak demand price is $0.067/kWh.

34 Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003

35 California Energy Commission. "Comparative Cost of California Central Station Electricity Generation Technologies." Final Staff Report. June 2003.

36 Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

Assuming that the peak demand is 8% of all hours, it is then calculated that a 0.8 kWh shift from peak power, is worth \$0.04 per ft^2 per year[37].

The two values above (\$0.024 and \$0.04) have a large gap. It is uncertain to say which is more accurate; thus, \$0.025 per ft^2 per year was used in the California study for a conservative estimate.

Putting it all together, green building energy savings primarily come from reduced electricity purchases, and secondarily from reduced peak energy demand. The financial benefits of 30% reduced consumption at an electricity price of \$0.11/kWh are about \$0.44/ ft^2/yr, with a 20-year present value of \$5.48/ ft^2. The additional value of peak demand reduction from green buildings is estimated at \$0.025/ ft^2/yr, with 20-year present value of \$0.31/ ft^2. Together, the total 20-year present value of financial energy benefits from a typical green building is \$5.79/ ft^2.[38] Thus, on the basis of energy savings alone, investing in green buildings appears to be cost-effective based on a 2%, or \$3-5/ft^2, increase in first cost.

Emissions

United States has the largest amount of global warming pollution. Though Americans make up just 4 percent of the world's population, they produce 25 percent of the carbon dioxide pollution from fossil-fuel burning, which is by far the largest share of any country. In fact, the United States emits more carbon dioxide than China, India and Japan combined. At the rate of 25 billion tons of carbon dioxide emissions per year,

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[37] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[38] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

coal-burning power plants in the US are the largest source of carbon dioxide pollution.[39] Automobiles, the second largest source, create nearly 1.5 billion tons of carbon dioxide. However, technologies do exist today to make cars run cleaner and burn less gas; modernized power plants also exist that generate electricity from nonpolluting sources and cut electricity use through energy efficiency.

The generation of electricity, particularly from fossil fuels, creates many harmful emissions. Air pollutants that result from the burning of fossil fuels include:

- Nitrogen Oxides—a principal cause of smog.
- Particulates—a principal cause of respiratory illness and an important contributor to smog.
- Sulfur Dioxide—a principal cause of acid rain.
- Carbon Dioxide—the principal greenhouse gas and the principal product of combustion.

Scientists believe that anthropogenic emissions, especially from burning fossil fuels, are the root cause of global warming. The United States is responsible for about 22% of global greenhouse gas emissions. Of this 22%, the US building sector is responsible for about 35% of US CO2 emissions.[40] CO2 is the dominant global warming gas, equal to about 9% of global anthropogenic emissions.

Air pollution from burning fossil fuels to generate electricity imposes large damage costs to people's health, the environment and the property. Demonstrated health costs include increased respiratory diseases and even mortality[41]. These damages associated with pollution are only partially reflected in the price of energy. Estimating

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[39] www.globalwarming.org
[40] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[41] http://www.epa.gov/air/urbanair/nox/what.html

the costs of externalities is technically difficult and politically problematic. However, the California Analysis suggests three ways of valuing the costs of air pollution associated with burning fossil fuels:

- Calculate the direct costs of pollution effects on property, health and environment and then allocate it on a weighted or a site-specific basis.
- Use the cost of avoiding or reducing these pollutants to determine market value of pollutants.
- Use the market value of pollutants if there is an established trading market (emission permits).

A value of $1.18/ft^2 was calculated for the 20 year present value of pollution reduction, which they believed to be a conservative number.

Water Conservation

Certain regions of the U.S., such as California and Nevada, face substantial water shortages that are expected to worsen. Urban water users have experienced mandatory rationing, small rural communities have seen wells go dry, and environmental water supplies have been reduced. For example, Las Vegas residents must obey a tough limit on landscape watering; in particular, lawn watering during hot daylight is prohibited. Without additional facilities, all of these conditions will only deteriorate, especially with the projected population increase.

One way to conserve water is through building green. Green building water conservation strategies typically fall into four categories[42]:

- Efficiency of potable water use through better design/technology.
- Capture of gray water, which is the non-fecal waste water from bathroom sinks, bathtubs, showers, etc, and use it for irrigation.
- On-site storm water retention for use or groundwater recharge.
- Recycled water use.

