Green Development: Creating Incentives for Developers

by

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ABSTRACT

With a slowly decaying environment, the development in the construction industry is steering towards sustainability. Researchers are aware of the need for an environmentally sound building technology; however, the maturity of the research in the fields of sustainable architecture and 'green' building design is not matched in practice. This is due to a rather limited research on the economical side of sustainable strategies and a lack of incentives to push developers and investors into a trend still perceived to be very expensive.

The financial equation behind 'Green' development can be simplified by the comparison between the increase in initial investment and the life-cycle cost benefits, discounted on the duration of the project. The latter can be divided into two major groups; savings due to lower operations and maintenance costs and benefits due to increased indoor environmental quality. Both would be reflected in a higher asset value which is an incentive for developers and investors to build 'green'.

The first part of this thesis will investigate two different approaches to create incentives for developers to build 'green'. First, it will analyze the role of the Federal Government and the impact of 'green' buildings on the economy. Then, it will evaluate 'green' strategies as separate investments within a construction project. However, previous studies have concluded that energy-efficiency savings do not always justify the initial investment due to ever decreasing energy prices in the United States. This will shift the focus on the value of productivity and health benefits.

The second part of this thesis, through a critical review of previous studies, will attempt to associate specific building upgrades with tangible productivity increases and health benefits, in the context of commercial office development. The outcome would be analyzed in the framework of a certification system adapted to indoor environmental quality. In conclusion, a comparative case study will investigate the financial performance of a regular office development versus a 'green' version of the same project, emphasizing on the impact of the productivity and health benefits.

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INTRODUCTION

"Treat the Earth well. It was not given to you by your parents. It was loaned to you by your children."

-- Kenyan Proverb

The central idea of environmental sustainability is to leave the Earth in good shape for future generations. Subsequently, a human activity is defined to be sustainable if it can be performed and maintained indefinitely without exhausting natural resources or spoiling the environment.

Since the industrial revolution, we have witnessed a huge amount of breakthroughs in science and technology, resulting in a rapid population growth and more demanding standards of living. This increased dramatically the resource usage. Nearly a century and a half later, we are reaping what we sowed: Pollution, global warming, acid rain, resource and ozone depletion, deforestation, toxic waste problems, and landfills exceeding capacity.

With the continuing population growth and threats to the environment becoming more serious every day, it is imperative to take decisive measures in all areas of human activity. Because of its enormous drain of resources, the built environment and the construction industry are one obvious sector where a lot could be done to lessen our impact on the environment.

Sustainability and Green Development

"Buildings have a significant impact on the environment, accounting for one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest, and two-fifths of its material and energy flows[1]. Structures also impact areas beyond their immediate location, affecting the watersheds, air quality, and transportation patterns of communities", (Gottfried, 1996)[2]. In the United States, buildings account for more than half the nation's wealth, and the construction industry represents more than 13 percent of the Gross Domestic Product (GDP). The resources required by this sector are diminishing, and to be able to continue to provide the same product quality and allow for future expansion, the building industry should address its environmental and economic impacts.

Recognizing the amplitude of the impact the building industry has on the environment leads us to rethink the way we design, construct and operate our buildings. This sustainability ethic is embodied in a growing trend: 'Green Development'. Green buildings are based on the principles of resource efficiency, health, comfort and productivity of the occupants. Economically, they analyze building projects on a life-cycle basis instead of concentrating on initial costs and savings.

Due to the complexity and wide scope of sustainability issues, it is very difficult to propose one single definition of green buildings. However, green buildings could be defined as those with minimum adverse impact on the built and natural environment, on three levels: the building itself, its immediate surrounding, and the broader regional and global setting. Green buildings involve an analysis of the entire life-cycle of the building, taking environmental and functional quality, as well as future values into account. The basic principles behind green buildings could be summed up with the following: resource efficiency, energy efficiency (with greenhouse gas emissions reduction), pollution prevention (including indoor air quality and noise pollution), harmonization with the environment, and integrated systems approach. These would be applied in practice by the implementation of green strategies in the design, construction and operations phases of the life of a building. These strategies are divided under five broad categories as defined by Thomas A. Fisher, (AIA)[3]:

- Healthful Interior Environment
- Energy Efficiency
- Ecologically Benign Materials
- Environmental Form (Climatic Architecture)
- Good Design

Furthermore, green buildings must take all these factors into consideration in a holistic and integrated approach. It is a non-linear, circular and multi-dimensional approach.

With a growing awareness for the need of green buildings, researchers worldwide are investing a large amount of effort to develop green strategies and put the foundations for an environmentally sound building technology. However, the maturity of research in the field of sustainable architecture of the last decade was not matched by an even implementation of green building practices around the world. If Europe and Japan, maintained a high interest in a greener future, such strategies are still very timidly implemented in the United States. Some would attribute this to the economic structure of the U.S. while other would blame it on the Government's energy policy. Whatever the reason is, it is imperative that drastic measures should be taken to promote green buildings especially that the U.S. are the lager emitter of Greenhouse Gases (GHG) in the world.

Promoting Green Buildings

The main theme of this thesis will be the promotion of green buildings in the United States. For that purpose, it will tackle the subject from its economical side, trying to create incentives for developers and investors to turn to green development, a trend perceived to be expensive and non-profitable. In fact, selling the tree-hugger slogan would not work in an economy based on competition and maximizing return and profit. It is only through the creation of an awareness of the economic benefits of green development that a rush towards sustainability is possible.

It goes without saying that green buildings would provide a lot of social benefits under the form of better environmental quality and less resource dependability.

However, the decision is most of the time in the hands of the private developers, who would only strive for their personal benefit, instead of that of the collectivity. However, there are many mechanisms, with which incentives could be created. These incentives fall under three categories:

- Public Awareness
- Government Incentives
- Economic Sense

"The market demand grows with awareness, and having projects that can be pointed to as examples are necessary for that educational campaign."

Chris Leary,
Vice President, Stubbins Associates

Creating a public awareness is crucial in promoting green buildings. It consists of educating the public opinion about the impact of what we build on the environment, as well as the cost of not doing anything about it. Although it takes a lot of time to generate, public awareness would ultimately make consumers demand green buildings and even pay a premium for it. This would certainly steer the construction industry towards sustainable development. However, educating consumers is very difficult and takes time especially that most people are only faced with such choices once or twice in their life-time. In other terms, if public awareness is a must in promoting green buildings, it is surely not the quickest and should not be the only way to do so.

A major player in promoting green buildings is the Government, both at the Federal and State levels. In fact, through Government sponsored incentive programs, green buildings could be proven cost efficient and rentable. In respect to the Government, funding green programs makes sense on the long run. Besides the obvious social benefits, the widespread of green buildings will help lower the cost of environmental remediation for problems such as global warming, ozone depletion and pollution (nuclear and toxic waste). However, the Government's involvement in the promotion of green buildings can also have an adverse effect. Many studies are proving that green buildings in themselves are cost efficient and make sense economically. Federal and State incentives might suggest the contrary, hinting that green buildings are expensive, and are only possible through Government sponsoring. In both cases, Government sponsored incentives are useful, but should be carefully designed and implemented.

Perhaps the most effective way of promoting green buildings, is to prove to developers that green development makes sense economically. For this purpose, many research programs and independent studies tackled the subject over the last decade. Some found interesting positive results while others were negative and related the outcome to the context of the United States. However, most of the studies pointed out a high level of uncertainty when dealing with green strategies benefits, especially in terms of health and occupant performance. For this reason, the need of a third party to certify, even guarantee the performance of a green building is being established. A good and recent example is the U.S. Green Building Council's LEED™ Rating System. In fact, if green strategies have a positive economic impact on building projects, and these results are backed up by credible studies and independent party guarantees, we should witness in the next decade, a rush towards green development.

Subsequently, the academic community involved in green building research and development should stress on the economic aspect, trying to provide proofs of cost-efficiency of green strategies. Moreover, it should strive to provide processes and mechanisms to promote green buildings. This thesis constitutes a modest input to this field, trying to analyze the different approaches to advertising green development.

Precedents

Numerous studies, theses, and research programs already approached the subject from an economic standpoint. Most of these studies also revolve around the developer, considered as the prime decision-maker in achieving a proliferation of green buildings. Some of these studies are sponsored and financed by the U.S. Government through agencies like the U.S. Environmental Protection Agency (US EPA) and the National Center for Environmental Economics (NCEE). But most of them are funded by the private sector through universities and educational institutions as well as non-for-profit consulting and research organizations such as the Rocky Mountain Institute in Colorado.

At the Massachusetts Institute of Technology (MIT), William Browning[4], in his thesis presented in 1991, tried to analyze the impact of green strategies on the overall budget of a construction project. At the time, the general belief was that green buildings are much more expensive to build than standard buildings. He tried to challenge that assumption by studying three community development projects incorporating green measures such as wetlands, natural landscaping, water and energy efficiency strategies, and ecologically sound building materials.

Christopher Trevisani (1998)[5], also from MIT, adopted a different approach, trying to associate environmental technology with increases in a development's asset value. He argues that green strategies such as energy and water efficiency, would increase the Net Operating Income (NOI) of a development. By capitalizing these increases, he was able to determine the resulting asset value. His study was based on the analysis of 100 case studies from the different sectors of real estate development.

Michael Finch (MIT, 1999)[6] goes further in his economic analysis of green buildings. He stresses on the non-material benefits of green strategies such as productivity improvement and reduction in negative health symptoms such as the Sick-Building-Syndrome. However, his approach leans toward discussing developmental issues instead of building-related issues, while also being more qualitative than quantitative.

Rocelyn Dee (MIT, 2002)[7], on the other hand, had a more technical approach to the subject. She achieved a detailed financial analysis of energy-efficient façade systems in the framework of commercial office development. The backbone of her approach was a comparative analysis of two case studies, one of them incorporating such a system. Energy simulations determined the amount of savings in each case. The economical performances of both projects were compared, and amazingly, the proposed façade systems were found to be cost inefficient. In fact, these systems widely used in Europe and Japan, were practically inapplicable in the U.S. market due to low energy prices.