Taken together, these strategies can reduce water use below common practice by over 30% indoors and over 50% for landscaping.[43] Of 21 reviewed green buildings submitted to the USGBC for LEED certification, all but one used water efficient landscaping, cutting outdoor water use by at least 50%. Seventeen buildings, or 81%, used no potable water for landscaping. Over half cut water use inside buildings by at least 30%.[44] This also translates into big savings for the building. Taking all factors into account, including the avoided cost of water and extra cost for new marginal water supply, the California Analysis calculated a 20-year present value of $0.51/ft^2 for water savings from green buildings.[45]

Waste Reduction

Another benefit of building green is waste reduction. Nearly 60% (over 21 million tons in 1998) of waste in the state of California comes from commercial

[42] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[43] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[44] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[45] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

buildings.[46] Additionally, 57% of the construction and demolition (C&D) debris nationally comes from the non-residential sector.[47] Waste reduction strategies, such as reuse and recycling, help to reroute some waste from being disposed of in landfills. These strategies help save on disposal costs as well as costs to society for creating new landfills and maintaining the existing ones. In addition, recycling and reuse have the potential to spur development in other industries, such as ones that process these diverted wastes and those that use recycled raw materials.

Green building waste reduction strategies can occur at time of construction and throughout the life of the building[48]. Construction waste reduction options include:

- Reusing the minimizing construction and demolition debris and diverting those wastes from landfills to recycling facilities.
- Source reduction, such as using more durable building materials that are also easier to repair and maintain, generating less scrap material through better dimensional planning, increasing recycled content, and using reclaimed building materials.
- Reusing existing building structure and shells in renovation projects.

Building lifetime waste reductions include:

- Developing indoor recycling program and reuse.
- Designing for deconstruction.

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[46] California Integrated Waste Management Board. "Statewide Waste Characterization Study: Results and Final Report." December 1999.
[47] US Environmental Protection Agency Municipal and Industrial Solid Waste Division, Office of Solid Waste. "Characterization of Building-related Construction and Demolition Debris in the United States." June 1998.
[48] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

Estimating the financial benefits of waste reduction, diversion and recycling for green buildings relative to conventional ones is rather difficult. Minimal data exists regarding the actual diversion and disposal rates, thus, making it hard to estimate the waste reduction benefits. However, based on a set of tentative assumption along with number from several other studies, the California Analysis calculated a rough conservative value of $0.03/ft^2 for C&D diversion for new constructions.

Productivity and health

In addition to energy savings, decreased emissions, water conservation and waste reduction, there are a number of studies that document great benefits for employees through natural day-lighting and better indoor air quality. There is growing recognition of the large health and productivity costs resulting from poor indoor environmental quality in commercial buildings; some estimates are as high as hundreds of billions of dollars per year. This is believable since people do spend a majority of their time indoors, and the concentration of pollutants indoors is typically higher than outdoors. There are numerous studies that find significantly reduced illness symptoms, reduced absenteeism and increases in productivity over workers in a group that lacked natural daylighting and better ventillation.[49]

Following are some relevant attributes common in green buildings that promote healthier work environments[50]:

- Much lower source emissions from measures such as better siting and better building material source controls. Less toxic materials, low-emitting adhesives &

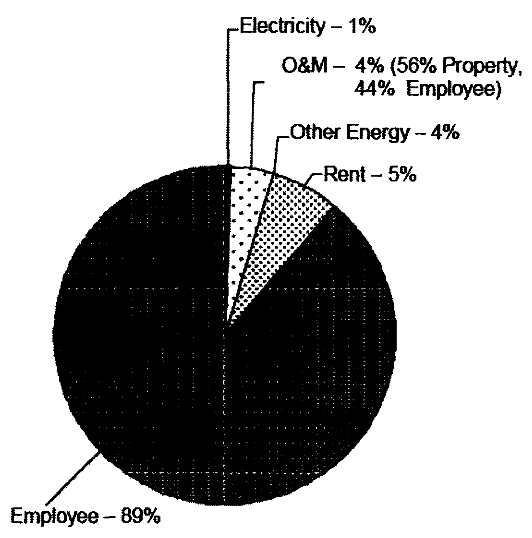
[49] Judith Heerwagen, "Sustainable Design Can Be an Asset to the Bottom Line - expanded internet edition," Environmental Design & Construction, Posted 07/15/02.
[50] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

sealants, paints, carpets, and composite woods, and indoor chemical & pollutant source control are used in LEED certified buildings.

- Significantly better lighting quality including: more daylighting (half of 21 LEED green buildings reviewed provide daylighting to at least 75% of building space), better daylight harvesting and use of shading (such as automated Venetian blinds), greater control over light levels and less glare.
- Improved thermal comfort and better ventilation—especially in buildings that use under floor air for space conditioning
- Commissioning and CO2 monitoring to ensure better performance of ventilation systems, heating units and air conditioning

In the California Analysis, the following chart is presented to show the state costs for 27, 428 state employees in 38 state-owned buildings.

Figure VIII-1. Costs in California State Employee-Occupied Office Buildings
(December 2001 - September 2002 with projections for November-December 2002)



Source: Real Estate Services Division of Department of General Services.[224]

Figure 4: Breakdown of costs for office buildings in California.

It shows the cost to the state of California for state employees to be ten times larger than the cost of property. Thus, measures that increase employee costs by 1% are essentially equivalent to an increase in property related costs of about 10%. In other words, if green design measures can increase productivity by 1%, this would, over time, have a financial impact roughly equal to reducing property costs by 10%.

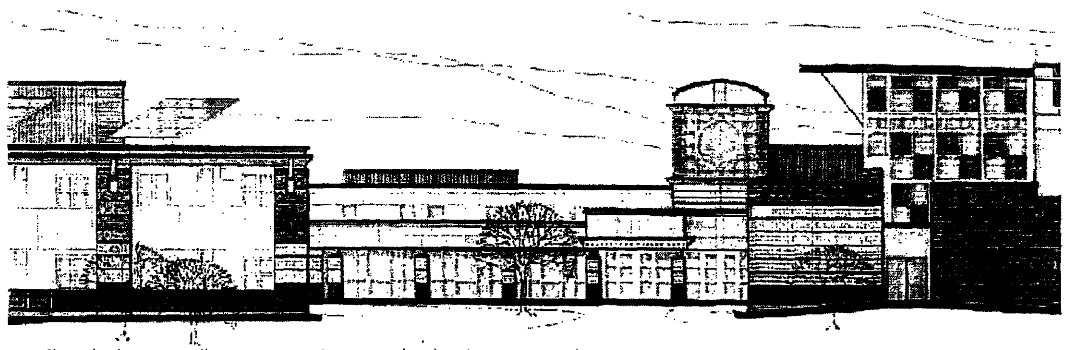
Measuring the exact financial impact of healthier, more comfortable and greener buildings is difficult. The costs of poor indoor environmental and air quality—including higher absenteeism and increased respiratory ailments, allergies and asthma—are hard to measure; they have traditionally been attracted to sick days, lower productivity, and medical / insurance costs. However, four of the attributes associated with green building design—increased ventilation control, increased temperature control, increased lighting control and increased daylighting—have been positively and significantly correlated with increased productivity. Increases in tenant control over ventilation, temperature and lighting each provide measured benefits from 0.5% up to 34%, with average measured workforce productivity gains of 7.1% with lighting control, 1.8% with ventilation control, and 1.2% with thermal control[51]. Additionally, significant measured improvements have been found with increased daylighting.

A study by the Heschong Mahone Group evaluated the test score performance of over 21,000 students in three school districts in San Juan Capistrano, CA; Seattle, WA; and Fort Collins, CO. This study found that in classrooms with the most daylighting, students' learning progressed 20% faster in math and 26% faster in reading than similar students in classrooms with the least daylighting. The overall findings show that a student's test performance can be significantly increased through daylighting and a

[51] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.

general improvement of the quality of lighting.[52] Another study at Herman-Miller showed up to a 7% increase in worker productivity after they moved to a green, day lit facility.[53] A Lawrence Berkeley National Laboratory study also found that U.S. as as much as $58 billion could be saved in lost sick time for businesses and an additional $200 billion could be gained through better worker performance due to improvements for indoor air quality.[54]

Green buildings are designed to be a healthier and more enjoyable working environment. The picture below shows a building retrofit that is expected to save over 500 kW a year through daylighting using the light tube technology.[55]



The Blackstone Valley Vocational Regional School District is planning an ambitious 80,000 square foot addition to accommodate four new vocational programs, and will renovate the existing building which has some systems that date back to the 1960's. Daylighting will be accomplished in this project by using light tube technology, which will save over 500 kW a year. Other efficiency measures include efficient air conditioning equipment and variable speed drives for the air handling unit. The school will also incorporate photovoltaic panels mounted on the roof and a solar thermal domestic water preheating system.

Figure 5: Picture of the Blackstone Valley Vocational Regional School District.