Many studies on the subject were also performed by the Rocky Mountain Institute (RMI), Snowmass, Colorado. Perhaps the one that relates the most to the approach taken by this thesis is a study by William Browning and Joseph Romm (1994)[8]. For this paper, the authors conducted a thorough analysis of six case studies, associating specific system upgrades to productivity increases. The cost of the upgrades and the savings due to better health and performance of occupants were compared to estimate the initial capital cost recovery period.

Another valuable information resource is a project sponsored by the National Science and Technology Council (NSTC)[9]: The Indoor Health and Productivity Project (IHP). The IHP project aims to develop an understanding of the relationships between the physical attributes of the workplace, e.g. thermal, lighting, ventilation, and air quality, and the health and productivity of occupants. This project emphasizes on communicating key research findings to policy makers, designers, facility managers, construction and energy services companies, and most of all, developers and investors. The IHP project has a steering committee that selects, reviews, and analyzes published papers on the topic and communicates a summary of findings along with its opinion of each paper.

The Approach

Among the previous studies that tackled the subject of green building economics, some yielded positive results, while others proved green strategies cost-inefficient. The negative results were mostly blamed on the economical context of the United States. It seems that a good understanding of the latter is a must when analyzing the feasibility of green buildings in the U.S. market. Consequently, this thesis will approach the subject from this corner. It will then analyze the two conventional macro and micro scale approaches to promote green development.

The macro-scale approach tackles issues of policies and incentives at the level of the Federal and State Governments. It weighs the impact of green buildings on the environment at the global level, as well as their implications on the U.S. economy, and the budget of the Federal Government. The widespread of green buildings would lower the Government's annual budget, resulting in lower taxes and hence, providing an incentive for consumers and developers.

The micro-scale approach will evaluate the impact of green strategies on the project's finances. By analyzing these strategies as separate investments and as integrated systems as well, we should be able to determine their impact on the project's economical performance. This part will show that the high level of uncertainty in quantifying health and productivity benefits in real monetary value is the main problem to be addressed in order to promote green buildings. Together, both approaches will define the problem and main theme of this thesis: How to quantify accurately and reliably the intangible benefits, like health and productivity, of certain green strategies.

The second and larger part of this thesis will be answering this central question. In fact, productivity benefits are of such amplitude that they could pay for the entire construction costs in a brief period of time. Quantifying them and being able to guarantee the result will definitely tip the balance towards green development creating the next revolution in the construction industry.

This part begins with a thorough literature review, analyzing published papers associating physical attributes of buildings with accurate measures of health symptoms and productivity. The results will then be summarized and organized under the guidelines for a certification system adapted to indoor environmental quality and its effect on human health and performance. The last section will apply the findings on a case study comparing a regular building to one incorporating green strategies. The comparison is done from the standpoint of the developer, evaluating the results of each case.

Finally, this thesis will conclude by providing a summary of findings and pointing out possible future research opportunities. It should also be said that this work does not aim to provide a full and comprehensive solution to the problem. It is just a humble input to this wide research field that aims to capture and organize what was already said and propose the broad guidelines for a possible solution.

Chapter Discussions

Chapter (I) introduces generalities about the geographical, economical, and socio-political contexts of the United States. Chapter (II) will discuss the macro-scale approach to the problem of providing incentives for green buildings. Chapter (III) will analyze the micro-scale approach studying specific green strategies and their impact on the evaluation of a project. Together Chapters (II) and (III) will define the problem and main theme of this thesis. Chapter (IV) will organize the reviewed papers and studies under broad categories of building systems and green strategies. Chapter (V) will develop a certification system adapted to indoor environmental quality, which in turn will be tested in a comparative case study presented in Chapter (VI). Finally, a brief conclusion will summarize the whole thesis and present possible future research opportunities.

Notes

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CHAPTER I
CONTEXT AND CONDITIONS

Sustainable development is the challenge of meeting growing human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future life and development. This concept recognizes that meeting long-term human needs will be impossible unless we also conserve the earth's natural physical, chemical, and biological systems.[1]

According to this definition of sustainability, green buildings are closely linked to their context. The basics of green development are very much sensitive to their situation, be it geographical, economical or socio-political. In other terms, the realities of green buildings are very much different between various parts of the world, and even between different regions and states in the US. It is crucial to define and acknowledge the factors that affect our perception of green buildings to be able to understand the economics of sustainability.

Context of the United States

Geographical Context

First and most obviously, green buildings are direct products of an environmentally conscious design approach. In order to create buildings with a lesser impact on the environment, we have to be responsive to climate and topography. The first example that comes to mind is the reduction in energy consumption of buildings. This can be translated by the use of passive solar heating for cold climate regions or the use of natural ventilation for hotter regions. The two approaches are similar in concept, and are both based on two principles: comfort and health of occupant and energy saving. However, the resulting buildings will be very different physically. The list of factors goes on and on to include climatic factors such as wind, sunlight, and temperature, and other physical factors such as topography, altitude, availability of resources, urban/rural setting, and so on.

Analyzing the situation of the United States in this respect, we find a wide range of settings that would require substantially different approaches to green building design. In contrast with small European countries like Iceland or Denmark, where the geography and climate are very much constant all over the country, the perception of green design in the United States is much more general. In some states, the major concern is heating and dealing with freezing conditions in winter, such as the case of New England and other Northern states, while, in the South and West, the major concern is cooling and natural ventilation. The same applies for water conservation in Nevada and Arizona, and the protection of wetlands in Florida and New Hampshire. In fact, the geographical situation of the US offers all the possible settings; hot, cold, humid, dry, mountains, plains, deserts, forests, lakes and seacoast. This complicates the adoption of a nationwide understanding of what issues should be addressed urgently by green buildings.

However, from another side, much more could be done in this respect on the state level. In fact, the variability in the geographical context in each state is much more limited. The state government can be much more effective in promoting an awareness of green building benefits and an understanding of green strategies. An example of that is a program launched by the Government of the State of Pennsylvania: the *Governor's Green Government Council* (GGGC). The GGGC was created in 1998 to help the state government adopt environmentally friendly operation policies and practices. The council works cooperatively across agency jurisdictions, putting sustainable practices into state government's planning, policymaking, and regulatory operations and striving for continuous improvement in environmental performance. Agencies will focus on planning and operations, particularly energy efficiency in areas such as building design and management, procurement of environmentally friendly commodities and services, vehicle purchasing and recycling.[2] One of the programs, *Building Green in Pennsylvania*, promoted the construction of a pilot project, Cambria Office Building, Ebensburg, PA; a 36,000 Sq.ft. commercial office building that incorporates all the issues a green building should deal with in Pennsylvania.

Understanding that green strategies are more of guidelines tailored for specific regions, rather than a set of standards to follow, is the focal issue when looking at the geographical context of the United States. Even though some green strategies apply nationwide and can be enforced by federal action, most of them should be tackled on the state and city levels. Having said this, we move on to the second most important dimension of sustainability: economics.

Economical Context

The second most important constraint is the economical context. In fact, if we refer to previous definitions of sustainable development, we find that the economical dimension is a crucial factor. Indeed, green buildings try to lessen their impact on the environment, while remaining cost effective, and possibly, perform better than conventional buildings. Be it on the level of energy efficiency and consumption, or on the level of innovative building materials or technologies, green buildings impact economies on the global scale. Furthermore, the feasibility of different green strategies is affected by the economical realities of its environment.

For example, Rocelyn Dee (2002)[3], through a comparative study of Double Skin Facades in U.S. commercial development, proved that this system, widely used in Europe is not feasible economically in the United States. Indeed, due to low energy prices in the US compared to Europe, and the lack of federal incentives for developers to build green, the proposed system should be ten times cheaper for it to become cost effective. Indeed, if we look at domestic energy prices in the U.S., 8.67 cents per kWh of residential electricity, it is relatively very cheap compared to 21 cents per kWh in Japan, and 12 cents per kWh as an average for the European Union. The same applies for residential natural gas prices of $7.50 per thousand cubic feet in the U.S. versus $28 in Japan and $11 as an average in the EU[4].

From another side, it is to note that the benefits of green development are sometimes only perceived when analyzed on a large scale. Environmental benefits such as reduction in CO_2 emissions do not affect building owners directly. It is only when analyzed in the government's perspective, that those savings can be quantified. Another example relates to health benefits from improvements in Indoor Air Quality (IAQ). According to William Fisk (1999)[5], in the US alone, green buildings may account for potential annual savings from reduced respiratory disease, allergies and asthma, and reduced symptoms from sick building syndrome (SBS), up to $57 billion. These benefits, not directly gained by the developer, would help lower the national health care bill, thus lowering taxes on property and income.

This leads us to look closer at the US economy, and especially, at the size of resources consumed by buildings and the construction industry. In the US, buildings use one third of the total energy (in excess of 36%) and two-thirds of the total electricity consumption (65.2%)[6], as well as one-eighth of potable water (12%)[7]. In addition, buildings use annually 40 percent (3 billion tons) of raw materials and 25 percent of all wood harvested[8]. With 98.520 quadrillion Btus of total energy consumption, these figures give us a sense of the huge amounts of money involved in the construction industry as well as the great impact it has on the economy. Slight changes in the way we conceive and design buildings will instigate substantial impacts on the economy. This is why it is crucial to analyze the impact of green development at a large scale, to see what kind of measures should be taken by the federal or state governments both for social and economic benefits. This issue is the subject of the next chapter; it will evaluate the impact of green development on the economy and will analyze options for possible strategies and solutions from the Government.

Socio-Political Context

The socio-political context becomes a by-product of the last two constraints. Whenever a balance between social benefits and economical considerations is created, a political struggle is involved. In fact, environmental concerns have always witnessed a clash between activists concerned about the future generations and political parties trying to secure what is best economically on the short run. The same is true with green buildings; many obvious changes in policy can affect positively the implementation of green strategies, however, they are counter balanced by other political and economical concerns.

For example, changing the U.S. policy regarding energy prices could create more incentives to be energy efficient. The Energy Information administration (EIA) estimated that electricity prices should be raised by 86 percent and gas prices by 53 percent to induce consumers and businesses to use less energy and lower GHG emissions in order to meet the goals set forth by the Kyoto Protocol. This will subsequently induce the development of green strategies and green buildings. However, the presence of a petroleum cartel, connected with highly placed government officials, is working against that, trying to maximize the use of energy, and thus returning high profits to a small minority in power on the expense of the environment.

Analyzing the context of the United States in light of the socio-political condition of the country is crucial. It will allow us to see how far we can count on federal intervention to create incentives for developers to turn to green development.

In order to analyze the U.S. political context framing issues of sustainability and green buildings, we should look closer at the U.S. government policies regarding those issues. Most importantly, dealing with energy efficiency, we should understand the current U.S. Energy Policy especially that it is coming as a response to the California energy crisis in 2000-2001, and the expectations that the blackouts, soaring wholesale electricity prices, spiking gasoline prices and shortages of natural gas might spread nationwide. President George W. Bush's National Energy Plan, released in May 2001, emphasized the expansion of energy supplies primarily from fossil fuels and nuclear power. This plan involves the construction of 1,300-1,900 new power plants, 38,000 miles of gas pipelines and 255,000 miles of power lines, as well as oil drilling in the Arctic National Wildlife refuge[9]; these options, designed by self-interested 'Washington players', will adversely impact the environment and will inhibit the development of the construction industry towards energy efficiency and green buildings.

There is no doubt that the current U.S. Energy Policy is sympathetic to the interests of energy companies. Bush has delighted oil and gas companies, and infuriated environmentalists, with repeated calls to allow drilling in the Arctic National Wildlife Refuge and on other federal lands. He did a big favor for major electricity wholesalers by keeping the federal government largely out of the California energy crisis, which has produced major profits for energy companies including Dynegy Inc., Enron Corp. and Reliant Energy Inc., all of which are based in Bush's home state of Texas. He sided with the coal mining and electricity industries when he reversed a campaign pledge to reduce carbon dioxide emissions and announced the United States' withdrawal from the Kyoto Protocol, an international treaty aimed at combating global warming[10]. This situation, largely unfavorable for green building lobbyists is expected to continue through the Bush and Republican periods. Bush's allegiance to the energy sector is based on more than past experience or even a pro-business ideology. Energy interests gave more than $48.3 million (75 percent of their total contributions) to Republican candidates and party committees in 1999-2000, including $2.9 million to Bush. By contrast, Al Gore received a relatively paltry $325,000. The oil and gas industry strongly favored Bush over Gore, giving the Texas governor $13 for every $1 they gave to the vice president. Electric utilities supported Bush over Gore by a factor of nearly 7 to 1, as did the coal industry[11].

Although this situation seems desperate and inhibits any move towards energy efficiency in buildings, many organisms in the U.S. are still battling to protect the environment and implement more sustainable ways of providing our energy needs. In May 2001, the Natural Resources Defense Council (NRDC) published a report[12], which presents an extensive analysis of the Bush administration energy plan that was released on May 17. NRDC's energy experts found it heavily biased in favor of the most polluting fossil fuels -- coal and oil -- at the expense of the environment and public health. Furthermore, the plan would have no impact on energy prices, and no practical effect on U.S. dependence on foreign sources of oil. The report also demonstrates that the United States can meet its energy needs without undermining environmental safeguards or ruining the last remaining pristine wilderness areas in the country[13]. From another side, the Rocky Mountain Institute (RMI), partnering with the Consensus Building Institute (CBI), created the National Energy Policy Initiative (NEP Initiative), whose goal is to set guidelines to help reframe the U.S. Energy Policy. The NEP Initiative rejects the conventional view that cleaner and safer energy services will cost more: they set a course of action for an energy system that is, simultaneously, more secure, more affordable, and much less environmentally damaging. It offers policies in five areas: transportation, electricity, climate change, energy security, and energy research, development and procurement[14].

In conclusion, the development of green strategies in the United States is closely related to the context they are brought into. Perhaps the one that affects it the most is the socio-political situation. Many organisms are trying to promote cleaner energy and better environment in a milieu framed by a carbon-dominated energy system. However, the situation will not easily change unless the government realizes the economical impacts of a poor environment, ranging from an inflated health bill to costly GHG remediation and severe weather disasters from global warming. In order to understand the scale of the impact of the implementation of green buildings on the economy, we have to evaluate the resources they involve, as well as the bottom line savings. From one side, green buildings involve some additional costs, but from the other, they will save on the annual energy bill, the defense bill due to the dependence on foreign sources of oil, the health bill because of better indoor air quality and the environment and GHG remediation bill. These savings will be reflected by a decrease in taxes on income and property. The next chapter will evaluate those impacts and the resulting savings while comparing them to the annual U.S. Federal Budget.

The next sections of this chapter will expand on the context of the United States in relation to green buildings by presenting the existing grant and incentive programs available to the developer and home-owner. It will also describe other marketing tools that could be used to promote green buildings, such as green building rating systems and building quality labels.

Existing Grant and Incentive Programs

Federal Programs

Federal 5-year Depreciation Schedule for Solar Energy Property

This program, proposed by the Federal Government, offers a 5-year accelerated depreciation for all solar energy equipment. Any commercial entity who invests in or purchases qualified solar energy equipment benefits from an accelerated depreciation schedule. The qualified solar energy equipment includes all machines that use solar energy to generate electricity, storage devices, power conditioning equipment, and transfer equipment. It excludes equipment that uses both solar and non-solar sources of energy with non-solar usage exceeding 25%. This program uses the following Tax Deduction Schedule:

Deduction Schedule	
Year 1	20.00%
Year 2	32.00%
Year 3	19.20%
Year 4	11.52%
Year 5	11.52%
Year 6	5.76%

It is to note that taxpayers who take advantage of the Federal Commercial Investment Tax Credit for Solar Equipment should use 95 percent of the original value of the equipment as the basis for depreciation. If not, they can use the full 100 percent[15].

Federal Renewable Energy Production Tax Credit

This incentive program was established by the Energy Policy Act (EPA) for generators of electricity using biomass and wind energy resources. All private entities subject to taxation including homeowners are eligible to receive a Production Tax Credit (PTC) for electricity sold to unrelated parties. The PTC is set at 1.5¢ per kWh (Kilowatt-hour), and is adjusted annually for inflation. As of November 1999, the adjusted rate was 1.7¢ per kWh. The PTC credit applies to electricity produced from qualified sources during a ten-year period after the facility is placed into service[16,17].

U.S. Department of Energy (DOE) Renewable Energy Research and Development Grant

These project grants are used to conduct balanced research and development efforts in renewable energy technologies. Assistance may be used to develop and transfer renewable energy technologies to the scientific and industrial communities, State, and local governments. Profit as well as non-profit organizations, intrastate, interstate and local agencies and universities are all eligible to apply for this grant. The amount of money available varies between $10,000 and $100,000, depending on the research proposal[18].

Many other Federal programs are also intended to provide incentives to go into green strategies, such as: Federal Commercial Investment Tax Credit for Solar Energy Property; U.S. Department of Commerce (DOC) Small Business Innovation Research Program; U.S. DOE Inventions and Innovation Program; U.S. DOE Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)

Programs; U.S. Environmental Protection Agency (EPA) Small Business Innovation Research Program. Others are provided by State governments or Private parties.

State Programs

Illinois Department of Commerce and Community Affairs (DCCA) Institutional Conservation Program

This program is designed to assist public institutions in making an effort to conserve energy. It provides financial and technical assistance to perform a comprehensive study to identify energy conservation opportunities. Financial assistance is also available for specific conservation measures that are subsequently installed. Schools, colleges, universities and non-for-profit hospitals in the State of Illinois are eligible to benefit from this program. The exact amount of grant funding provided is based on the square footage of each building but does not exceed $40,000 per building and $80,000 per institution. Grants require a matching grantee investment of 50 percent[19].

Indiana Department of Commerce Renewable Energy Demonstration Project Grants

This program makes small-scale grants for projects that demonstrate applications of renewable energy technologies. Funding is available for all commercial, public and non-profit entities. To be eligible, a project must demonstrate either a novel technology or a novel application of an available technology (research projects are not eligible). The project is also required to have a high degree of public visibility to serve as a demonstration for future projects[20].

Michigan Department of Consumer & Industry Services (CIS) Small Business Energy Analysis

The Energy Division is offering free energy analyses of small commercial buildings. This is intended as a promotion for energy efficiency that would help save small businesses hundreds and even thousands of dollars each year. Businesses with 5 to 50 employees with lighting and HVAC equipment older than five years qualify for this program. After a site visit, a detailed report will identify where the business' energy dollars are spent and what are the potential savings and energy efficiency strategies[21].

Private Initiative Programs

The Home Depot Environment Grants

The Home Depot awards grants to support a variety of environmentally focused non-profit organizations throughout the communities it serves in the United States and abroad. The grants program focuses on the following areas: sustainable and green building practices; forestry and ecology; clean up and recycling; lead poisoning prevention; and consumer education[22].

The McKnight Foundation Environment Program

The program has the goals of maintaining and restoring a healthy sustainable environment in the Mississippi River basin, as well as encouraging energy conservation and the use of alternative energy in Minnesota. To be eligible for a grant, organizations must be qualified by the IRS as tax-exempt non-for-profit. Grants are available in the ten states bordering or encompassing the Mississippi River. Grants, varying between $40,000 and $750,000, will be used for project support to develop or implement special programs closely related to the Foundation's priorities[23].

At this stage, it would also be useful to identify certain procedures that would define green buildings. These rating systems work mainly as an educational tool for building owners that tells them how environment conscious their property is. Two existing rating systems are particularly famous: The U.S. Green Building Council's LEED™ and the EPA's Energy Star Label. This next section will present the two systems with suggestions of what could be done as a future step towards a sustainable construction industry.

Existing Rating Systems and Institutions

U.S. Green Building Council: Leadership in Energy and Environmental Design (LEED™)

LEED™ is a program developed and maintained by the U.S. Green Building Council. It is a voluntary consensus-based, market-driven rating system based on existing and proven technology. It evaluates the environmental performance of a building over its life cycle, providing a standard for what constitutes a "green building". It is designed for rating all kinds of buildings. It is a self-assessing, feature-oriented system; credits are earned for satisfying a set of criteria. The resulting total of earned credits will determine the level of green building certification awarded[24].