According to the California Analysis, a 1% increase in productivity, which is equal to about 5 minutes per working day, is equivalent to $600 to $700 per employee per year, or

[52] Heschong Mahone Group, "Daylighting in Schools: An Investigation into the Relationship Between Daylight and Human Performance." Fair Oaks, CA. 1999.
[53] Judith Heerwagen, "Do Green Buildings Enhance the Well Being of Workers?" Environmental Design and Construction Magazine. July/August 2000.
[54] William Fisk, "Health and Productivity Gains from Better Indoor Environments and Their Implications for the US Department of Energy." Lawrence Berkeley National Laboratory.
[55] http://www.cap-e.com/ewebeditpro/items/O59F3481.pdf

$3/ft^2 per year. Over 20 years and at a 5% real discount rate, the present value of the productivity benefits ranges from $35/ft^2 to $55/ft^2 depending on the building's level of certification. This is a much larger number than the energy savings; it reflects the fact that the direct and indirect cost of employees is far larger than the cost of construction or resources. Even a small change in productivity and health can translate into huge financial benefits. The graph below, from the California Analysis, shows the potential savings from several sources of productivity gains and health benefits:

Figure VIII-2. Potential Productivity Gains from Improvements in Indoor Environments

Source of Productivity Gain	Potential Annual Health Benefits	Potential U.S. Annual Savings or Productivity Gain (2002 dollars)
1) Reduced respiratory illness	16 to 37 million avoided cases of common cold or influenza	$7 - $16 billion
2) Reduced allergies and asthma	8% to 25% decrease in symptoms within 53 million allergy sufferers and 16 million asthmatics	$1 - $5 billion
3) Reduced sick building syndrome symptoms	20% to 50% reduction in SBS health symptoms experienced frequently at work by ~15 million workers	$10 - $35 billion
4) Sub-total		*$18 - $56 billion*
5) Improved worker performance from changes in thermal environment and lighting	Not applicable	$25 - $180 billion
6) Total		*$43 - $235 billion*

Adapted from: William Fisk, "Health and Productivity Gains from Better Indoor Environments"[234]

Figure 6: Potential savings from productivity improvements resulting from better indoor environments.

Though large, these numbers are very subject and are hard to substantiate; thus, they have less credibility than concrete savings calculated through documented energy consumption.

Overall Cost and Benefit Analysis of Green Buildings

Green buildings provide financial benefits that conventional buildings do not. As indicated in Figure below, the California Analysis concluded that financial benefits of building green are between $50 and $70 per square foot in a LEED building, which is over 10 times the additional cost associated with green buildings.

Figure ES-1. Financial Benefits of Green Buildings Summary of Findings (per ft²)

Category	20-year NPV
Energy Value	$5.79
Emissions Value	$1.18
Water Value	$0.51
Waste Value (construction only) - 1 year	$0.03
Commissioning O&M Value	$8.47
Productivity and Health Value (Certified and Silver)	$36.89
Productivity and Health Value (Gold and Platinum)	$55.33
Less Green Cost Premium	($4.00)
Total 20-year NPV (Certified and Silver)	**$48.87**
Total 20-year NPV (Gold and Platinum)	**$67.31**

Source: Capital E Analysis

Figure 7: Summary of findings from the California Analysis. It includes the extra cost of initial investment and various benefits for green buildings.

The financial benefits are in lower energy, waste and water costs, lower environmental and emissions costs, and lower operational and maintenance costs and increased productivity and health. Despite data limitations and the need for additional research in various areas, the data set still demonstrates that building green is cost-effective today, particularly for those projects which start designing green early in the process. Energy savings alone ($5.79/ft^2) exceed the average increased cost associated with building green, equivalent to $3-5/ft^2 assuming conservatively (a 2% green building premium on commercial construction costs of $150/ft^2 to 250/ft^2).

This conclusion indicates that while green buildings generally cost more than conventional buildings, the "green premium" is lower than commonly perceived. The cost of green buildings tends to rise as the level of greenness increases, while the premium to build green is decreasing over time. More importantly, the cost tends to decline with increasing experience in design and development.[56] As mentioned above in the Cost section, this trend has already been observed in Portland, where three reported completed LEED Silver buildings, finished in 1995, 1997, and 2000, incurred cost premiums of 2%, 1% and 0% respectively.

Alternative Energy

"Fossil fuel-based electricity is projected to account for more than 40% of global greenhouse gas emissions by 2020," said Dr. John Deutch[57]. "In the U.S. 90% of the carbon emissions from electricity generation come from coal-fired generation, even though this accounts for only 52% of the electricity produced."

The average US citizen uses 100 times more commercial energy than the average person in Bangladesh. If today's energy use were distributed equally over the world population, each person would use about 1.4 tons of oil equivalent per year.[58] World population has tripled since the late 1930s and it is still increasing. The increasing number of people and developments suggest even higher energy needs for the future.