The major advantage of the LEED™ rating system is that it is trying to establish a definitive and comprehensive standard to what constitutes a green building. The simplicity in operation made the LEED™ rating system very popular and widespread. With more than 50 certified projects and 400 in the pipeline, as well as thousands of LEED™ accredited professionals, LEED™ is the most recognized green building rating system in the U.S. today. However, a major drawback is that LEED™ tends to be educational and informative in nature, without taking a step forward in promoting the certified projects as projects that make more sense economically. It doesn't provide any kind of guarantees that the certified buildings will perform better economically, or that the certification will result in a higher asset value. LEED™ becomes merely a marketing tool for the developer to use and promote his development as healthier, safer, and cheaper to maintain. How to develop a rating system that makes this additional step will be the main theme in the chapters to follow.

U.S. Environmental Protection Agency: Energy Star Label for Buildings

EPA's Energy Star Label for Buildings is a partnership between the U.S. Department of Energy, the U.S. Environmental Protection Agency and building owners and managers. The Energy Star benchmarking compares the energy performance of a building to that of similar buildings throughout the United States. The buildings that rank among the top 25% nationwide in terms of energy efficiency as well as health and productivity, qualify to receive the Energy Star Label for Buildings. However, just like the LEED™ rating system, it works just as a marketing tool without providing any kind of guarantees whatsoever. However, it is to note that in most cases, having the Energy Star Label for Buildings did increase the asset value.

In conclusion, all these programs are precious tools to promote the implementation of environment conscious development and green strategies. However, they are scattered, not well consolidated and often, if taken alone, do not represent an incentive big enough for a developer to think seriously of green strategies. The results are clear, the United States rank poorly, compared to European and Asian counterparts, in respect of the spread of sustainability. This is especially alarming, knowing that the U.S. is one of the biggest polluters in the Globe. The chapters to follow will try to present possible solutions that would help promote a change in the construction industry.

Notes

[1] Sustainable development definition from the Civil Engineering Foundation, Washington, D.C.
[2] The Governor's Green Government Council Homepage, http://www.gggc.state.pa.us/about/default.html
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[9] Burns, Cameron M., *Time for a Switch: RMI Helps Reframe U.S. Energy Policy*, Rocky Mountain Institute: 2002 Spring Newsletter
[10] The Center for Responsive Politics, *President Bush's First 100 Days: A Look at How the Special Interests Have Fared*, http://www.opensecrets.org/bush/100days/energy.asp
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[14] Burns C, *Time for a Switch: RMI Helps Reframe U.S. Energy Policy*, Rocky Mountain Institute: 2002 Spring Newsletter
[15] Contact: Solar Energy Industries Association, 1616 H Street, NW 8th Floor, Washington, DC 20006, www.eren.doe.gov/consumerinfo/refbriefs/la7.html
[16] Contact: Same as Above
[17] Rincones D, *Green Building Resources Guide*, U.S. EPA, Region 5, December 2000
[18] Ibid
[19] Contact: Illinois DCCA, Bureau of Energy and Recycling, Institutional Conservation Program, 620 East Adams Street, Springfield, Illinois 62701,
[20] Indiana Department of Commerce, Energy Policy Division, One North Capitol, #700, Indianapolis, IN 46204-2248, www.dcs.ncsu.edu/solar/dsire/incentive.cfm?Incentive_Code=IN04F&Back=tsrch&state=IN&type=Grant
[21] Michigan CIS, Energy Office, P.O. Box 30221, Lansing, MI 48909, www.cis.state.mi.us/opla/erd/audits.htm
[22] Contact: Director, Community Affairs, The Home Depot, 2455 Paces Ferry Road, Atlanta, Georgia 30339, www.homedepot.com
[23] The McKnight Foundation, 600 TCF Tower, 121 South Eighth Street, Minneapolis, MN 55402, www.mcknight.org
[24] Contact: U.S. Green Building Council, 1015 18th Street, NW, Suite 805, Washington, DC 20036, www.usgbc.org

CHAPTER II
IMPACT OF GREEN BUILDINGS ON THE ECONOMY

If green buildings were to become widespread, they would impact the economy in a substantial way. In fact, due to huge resources savings, such as energy, materials, waste, and labor, green buildings would probably provoke a restructuring of the present U.S. economy. However, the results are far too complex to study and analyze. The economy could be affected by so many factors, that the association of the impact of green buildings and economy ups and downs is impossible to establish. It goes also without saying that any positive impact on the economy by green buildings will result in lower taxes and better value for money for the consumers.

However, another way to approach this issue is relating the impact of green buildings to the U.S. Federal Budget. For instance, if the size of energy consumption decreases by 20 percent, we could assume that the budget of the U.S. Department of Energy would also be decreased by the same proportion. This is of course just an assumption based on estimations; however, it would give an idea of the direct savings the tax payers would enjoy. This could also be applied on many others U.S. departments. The total savings on the budget would then be reflected by lower income and property taxes.

This approach would represent the perspective of the Government in promoting green development. In other terms, looking at the problem at the macro-scale, the Government could implement incentive programs for developers, using Federal funds, to save on the annual Federal expenditures. This would also be followed by huge social benefits. This chapter will evaluate the potential savings on the budgets of the U.S. Departments of Energy, Health, Medicare, Environment, and Defense. It will conclude on the ability of the Government to promote green buildings.

Energy Consumption

Buildings fundamentally impact the energy sector in the United States. As we have already seen, they are responsible for more than 36% of primary energy and 65.2% of electricity consumption. Any reduction in energy consumption in buildings will be reflected in the annual U.S. Federal Budget for the Department of Energy (DOE). Based on previous research and case studies, green strategies are responsible for energy savings between 10% and 90%. However, for the sake of the argument, let us assume savings in the order of 50%[1]. This would reduce the gross primary energy consumption by 18% and electricity consumption by at least 30%[2]. In other terms, the DOE would be dealing with a smaller quantity of energy nationwide, along with a slower growth in supply and demand.

Based on the previous estimations, and including factors such as the time required for green buildings to become widespread, we can safely assume that green buildings are able to reduce the size of the energy sector by 20%. This will directly affect taxpayers by a 20% reduction in the DOE's annual budget. In 2002, the budget for the DOE was in the order of $17.06 billion[3], with an expected growth of 2.5% per year. This reduction will be equal to $3.41 billion per year. Moreover, a restructuring of the DOE's annual budget can also help steering towards green buildings. The DOE spends $1,058 million for energy programs for the management and remediation of uranium facilities, fossil energy research and environmental management. Meantime, only $795 million are spent each year for energy conservation and incentive programs. A rebalancing of the internal DOE budget should also be very effective in promoting green buildings.

From another perspective, with 39% of total U.S. primary energy use coming from oil and half of it imported, energy security and oil dependence become a very important factor. However, the complexity of the political and military situation between the U.S. and oil exporting Gulf countries makes it very difficult to evaluate the indirect savings in the U.S. Department of Defense Budget. However, with the latter being in the order of $309.4 billion per year[4], a 5 percent reduction would be equal to the entire actual U.S. Department of Energy Budget. This is why rethinking the U.S. energy dependence and energy system is crucial. Green Buildings are not the only solution, but they contribute a great deal in saving taxpayers' money and providing a more stable and environmentally sound energy system.

Health and Medicare Bills

There is strong evidence that certain characteristics of buildings and especially those dealing with indoor environments influence the health of building users. The resulting health problems are summed up by respiratory disease, allergy and asthma symptoms, and symptoms of sick building syndrome as well as worker performance and productivity. Green buildings promote better indoor air quality (IAQ) and thus reduce the incidence of those health problems. According to a study done in 1999 by William J. Fisk, staff scientist and head of the Indoor Environment Department at the Lawrence Berkeley National Laboratory, the potential annual savings on the Health and Medicare bills are substantial. "For the U.S., we estimate potential annual savings and productivity gains in 1996 dollars of $6 to $14 billion from reduced respiratory disease; $2 to $4 billion from reduced allergies and asthma, $15 to $40 billion from reduced symptoms of sick building syndrome, and $20 to $200 billion from direct improvements in worker performance that are unrelated to health"[5]. Moreover, Fisk evaluates that the potential benefits from those improvements to indoor environments exceed costs by factors of 9 and 14.

Taking the middle range of Fisk's estimates, we get total savings of $48 billion in 2002 dollars. Comparing this to a 2002 budget of $226 billion for Medicare and $108 billion for the U.S. Department of Health[6], we find that the savings are substantial (around 15%). These savings will benefit taxpayers directly.

Impact on the Environment

In the U.S., buildings are responsible for 30% of greenhouse gas emissions (GHG)[7]. In 1990, says the U.S. Energy Information Administration (EIA), global emissions of carbon dioxide, the main greenhouse gas, totaled 5.8 billion tons of "carbon equivalent". The EIA predicts that if nothing is done, emissions will rise 34 percent to 7.8 billion tons by 2010. These emissions contribute to global climate change and acid rain, which are the causes of major human and agricultural disasters. It is very difficult to evaluate the amplitude of the damage directly due to GHG emissions and global warming, because weather caused disasters existed well before the industrial ages. However, scientists expect that the resulting climate changes will be catastrophic in the next one hundred years and some even go as far as predicting the extinction of the human race. From another side, it is also very difficult to evaluate any savings on the annual U.S. budget if green buildings were to become prevalent because any amount saved from the remediation of GHG emissions could be re-invested in other environmental issues. However, green buildings contribute to a much wider plan that would eventually lead to a cleaner and safer planet.

On a larger scale, the U.S. is the biggest emitter of GHGs in the world. After its withdrawal from the Kyoto Protocol, an international treaty intended to control GHG emissions, the whole world was waiting for the U.S. Energy Plan addressing climate change. In his climate initiative, the problem was that President George W. Bush addressed the issue by redefining the method of measuring GHG emissions. GHG intensity, a ratio of GHG emissions per GDP, has been decreasing since the early 1990s by precisely the same amount as the president has proposed for the plan's 10-year target. "Greenhouse gas emissions in the United States grew at an average annual rate of about 1.2 percent since 1990, much slower than real GDP, which grew at 3.5 percent," writes economics professor Frederic C. Menz in the Norwegian Journal on climate change *Cicerone*. GHG intensity, then, has in fact decreased by 15% since 1990. Thus, the president's initiative to achieve a 1.8% annual reduction in greenhouse gas emissions over the next ten years corresponds to what was happening since 1990 without the policy[8]. This resulted in a worldwide criticism of the Bush administration and the U.S. in this respect.