[56] Kats, Gregory. "The Costs and Financial Benefits of Green Buildings." Californa, October 2003.
[57] http://web.mit.edu/nuclearpower/
[58] Tester, Drake, Driscoll, Golay, and Peters. "Sustainable Energy: Choosing Among Options." Cambridge, MA: The MIT Press, 2005. Page 3.

The most available and affordable sources of energy in today's economic structure are fossil fuels (about 85% of all commercial energy is derived from them). Efficiency improvements and new technology are part of the solution. However, society still needs to make major changes in order to stabilize greenhouse gas emissions.

In a typical developed country, such as the US, electricity production accounts for about 25% of total energy consumption, with the remainder of energy needs met by direct fossil fuel consumption[59]. Use of geothermal energy and the renewable technologies are negligible. Coal is used almost exclusively for electricity production; the remaining needs, especially in transportation, are met mainly through petroleum consumption and natural gas. Extracted in many countries and consumed primarily in the industrialized countries, petroleum is the most important fuel worldwide. In 1997, the world used almost 450 quads of energy—the magnitude of this amount of energy is astonishing. If it were entirely petroleum, it would be enough to cover an area of about 15,600 square miles with a 1-foot deep layer of oil.[60] The energy consumed varies by country and region. There are also huge differences among nations—developed countries account for large portions of the world's total annual energy consumption, as well as for much of the world's economy.

Energy production or utilization is often associated with consumption of other natural resources, such as minerals, forests, water, food and land. Furthermore, the everyday use of energy can damage human health and the earth's ecosystems. Policy options should be developed to ensure a more sustainable energy future; increased

[59] Tester, Drake, Driscoll, Golay, and Peters. "Sustainable Energy: Choosing Among Options." Cambridge, MA: The MIT Press, 2005. Page 5.
[60] Tester, Drake, Driscoll, Golay, and Peters. "Sustainable Energy: Choosing Among Options." Cambridge, MA: The MIT Press, 2005. Page 24.

efficiency of energy production and reduced energy demands could be a start. If fossil fuel prices were to rise to include externalities, such as the costly carbon management, then consumers may also change their consumption pattern. Sustainability concepts provide a framework to evaluate energy production technology and policies and thus guide future decision making regarding energy through the balancing tradeoffs.

End-use energy consumption can be divided into four major sectors—transportation, residential, commercial, and industrial—which respectively consume about 28%, 21%, 18%, and 33% of the total US energy. Total consumption in 2001 was about 97 quads, which was about 1/5 the world's total energy use, and fossil fuels accounted for about 85% of this amount.[61]

Given the current method of energy supply, the worldwide growing demand for energy raises concerns for the long term. Instead of decreasing energy demand through energy efficient practices, people often times only focus on increasing supply to meet the demand. There are many energy producing options available, but the most attractive one is fossil fuels due to their high energy density and relatively low cost. The growing population, as well as requirements for sustaining industries and human lives, has all caused fossil fuel consumption to increase dramatically. With growing concerns about the environment and health impacts of fossil fuel emissions, and about the depletion and uneven distribution of world's oil and gas resources, people are looking for options for cleaner and affordable energy supplies. For example, electricity generation from renewable sources has gained tremendous support in the last decade. Using renewable

[61] Tester, Drake, Driscoll, Golay, and Peters. "Sustainable Energy: Choosing Among Options." Cambridge, MA: The MIT Press, 2005. Page 25.

energy has many benefits, such as lowered emissions and alleviated depletion of natural resources.

The US has a rich diversity of resources for solar, biomass, wind and geothermal energy—all of which can help diversify the energy supply and become energy independent. Renewables are environmentally attractive due to lower emissions and minimal impacts, but they do have some drawbacks. They are generally more expensive and a huge initial investment is required; there are also deployment limitations associated with each type of renewable energy. For example, large wind turbines and solar towers need to be placed in appropriate locations (areas with a lot of wind or sun). Whether or not these options are viable is directly related to the availability of high-grade resources in each region, such as solar in the US Southwest or wind in North Dakota. In addition, the natural variability of many renewables on seasonal time scales limits the use of those technologies without large energy storage.[62]

[62] Tester, Jefferson. "Universal Geothermal Energy—An Opportunity for Sustainable Energy." November 2005.