It is hard to know why the U.S. Policy regarding climate change and environmental issues is still very slow compared to other European industrialized countries. More so, it is even harder to figure out how much it costs the U.S. Government annually or its implications on the U.S. economy. But one thing is sure, is that green buildings are a step towards a better environment while protecting economical prosperity. Their impact can hardly be put in currency units, but it is surely a substantial amount.

Large Scale Economical Analysis of Green Buildings

As we have already seen, approaching the economical aspect of green buildings can be done on two levels. Either the direct impact they have on the owner or users of the building, as well as the project finance, or the impact they have on the economy and the government's budget, which would be reflected on taxpayers by lower taxes and a better environment.

The first, the micro-scale analysis, is the subject of the chapter to follow. However, at the macro-scale, the numbers have already been presented: an estimated amount of $60 to $80 billion could be saved annually on the United States Government Budget in 2002 dollars, if green buildings were to become widespread. This number is substantial compared to the total budget of $1,961 billion in 2002 (about 3.5%). However, 3.5 percent savings on taxes is not an incentive big enough for developers to venture into green development, especially that these savings won't become effective unless all new developments turn green and for a long period of time. Unless these numbers instigate a bigger interest in government officials to take green buildings more seriously, and propose more lucrative incentives for developers, we cannot consider these savings as valid incentives to steer the construction industry into green development. For this reason, the chapters to follow will investigate ways of creating incentives for building owners and developers by tackling the issues of cost versus reward at the level of the project itself.

On the other hand, saying that the Government is not doing anything to promote green development would be disregarding the efforts of a few agencies and individuals working hard to provide Federal and State programs. The point here is that these programs are not enough and do not fit well under a larger plan that involves the country as a whole.

Finally, the involvement of the Government, at least at the level of policies and regulations is a must for a fuller development of green buildings. The incentive programs now offered are starting to show some results. But we should acknowledge the limitations of the Government due to internal struggles between agencies and policy makers. But one thing is sure, the promotion of green buildings cannot rely solely on the public sector. Approaching this issue at the micro-scale of the project's economics is crucial. This is the main subject of this thesis, and it will be discussed in the chapters to follow.

Notes

[1] We assume here energy savings both from energy efficiency strategies and innovative materials with less embodied energy including recycled products

[2] We assume that green buildings become the norm in the construction industry

[3] Executive Office of the President of the United States, Office of Management and Budget, *Budget of the United States Government: Fiscal Year 2002*, http://w3.access.gpo.gov/usbudget/

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[4] Ibid

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CHAPTER III
IMPACT OF GREEN STRATEGIES AT THE PROJECT LEVEL

In the previous chapter, we have investigated a macro-scale approach for dealing with the problem of promoting green development. By providing financial and tax shield incentives for developers from Federal and State Funds, and creating an awareness that green buildings will save the Government money and decrease income and property taxes, the Government would get us one step closer to a greener future. However, the presence of a tension between different agencies and parties, at different levels within the Government, with conflicting interests, makes the implementation of these drivers very difficult, lengthy and inefficient. Moreover, these incentives would only become effective when most of the building stock would have implemented green strategies.

While still recognizing that Government incentives are crucial and necessary for the promotion of green development, the remaining part of this work will focus on the green strategies and the way their benefits are reflected on the developer's finances and asset value. It will explore ways of evaluating those benefits and create a mechanism that would present the savings as a form of incentive for building owners and developers. The result would be a set of incentives that would work within the current situation of the industry and markets in the United States.

This chapter will start by evaluating the material benefits from green strategies and then put the results under the form of savings per square foot. Although these results are now familiar to professionals in the industry, it is still crucial to mention them before tackling the intangible benefits, such as health and human performance, which would tip the balance towards green development.

Investment vs. Life-Cycle Cost Savings

Viewed over a 30-year period, initial building construction costs account for two percent of the total spending. Operations and maintenance will count for six percent, while personnel cost equal 92 percent[1]. With operations and maintenance being three times more important than initial construction investment, it is crucial to look at the financial analysis of construction projects, be it the building as a whole or a green strategy in particular, as an investment versus life-cycle costs and savings.

In fact, construction projects, especially in the commercial sector are analyzed as investments with the Net Present Value Method (NPV) over the life of the project. A major investment is needed in the initial period for construction. Then smaller payments every year for operations and maintenance like energy, waste management, and water bills as well as repairs and replacement of systems. The cash flows are discounted each year (present value) using a discount rate specific to the developer, which represents the rate of return he wishes to be making on his investment. The present values are then added, which results in the NPV of the project. If the NPV is positive, then the project would be making the desired Internal Rate of Return (IRR) with an additional profit, equal to the NPV in current dollar value. However, if the NPV is negative, it means that the project is not meeting the targeted IRR. The NPV method is generally used to evaluate as well as to compare two investments.

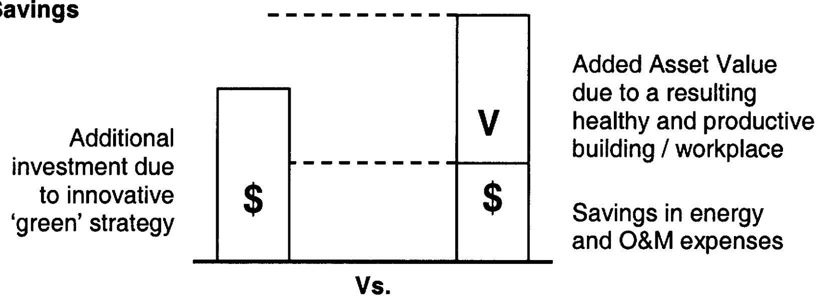
Similarly, the same method can be applied to evaluate the economical sense of a specific green strategy. If for example, a certain passive solar heating device costs an additional investment of $20,000, but saves $2,000 per year on the energy and maintenance bills, it can be analyzed by the same method, to see if it makes sense within the proposed building. The following example will illustrate this concept. Let us assume a building project that requires an initial investment of $800,000. The project life span is 30 years including one year for construction. The rent is $65,000 in the first year and increases 2% annually. The operations and maintenance costs are $8,000 per year and also increase by the same rate than the rent (2%). The discount rate is fixed at 7 percent. The 30-year NPV analysis gives a $51,800 for the base case. After adding another $20,000 to the initial investment, and subtracting $2,000 from the operations and maintenance bills for the first year, the resulting NPV would be $61,200. In other terms, the NPV for the proposed 'green' strategy alone is $9,400. In this case, the proposed technology makes sense economically. Besides the social benefits it has due to a lesser impact on the environment, this strategy carries its own financial incentive for the developer.

It is easy and straightforward to apply this kind of analysis on a specific strategy. In the example above, estimating the additional investment required for the proposed system is simple and performed before construction. The savings on the operations and maintenance bills are a bit more difficult to frame. The energy savings can be evaluated accurately using scientific methods (in this case, using energy simulation software). However, a problem arises while converting the savings in dollar figures. In fact, energy prices are not fixed, especially when looking at the problem over a 30-year period; they are constantly fluctuating, which involves uncertainty and risk in the analysis. The uncertainty even grows bigger since energy prices in the U.S. are constantly going down and the current energy policy is not predicting a reversal of this situation.

On the other hand, there are other kinds of intangible benefits imbedded in green strategies especially if these are incorporated in the design efficiently. Due to the situation and structure of the U.S. economy, the results of the economical analysis of most 'green' strategies are giving tight results. This makes the indirect benefits, like better Indoor Air Quality (IAQ), healthier buildings and more productive workplaces, crucial in tipping the balance towards green development (Figure III.1).

The next section will investigate examples of green strategies providing a representative case study with an economical analysis evaluating the direct savings. The chapters to follow will deal with the issues of intangible benefits, trying to evaluate the savings in monetary figures and setting the basis for the creation of incentives for developers.

Fig. III.1 – Investment vs. Life-Cycle Cost Savings



Energy Efficiency

Based on previous studies, around 50 percent of the energy consumption in buildings is used to provide user comfort by creating artificial indoor climate conditions through heating, cooling, ventilation, humidity control and lighting[2]. Moreover, approximately 25 percent of a typical building's operations and maintenance costs are devoted to its energy bill. According to David A. Gottfried, "estimates indicate that climate-sensitive design using available technologies could cut heating and cooling energy consumption by 60 percent and lighting energy requirements by at least 50 percent in U.S. buildings"[3].

By definition, what is meant by energy efficiency in respect to the building industry is using the Earth's energy resources more efficiently. This is done either by using less energy for the same level of comfort in buildings, or by using more energy from renewable sources, i.e. sun, wind, water, ground. Many research programs nation and worldwide are working to develop and perfect such technologies that make energy efficiency and renewable energy possible, affordable and accessible. Energy efficiency strategies include but are not limited to: better insulation through innovative techniques and materials; higher performance HVAC equipment with climate control and monitoring devices; natural ventilation through a better building systems design; efficient lighting design and better lighting equipment; better site planning and building positioning; solar and climatic design. Renewable energy applications include: passive solar heating and natural ventilation; domestic water solar heating; conversion of the sun's energy into electricity (photovoltaic systems); wind power; hydropower; biomass. The use and impact of each of those systems varies widely with regions, locations and building function. However, energy efficiency is measured relatively to similar buildings in the same location.

The following is an example of an energy retrofit project in San Diego, California. In 1995, this building renovation project for the city's Environmental Services Department proposed an extensive energy-efficiency retrofit package, projected to yield a four-year payback on investment. Using efficient mechanical systems, lighting, appliances, and computer-control measures, the building achieved energy savings of approximately 60 percent over those required under California's Title 24 Energy Code.

The annual energy savings are estimated at $66,000 for the 73,000-square-foot building, i.e. $0.90 per square foot, compared to typical energy costs in a similar building. DOE-2 energy-modeling software projected the building's total electricity consumption at approximately 8.4 kilowatt-hours per square foot, placing the project in the lowest five percent of all energy consumers among buildings in the city. Moreover, the local utility, San Diego Gas & Electric, offered incentives that covered most of the up-front costs of the energy related improvements, thereby yielding an even earlier payback than projected[4].

Energy-efficiency strategies, if well studied and integrated, will result in returns on investment higher than the rates of return on conventional investments. Projects that participated in the Green Lights program proposed by the U.S. Environmental Protection Agency (EPA) yielded annual rates of return in the order of 30 percent for lighting retrofits. If it is widely adopted, Green Lights could save over 65 million kilowatts of electricity, reducing the nation's electric bill by $16 billion annually[5]. From another side, if taken individually, some systems would not make sense economically, unless integrated in a specific context.

For example, the photovoltaic system (PV), used to convert the sun's energy into electricity, may result in un-economical results over the life of the system. In fact, the PV system requires an important initial investment, and saves money on the life of the product by producing electricity maintenance and resources free. However, discounted on the life of the equipment, PV generated electricity costs around 25 cents per kilowatt-hour, which is about two to five times the retail price paid by residents (average 8.4 cents per kilowatt-hour)[6]. Solar rebate programs, tax credit and accelerated depreciation incentives as well as net metering can help make PV supplied electricity cheaper and more affordable, but it still doesn't match today's price of utility supplied electricity. This is why PV systems are only common in projects with high exposure where developers are ready to spend the extra money for propaganda or as a marketing tool. In a few cases, like remote sites for instance, utility supplied electricity is either very expensive or simply not accessible; in this case PV systems would result in savings on the electricity bill, thus making sense economically.

Water Efficiency

Water efficiency is achieved by any strategy aimed at reducing the water consumption in buildings. This is done through storm water management and water efficient landscaping, innovative wastewater technologies and water use reduction. According to Richard Bennett[7], water-efficient appliances, behavioral changes and changes in irrigation methods can reduce consumption by 30 percent or more. Investing in such strategies can yield payback in one to three years; even higher returns can be achieved by the help of fixtures rebate and other incentive programs offered by water utilities.

A figurative case study prepared by David Gottfried[8] with the help of Water Department specialists in San Diego, Phoenix and Sacramento, gives an idea about the amplitude of the investment and resulting savings due to water efficiency strategies. For a typical 100,000-square-foot office building, a 30 percent reduction in water usage through the installation of efficiency measures will result in annual savings of $4,393.

Table III.1 - Water Efficiency in a typical 100,000 sq. ft. Office Building	
Water Usage	
Number of Building Occupants	650
Water Use per Occupant per Day	20
Total Annual Building Water Use (gallons)	3,250,000
Total Annual Building Water Use (HCF*)	4,345
Water Cost	
Water Cost per HCF	$1.44
Sewer Cost per HCF	$1.93
Total (Water + Sewer) Cost per HCF	$3.37
Total Annual Cost	$14,643
Savings	
Initial Cost of Water Efficiency Measures	$10,983
Annual Water Conservation, at 30% Reduction (HCF)	1,304
Annual Savings	$4,394
Payback Period	2.5 years
* One Hundred Cubic Feet (HCF) = 748 gallons	

In other terms, an initial investment of $10,983 would yield an annual 40 percent return on investment. In addition, these measures would result in an annual conservation of 975,000 gallons of water. In the states where water shortage is an urgent issue, this kind of conservation is highly appreciated and rewarded by many incentives programs.

Waste Management and Recycling

With three quarters of U.S. landfills reaching capacity, the cost of dumping construction-related waste is increasing dramatically. This creates a growing awareness that the quantity of materials involved in construction is huge and that solutions like recycling and adaptive reuse are strategies that are both economical and environment conscious. Materials such as gypsum, glass, carpet, aluminum, steel, brick and other disassembled building components can be either reused or recycled. Moreover, adapting and reusing the old building stock, as opposed to demolition, can achieve significant waste reduction. A good example is a 1993 building restoration project in New York. The recycling of this 100-year old eight story building saved approximately 300 tons of steel, 9,000 tons of masonry, and 560 tons of concrete. The owner of the project, the National Audubon Society, estimates the savings to be in the order of $8 million[9].

Another example that would illustrate the direct benefits of construction waste reduction and recycling strategies is the Portland Trailblazers Rose Garden Arena project in Portland, Oregon. In this 750,000-square-foot stadium built in 1995 to replace an old stadium, the contractor was able to divert from landfills most of the demolition debris including 1,300 tons of wood, 1,000 tons of metal, and 29 tons of cardboard through recycling and reuse. The recycling operation cost $19,000, but the contractor was able to save $166,000 in landfill costs and $39,000 from selling the metal and cardboard. The return on investment was huge if we compare the $19,000 investment to the $186,000 savings in addition to new material costs[10].

Furthermore, other strategies can save on the operations and maintenance bills of a building. It was estimated that a typical 20-floor building could achieve annual labor savings of $27,200 for handling recyclables with a chute system, as opposed to floor-by-floor collection. The potential annual savings from reduced hauling are $4,800. In other terms, an initial investment of $24,000 for installing a chute system would realize total annual savings of $32,000, i.e. a payback period of nine months[11].

Bottom Line

Green strategies are varied, but they all share the same goal: decreasing the negative impact our buildings have on the environment. However, they differ a lot in the way they affect other aspects of buildings, especially the economical sustainability of building projects. The different groups of green strategies considered in the previous sections, all combine direct economical benefits with the inherent social benefits of resulting in a better environmental quality. From another side, many other strategies with major impact on the environment were not presented because they do not make sense financially. They sometimes include big initial investments with no direct benefits. Providing incentives for such strategies can't be done but with the involvement of a third party promoter, namely the Government and/or other non-for-profit institutions. But this remains outside the scope of this work and should be analyzed in future studies. A third category of green strategies, while resulting in higher operations and maintenance costs as well as a substantial initial investment, will yield intangible benefits reflected in healthier buildings and more productive workplaces as well as better performing retail spaces. These strategies will be scrutinized in the next chapter.

The economical feasibility of green buildings is analyzed in a holistic approach rather than an analysis on the level of each strategy. A repertory of all the strategies implemented should be detailed. The initial investments are then compared to savings on the operations and maintenance costs, and the NPV of the green building proposed is calculated. If the results were positive in comparison to the same building without the proposed strategies, then the building would make sense economically. This economical feasibility of green buildings by itself, would present incentives big enough for developers to turn green.

However, many developers are interested in selling their project upon completion, or perhaps contract with a property manager to operate and maintain their properties. Studies have shown that buildings with cheaper operations and maintenance costs have typically higher rent compared to similar buildings (in quality, location and function) with higher O&M costs. In other terms, a building implementing green strategies will results in higher rent, subsequently a higher Net Operating Income (NOI) which will raise the value of the project (Value V = NOI/Cap Rate). This is why we can say that green buildings have higher asset value than similar regular buildings.

According to Christopher Trevisani[12] who conducted a study about the potential increase in asset value through the implementation of innovative environmental technology, presented the financial results of more than a hundred case studies. They are summarized in the following:

Table III.2 - Potential Increase in Asset Value Due to the Implementation of Innovative Environmental Technology

Sector	Average Annual Energy Savings per sq. ft.	Average Potential Increased Asset Value per sq. ft.
Residential	$0.48	$6.46
Office	$1.03	$10.32
Hotel and Resorts	$0.51	$5.36
Institutional	$0.65	$6.45
Retail	$0.60	$6.01
Industrial	$0.70	$9.22

Source: Christopher D. Trevisani

However, as we have already seen in the previous chapter, the direct savings are related to the context in which they are studied. For instance, energy savings in the U.S. are smaller in value than the same amount of savings in Europe or Japan, due to energy prices. This is why, if taken alone, the direct savings on O&M costs are not always enough in the context of the United States. However, they do represent a base amount of savings that would get us closer to a threshold in the mind of the developer that would tip the balance towards the decision to build green.

Defining a Solution

Having analyzed the macro and micro scale approaches, we find that both have failed to provide substantial results in promoting green buildings. Meantime, the problem still exists and grows constantly.

On the other hand, we find that there still exists a certain aspect of green strategies benefits that is not fully exploited. This leads us to look closer at those benefits such as health and productivity. The main problem is that they are intangible; issues such as health in buildings and productivity levels in a workplace are very difficult to define, measure, and quantify in monetary terms or dollars per square foot. Most of the precedent studies did in fact acknowledge those benefits, but very few tried to quantify them. However, there is a general consensus that they are considerable and that they do have the potential to turn the whole situation around.

However, due to the nature of the relationship between the developer and the tenant, with an existing conflict of interest, it would be very difficult for the developer to use the tenant's savings as a basis for economic analysis. For this reason, up till now, those intangible benefits were never used beyond a simple marketing tool. With the involvement of a qualified third party, capable to organize and guarantee the research findings, this situation could be solved.

The next chapters will try to define those benefits, then, basing the analysis on the research works of many leading national laboratories, it will try to evaluate and quantify them. At later stages, a system would be developed and tested in a case study to allow the developer and tenants to split the benefits. Then, at later stages, these intangible benefits will be combined with direct O&M savings and the existing external incentive programs, to develop a new set of incentives for developers to build green.