The Table below shows a breakdown of the total generating costs for various renewable and non-renewable power generating options from two different sources:

	Technology	Investment costs ($/kW) Source 1	Total generating costs (¢/kWh) Source 1	Investment costs ($/kW) Source 2	Total generating costs (¢/kWh) Source 2
Non-renewable					
	Natural gas combined cycle	500-700	3.0-4.0	600	2.9-4.7
	Coal	1,000-1,300	4.0-5.5	1,200	3.9-7.3
	Nuclear	1,200-2,000	3.3-8.0	2,400	7.3
Renewable					
	Wind	800-2,000	3.0-8.0	1,500	6.5
	Biomass (25 MW)	1,500-2,500	4.0-9.0	-------	0.3-4.0
	Small hydro	800-1,200	5.0-10.0	1,000-2,500	2.6
	Solar thermal electric	4,000-6,000	12.0-18.0	4,000-8,000	8.0
	Solar PV	6,000-8,000	30.0-80.0	7,000	>10

Table 1: Cost of electricity generation for both renewable and non-renewable sources. Source 1 is from "Designing A Clean Energy Future: A Resource Manual, Developed for the Clean Energy Resource Teams," by Melissa Pawlisch, Carl Nelson and Lola Schoenrich, The Minnesota Project, and source 2 is from "Sustainable Energy: Choosing Among Options," by Tester, et al,.

These costs also do not include externality costs, which is also known as health and environmental costs, since they are hard to quantify. However, the general trend does show bigger generating costs for renewables compared to non-renewables. In some studies, Solar PV has been shown to be so expensive that the initial investment would never be paid back throughout its entire life time.[63]

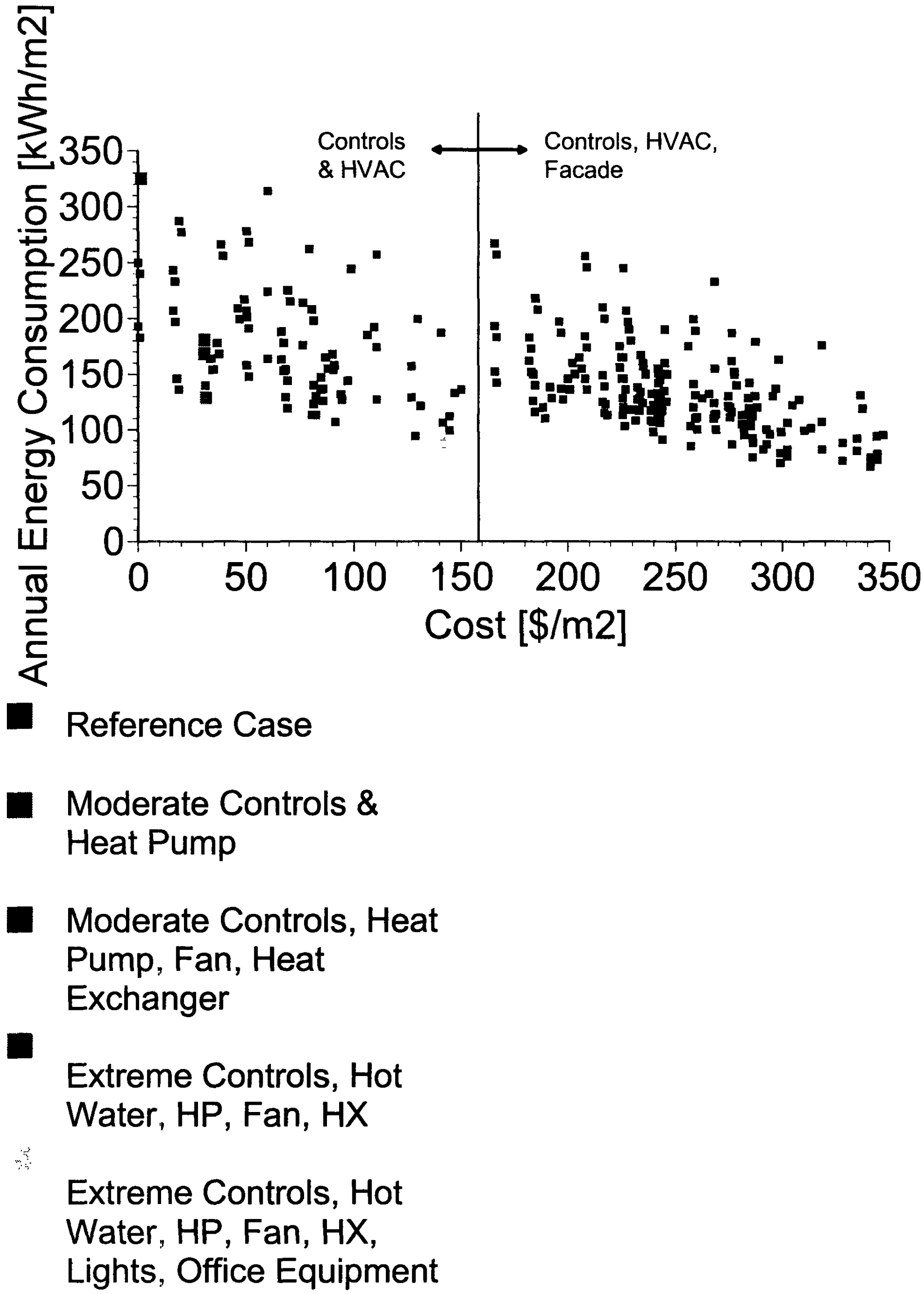
[63] Murray, Michael and John Peterson. "Payback and Currencies of Energy, Carbon Dioxide and Money for a 60 KW Photovoltaic Array." Oberlin, OH.

In general, both set of data do agree with and thus valid each other. The differences in generating cost for biomass, hydro, and solar are due to the fact that the numbers from the "Sustainable Energy" textbook calculated electricity generation costs for a different range of generation capacity. Nonetheless, they are on the same order of magnitude.

Norway Building Retrofits

Comparing the cost and benefit of renewable electricity generation to sustainable buildings, it should be clear that reducing demand through building green is more cost-effective than finding different ways to supply the increasing energy demand. Based on Lisa Enblom's "Scenario Analysis of Building Retrofits", the cost of retrofitting a building in Norway may range anywhere from $\$0/m^2$ to $\$150/m^2$ (adding controls and changing the HVAC without external façade renovation) depending on the how the building is retrofitted.

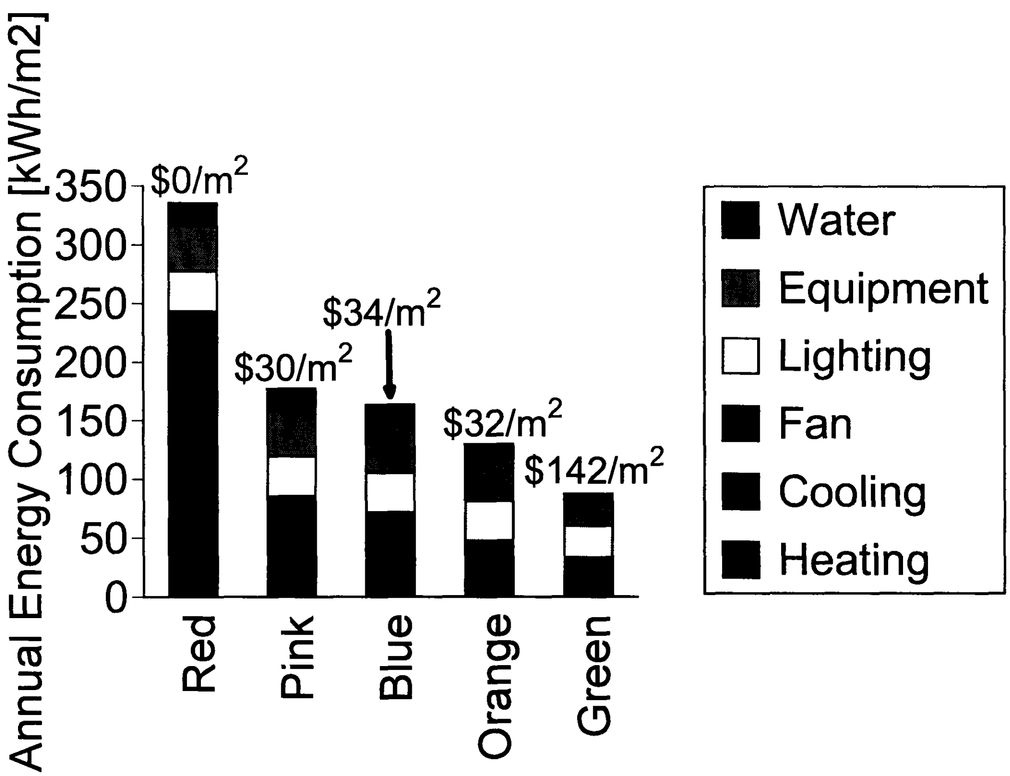
The graph below, taken from Enblom's presentation, shows a wide variety of retrofitting scenarios and the related costs and annual energy consumption for each:



Graph 1: Annual energy consumption versus the cost of retrofitting for various scenarios.