Notes

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[2] Rodman D and Lenssen N, *A Building Revolution: How Ecology and Health Concerns Are Transforming Construction*, (Worldwatch Paper 124, March 1995)
[3] Gottfried D, *Sustainable Building Technical Manual: Green Building Design, Construction, and Operations - Chapter 1: The Economics of Green Buildings*, Public Technology, Inc., 1996
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[5] Green Lights Program literature (Washington, D.C.: U.S. EPA, December 1993)
[6] Starrs T, and Wenger H, California Energy Commission, *A Consumer's Guide to Buying a Solar Electric System*, written for the U.S. Department of Energy, National Renewable Energy Laboratory, September 1999
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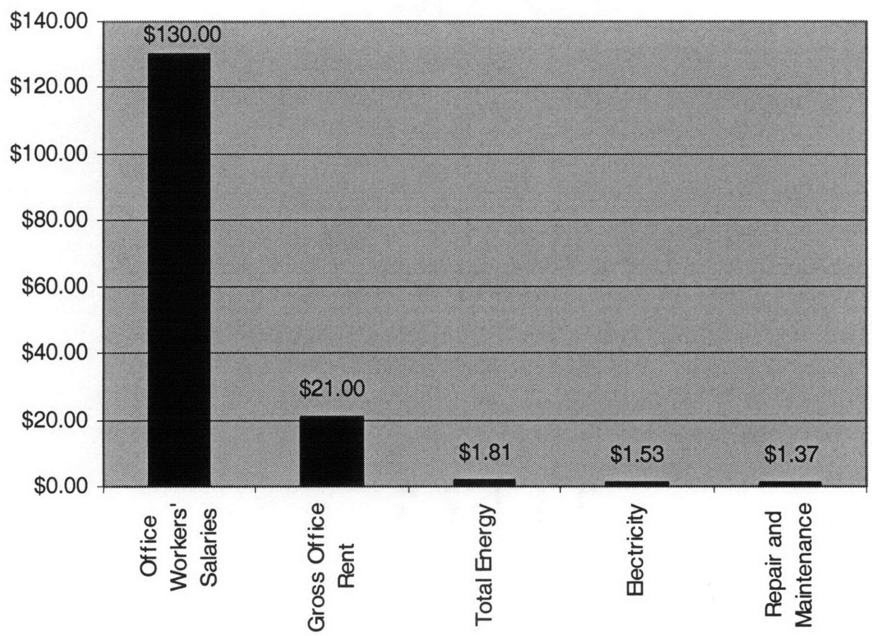
CHAPTER IV
HEALTH AND PRODUCTIVITY IN THE GREEN WORKPLACE

Comfort, Health and Increased Productivity: An Overview

"On average, Americans spend 80% to 90% of their time indoors and as a result, the quality of the indoor environment has a significant influence on health, productivity, and quality of life"[1]. Almost seventy percent of the U.S. work force, approximately 89 million persons, works in non-industrial, non-agricultural, indoor work settings. Moreover, 34 percent of the building stock in the U.S. is commercial office development. Focusing our approach on the workplace - in particular the office space - seems natural when dealing with issues of health and productivity. In fact, only corporate owners or tenants can convert increases in human response and performance into monetary value. In the same time, healthier buildings and workplaces would provide them with lower health care costs and liability risk. According to a study done by the Building Owners and Managers Association (Figure IV.1), a corporate tenant spends annually around $130 per square foot in office workers' salaries compared to $21 for rent, and $1.81 for energy.

Figure IV.1 Average Annual Commercial Expenditure (Dollars per Square Foot)



Source: *Building Owners and Managers Association*; Electric Power Research Institute; Statistical Abstract of the United States 1991

In other terms, if the strategies we analyzed in the previous chapter proposed savings on the energy bill along with increases in rent, the following section will investigate possible ways to increase the output out of the $130 per square foot paid in salaries. The gains in value at this level are much more substantial and can hold the key to the success of green development. For instance, a one percent increase in productivity has a value of $1.3 per square foot, enough to offset most of the energy bill for the building.

On the other hand, recent studies suggested that productivity could be increased by up to 16% due to indoor environmental quality (IEQ) improvements. In that case, increases in value in the order of $21 per square foot could be achieved, which is enough to cover the rent.

Research over the past decade has increased our understanding of the indoor work environment, revealing problems and potential solutions. Both theoretical considerations and empirical data suggests that green strategies, improving indoor environmental quality (IEQ), influence positively the rates of communicable respiratory illness, allergy and asthma symptoms, and Sick-Building-Syndrome (SBS). In turn, these would reduce the occurrence of long and short-term sick leave, as well as increasing productivity. Moreover, certain strategies dealing with Daylighting and indoor air quality (IAQ) would improve directly the comfort of occupants, human performance and productivity. Research into IEQ and the way it affects health and productivity is becoming increasingly essential. Facility managers are interested in IEQ's relationship to energy efficiency while employers are looking more into health and productivity benefits as well as the reduced risk of litigation.

Conventional office design, construction, and operation with low quality IEQ result in health hazards associated with economic costs and liability. For instance, the U.S. Environmental Protection Agency (U.S. EPA) considers poor IAQ to be among the top five environmental risks to public health while 30 percent of new and renovated buildings are found to have polluted indoor air. Sick Building Syndrome (SBS) and Building Related Illness (BRI) are becoming more common in the workplace, increasing employer costs due to liability claims.

A case settled in 1995, involved a suit between Polk County, Florida, and the insurance company of the builders of the county eight-year-old courthouse. The court awarded the county around $26 million to correct design and construction flaws that resulted in a high level of mold growth and caused occupant illnesses[2]. In another highly publicized lawsuit concerning SBS, a number of employees of the U.S. EPA successfully sued the agency for $1 million for building related illnesses and multiple chemical sensitivities. A growing public awareness of the relationship between IEQ characteristics and potential health problems is increasing the number of liability cases, making it a substantial risk faced by building owners and employers.

Health and Productivity: An Economic Perspective

Looking at the issues of health and productivity from the developer's perspective can be somehow different from the tenant/employer's view. In most cases, the developer and the tenant are two separate parties with completely different priorities. The employer looks at those benefits in terms of added productivity for the same amount of workers' salaries coupled with a decrease in health care cost and liability risk. From his side, the developer weighs the additional investment required for green IEQ strategies against increases in asset value or rent that the corporate tenant is willing to pay. Knowing that the employer is ready to pay higher rents up to the value of those added benefits, the developer can evaluate them and increase his rent accordingly.

The following example (Table IV.1) illustrates, in a simplified way, how the developer can profit from increases in productivity of the tenants workforce. Let us consider a typical 100,000 sq. ft. office building designed to be leased to one tenant. The typical utility costs for the tenant are $1.80 per square foot, totaling $180,000 per year. The personnel expenditure is in the order of $23,345,000 per year, i.e. $233 per square foot. The developer proposes the implementation of green strategies enhancing the IEQ quality of the facility. They result in a 6 percent increase in productivity and 30 percent savings on the utility bills for the tenant[3]. The benefits are valued to $14.5 per square foot. The developer and tenant agree to split those benefits in half, or in other terms, the tenant is ready to pay an increment of $7.25 per square foot, to be able to benefit from increases in outcome in the order of $14.5 per square foot. From the developer's perspective, a $200 per square foot investment is needed for construction instead of $180 to be able to raise the annual rent from $21 to $28.25 per square foot. However, the Internal Rate of Return (IRR) over a 12 years period will be increased from 5.6 percent to 9.22 percent.

Table IV.1 - Conventional Vs. Green: Productivity Gains			
for a Typical 100,000 sq. ft. Office Building			
Tenant's Perspective		*Developer's Perspective*	
Utility Costs		**Initial Project**	
Annual Utility Cost per Square Foot	$1.80	Construction Cost per Sq. Ft.	$180
Total Annual Utility Cost	$180,000	Total Construction Cost	$18,000,000
Personnel Costs		Annual Rent per Sq. Ft.	$21
Average Employee Salary & Benefits	$35,000	Total Annual Rent	$2,100,000
Average Employee Working Space	150	Internal Rate of Return (IRR) over 12 y.	5.60%
Estimated Number of Occupants	667	**Green Project**	
Total Annual Building Personnel Cost	$23,345,000	Additional Construction Cost per Sq. Ft.	$20
Annual Average Personnel Cost per Sq. Ft.	$233	Total Construction Cost	$20,000,000
Savings		Annual Rent per Sq. Ft.	$28.25
Value of 6% Productivity Increase per Sq. Ft.	$14	Total Annual Rent	$2,825,000
Value of 30% Utility Bill's Savings per Sq. Ft.	$0.54	IRR over 12 years period	9.22%
Bottom Line		**Bottom Line**	
Increase in Value per Sq. Ft. (50% of Total Incr.)	$7.25	Increase in IRR	3.62%

It should be noted that in this example, many parameters including inflation and market demand as well as financing mechanisms were neglected for simplicity reason. Moreover, the costs of construction, IEQ strategies, energy, rent, as well as the productivity increase and utility bill's savings are all rough estimates and are the subject of the sections to follow. This example clearly shows the IEQ strategies' potential in influencing the economic side of building projects.

Another way of valuing buildings and their increase in value due to better IEQ is through the use of Market Capitalization Rate (MCR) (Table IV.2). This method used by building appraisers, brokers and lenders consists of dividing the Net Operating Income (NOI) by the MCR. Using a fairly conservative MCR of 10 percent, the example discussed above would result in an increase in value in the order of $14,540,000 with an investment of only $2 million for IEQ improvements. However, the developer in this case, is sharing this increase with the tenant.

Table IV.2 - Increase in Building Value
for a Typical 100,000 sq. ft. Office Building

Annual Utility Bill's Savings	$54,000
Value of 6% Productivity Increase	$1,400,000
Total Annual Increase in NOI	$1,454,000
Market Capitalization Rate (MCR)	10%
Increase in Building Value	$14,540,000

Green Strategies Influencing the Indoor Environmental Quality (IEQ)

Indoor Environmental Quality (IEQ) is influenced by many indoor and outdoor factors and the only way we can actively manipulate it is through the design, construction and operation of a specific set of building systems. The next section will divide those building systems into five broad categories. This will provide a description of each set of systems and the way it affects health and human performance. The sections to follow will be devoted to present innovative designs as well as the human response to each of the proposed solutions.

1- Heating, Ventilating and Air-Conditioning (HVAC):

These building systems basically deal with the Indoor Air Quality (IAQ) which in turn affects health and productivity in the workplace. In fact, the HVAC systems design determines how much fresh air is provided, as well as the rate at which it is re-circulated. In turn this will also control the carbon dioxide levels (CO_2) which is a major source of headache and SBS for building occupants. The design and operation of HVAC systems also affects the rate at which the volatile organic components (VOC) and other microorganisms and contaminants emitted by building materials like paints and carpets can affect the health and performance of workers. Moreover, the HVAC systems also affect the thermal comfort of building occupants. This includes temperature and humidity, as well as individual climate control. Other HVAC issues such as natural ventilation (versus mechanical ventilation) and passive solar heating substantially affects the energy bill in addition to inherent health and performance benefits.