Each of the squares on the graph represents a retrofit possibility with different combinations of heating, cooling, lighting, water, fan, and equipment options. The x-axis shows the cost of each case of retrofits depending on what is implemented; the y-axis shows the annual energy consumption for each scenario. Sometimes, the extra cost may be really large compared to the savings it bring, especially if external façade renovations are included; other times, the extra cost is minimal compared to the savings. Thus, a balance needs to be found between the cost of the retrofitting measures and the benefits they bring. In the graph above, the red square is the reference case where no changes occurred; each of the other four colored squares represents a particular combination of controls and changes. In order to calculate savings associated with different retrofits, the annual energy consumption of each representative case is subtracted from the reference case and then this savings must be converted to total savings over the entire lifetime of the building based on a Net Present Value Analysis. The retrofitting cost divide by this total savings will give the actual cost of energy savings.

In order to see each of the cases more clearly, the graph below is taken from Lisa Enblom's presentation and it shows a breakdown of the energy consumption and associated cost with each case.



Graph 2: A closer examination of the highlighted cases from Graph 1. Red is the reference case.

A closer examination reveals that the reference case consumes about 330 kWh/m^2 annually, while pink, blue, orange and green each consume 180 kWh/m^2, 165 kWh/m^2, 130 kWh/m^2 and 80 kWh/m^2 respectively. The orange case (with extreme controls, hot water, heat pump, fan and heat exchanger retrofitting) appears to be the most efficient since it consumes the least amount of energy compared to scenarios with similar costs.

To compare all the cases more precisely, the cost of energy savings per kWh of electricity was calculated for each. Table 2 below shows the detailed calculations and the final end results:

Retrofit scenario	Annual energy savings (kWh/m^2)	NPV of energy savings over 25 years(kWh/m^2)	Cost of retrofit ($\$/m^2$)	Cost of energy savings (¢/kWh)
Pink	150	2,114.09	30	1.42
Blue	165	2,325.50	34	1.46
Orange	200	2,818.79	32	1.14
Green	250	3,523.49	142	4.03

Table 2: Cost of energy savings for different building retrofits.

Annual energy savings were first calculated for each case and that was simply accomplished by subtracting the new annual consumption from the reference case. The NPV of each savings was calculated using Equation 1; these calculations assumed a 5% real interest and a 25-year-lifetime. This total savings then get divided into the cost for each scenario and this yields the final cost of energy savings. As expected, orange is the most cost-efficient since it has the least cost of energy savings at 1.14 ¢/kWh. Even the green case only cost 4 cents per kilowatt hour of energy savings; this is the largest cost scenario for retrofits without façade renovation and is taken as a conservative measure. Thus, the cost for energy savings ranges from a mere 1 cent per kilowatt hour to 4 cents per kilowatt hour. This does not even take into account those cases where it does not cost anything extra to build a green building, in which case the cost of energy savings would be zero. Therefore, instead of focusing on new ways to provide energy, attention should shift to decreasing demand through energy efficient building.

Conclusion/Recommendations

Although there is a cost premium associated with green buildings, their benefits far exceed the cost. Some of these associated benefits are easily quantifiable, such as reduced energy consumption and water conservation; other benefits like increased health and productivity from natural daylighting and improved ventilation are hard to prove. Doing a Net Present Value analysis of just energy savings over 20 years, assuming a 5% real interest rate, already surpass the 2% cost premium of \$3-\$5/ft^2. There is an associated payback time for the initial investment of green buildings through energy savings; the payback time is even shorter if additional savings through reduced emissions, water conservation, waste reduction and health improvements are taken into account. On the other hand, some renewable generations can never be paid back even when the externalities are taken into account; the initial cost is far too much for the associated benefit. Comparing the cost of renewable energy generation to the cost of sustainable buildings, Table 3 below shows that green buildings are a more effective solution to meet the increasing energy demand:

	Technology	Cost (¢/kWh)
Electricity generation		
	Natural gas combined cycle	2.9-4.7
	Coal	3.9-7.3
	Nuclear	3.3-8.0
	Wind	3.0-8.0
	Biomass	0.3-9.0
	Hydro	2.6-10.0
	Solar thermal electric	8.0-18.0
	Solar PV	30.0-80.0
Energy savings		
	Green buildings	**1.1-4.0**

Table 3: The cost of various modes of electricity generation versus the cost of energy savings.

While the cost of electricity generation ranges from 0.3 ¢/kWh to 80.0 ¢/kWh, there are huge variations in cost and limitations exist for different options. The cost of energy savings is in a small range from 1.1 ¢/kWh to 4.0 ¢/kWh; this is not taking zero green premiums into account, which are possible as shown in studies above. Therefore, sustainable buildings are very cost effective and should be pursued more frequently in the U.S. as well as the rest of the world.

Acknowledgements

This study was conducted under the supervision of Professor Leon Glicksman. It draws extensively from the California Sustainable Energy Task Force Study. Thanks to Lisa Enblom for her Norway Presentation slides.