2- Lighting:

Lighting and more importantly, Daylighting, affects tremendously the performance of workers. The design of this set of systems, including lighting fixtures, windows, skylights and surface materials is very delicate since it doesn't allow over design. It is very crucial to design for an optimum amount of illumination in a well balanced light tone to provide a comfortable workplace that boosts productivity. With lighting devices consuming up to 40 percent of a building's total energy, it is also important to balance the use of fixtures versus daylight whenever possible. We should also note that windows and skylights can also be a major source of heat gain, which makes the design of lighting systems go in parallel with the development of the building envelope.

3- Building Envelope:

Two aspects of the building envelope affect the IEQ remarkably. First, its relation to Daylighting (mentioned in the section above), and second, the way it affect the thermal comfort and energy use in buildings. The latter affects the way the building transpires, regulating the infiltration of outside air and moisture, the major source for mold, bacteria and fungi growth. In turn, these would affect the health of the building occupants.

4- Construction Materials, Furnishings and Equipment:

Construction materials, furnishings and equipment can be a source of odors, particles and volatile organic compounds (VOC), others like carpets for instance, can also absorb VOCs. A careful choice of these materials can help reduce the exposure to VOCs and reduce the risk of health problems. This should also be done in coordination with HVAC and building envelope systems to minimize their effect.

5- Occupants Behavior, Acoustics and Maintenance Practices:

The number of employees in a workplace as well as the amount of equipment can contribute substantially to indoor air pollution. Their behavior and work ethics can also add to the mess and be a major source of acoustic pollution which affects productivity. Moreover, maintenance practices are crucial in fighting the accumulation of dirt, dust, mold, and other particles and odors. For instance, the use of high-VOC cleaning agents pollutes air. This is why, it is important to design office spaces keeping in mind the easiness of maintenance and cleaning, as well as human circulation and acoustics. The latter can be affected by human behavior, HVAC and building envelope systems, as well as the choice of materials.

Poor Indoor Environmental Quality (IEQ) Consequences:

Poor IEQ can cause human illness, which in turn may result in increases in sick leaves, and decreases in productivity. Problems that can result from deficient IAQ may be short-term to long-term, and range from minor irritations to life-threatening illnesses. They are classified as follow[4]:

1- Sick-Building-Syndrome (SBS):

SBS describes a collection of symptoms experienced by building occupants that are generally short-term and may disappear after the individuals leave the building. The most common symptoms are sore throat, fatigue, lethargy, dizziness, lack of concentration, respiratory irritation, headaches, eye irritation, sinus congestion, dryness of the skin (face and hands), and other cold, influenza, and allergy symptoms[5].

2- Building-Related Illnesses (BRI):

BRIs are more serious than SBS conditions and are clinically verifiable diseases that can be attributed to a specific source of pollutant within a building. Examples include cancer and Legionnaires' disease[6].

3- Multiple Chemical Sensitivities (MCS):

The initial symptoms of MCS are generally acquired during an identifiable exposure to specific VOCs. While these symptoms may be observed to affect more than one body organ system, they can recur and disappear in response to exposure to the stimuli (VOCs). Exposure to low levels of chemicals of diverse structural classes can produce symptoms. However, no standard test of the organ system function explaining the symptoms is currently available[7].

4- Non-Health Related Productivity Decrease:

While the health problems mentioned above all result in decreases in productivity and more frequent sick-leaves, poor IEQ can sometime have the same result without actually affecting the health of the occupants. In fact, bad lighting and ventilation can have direct effects on human response and performance. This issue will be dealt with extensively in the sections to follow.

Methodology

The published literature on the relationship of indoor environments to health and productivity consists primarily of reports on individual laboratory or field studies or reviews, without synthesizing the results in the form of guidelines for better IEQ. The information is present in hundreds of papers and studies, however each in its own approach and format. This is normal due to the complexity of the issues involved and the difficulties in designing experiments to quantify those relationships. Many organizations or individuals have tried to identify relevant papers and try to understand, summarize and combine the findings.

William J. Fisk, head of the Indoor Environment Department at the Lawrence Berkeley National Laboratory (LBNL) in California, in his *paper "Health and Productivity Gains from Better Indoor Environments and their Relationship with Building Energy Efficiency"* published in 2000, summarized 75 papers and wrote recommendations for better IEQ. He also researched the cost of improving indoor environments as well as the impact that they would have on energy consumption.

Another project, the Indoor Health and Productivity (IHP), also aims to develop a fuller understanding of the relationships between the physical attributes of the workplace in non-residential and non-industrial buildings and the health and productivity of occupants. Developed by the National Science and Technology Council (NSTC) and sponsored by the LBNL, this project has a particular emphasis to identify and communicate key research findings, with their practical and policy implications, to policy makers, design practitioners, facility managers, construction and energy services companies, and building investors[8]. Consequently, the IHP project has worked with a peer review panel to select five key IHP papers, out of a pool of 26 papers, and then write summaries for the *ASHRAE Journal.*

In the following sections, papers relevant to IEQ and its relation to health and productivity were identified through computer-based literature searches, as well as through the two studies presented above. They will then be summarized and divided into five broad categories: HVAC, lighting, building envelope, building materials, and maintenance and occupant behavior (including acoustics). After a brief presentation of the findings of each study relevant to a certain category, a small table will relate quantified decreases in health problems and increases in productivity to specific attributes of the indoor environment. The next step would be to join those tables into a unified set of IEQ guidelines that would relate indoor environment improvements to quantified health and performance benefits.

The table will then be tested against six case studies developed by J. Romm from the U.S. Department of Energy and W. Browning from the Rocky Mountain Institute[9]. The chapters to follow will propose ways of making use of the resulting table in order to promote green development and more specifically, the energy-efficient strategies that improve IEQ, and create incentives for developers to use them.

Quantifying Health and Productivity Improvements

HVAC Systems: Thermal Comfort and Indoor Air Quality (IAQ)

1- Fisk WJ (2000), *Health and Productivity Gains from Better Indoor Environments and their Relationship with Building Energy Efficiency*, Annual Review of Energy and the Environment 25(1): pp. 537-566:

This paper summarizes available research on the major indoor environment factors affecting human health and productivity, in particular IAQ and thermal comfort. It provides an elaborate discussion of the health issues, their cost implications, and the potential cost savings associated with intervention. The strong point of this analysis is that it uses appropriate statistical rigor in reaching estimates. The author divided his approach into four categories: Communicable respiratory illness, allergies and asthma, SBS, and direct productivity gains. Please refer to Appendix A for a list of the papers and studies cited and analyzed in the elaboration of this analysis.

Communicable Respiratory Illness (CRI): Eight studies identified reported statistically significant 23% to 76% reductions in CRIs such as influenza and common colds with the increase of ventilation rates, reduction in space sharing and occupant density as well as the irradiation of air with ultraviolet light. One of the studies resulted in a 35% reduction in short-term absences due to CRI with the doubling of ventilation rates from 12 Ls^{-1} to 24 Ls^{-1}.

Table IV.3 - Association of IEQ Characteristics with CRI

Higher Ventilation (Barracks)	33% lower CRI
Ultraviolet Irradiation of air	23% lower CRI
Space Sharing (1 Roommate vs. 0 RM.)	17% lower CC*
Size of Living Quarters	Up to 50% lower with Larger Quarters
Window Vs. Fan Ventilation	41% lower CRI and 15% lower STA*
No Recirculation of Ventilation Air	50% lower CRI
Higher Ventilation (Office)	35% lower STA
* Common Cold	
** Short-Term Absence	

Allergies and Asthma: This section relates allergen concentration, moisture and mold problems to lower respiratory symptoms indicative of asthma. It will be tackled in the section on building envelope.

Sick Building Syndrome (SBS): Lower ventilation rates, high carbon dioxide concentrations, presence of air-conditioning, and higher indoor temperatures are all proven to be factors that increase the risk of SBS. It has also been found that workers showing SBS symptoms at work take 7% more time to respond and have a 30% higher rate of error totaling a 14% decrease in productivity. Multiplying this by the 23% of office workers with 2 or more SBS symptoms, we find that indoor environments causing SBS will yield a 3% decrease in performance. Other studies suggested that SBS symptoms are associated with decrements on the order of 3% to 5% in specific aspects of performance. The estimated potential reduction in SBS symptoms due to better ventilation and IAQ is between 20% and 50%. For instance, a 10 cfm per person increase in ventilation rate would decrease SBS symptoms by 35 percent.

Table IV.4 - Association of IEQ Characteristics with SBS	
IEQ Characteristic	**SBS and Productivity**
Individually Controlled Ventilation	Low SBS - 15% Increase in Productivity*
Increase Ventilation by 5 Ls^{-1} per Person	Decrease SBS by 35% - 1% Incr. in Prod.
* Productivity Results are not Certain	

Direct Productivity Gains: Some studies demonstrate the presence of a direct relationship between worker performance and air temperatures and lighting conditions. Differences in temperatures of a few degrees can influence workers' speed and accuracy by 2% to 20%. Lighting's direct effect on human performance will be tackled in the section to follow.

Table IV.5 - Association of IEQ Characteristics with Productivity	
IEQ Characteristic	**Productivity**
±3°C of Individually Controlled Ventilation	Increase 3% - 7%

<u>2- Milton DK, Glencross PM, Walters MD (2000), *Risk of Sick Leave Associated with Outdoor Ventilation Level, Humidification, and Building Related Complaints*, Indoor Air, 10(4): pp. 212-21:</u>

In this study the sick leave for 3,720 hourly employees of a large Massachusetts manufacturer were analyzed, in 40 buildings with 115 independently ventilated work areas. Corporate records identified building characteristics and IEQ complaints. The ventilation was rated as moderate (~25 cfm/person, 12 Ls^{-1}) or high (~50 cfm/person, 24 Ls^{-1}) outdoor air supply based on knowledge of ventilation systems and CO_2 measurements on a subset of work areas. Then a Poisson regression was used to analyze sick leave controlled for age, gender, seniority, hours of non-illness absence, shift, ethnicity, crowding, and type of job (office, technical, or manufacturing worker). The study found consistent associations of increased sick leave with lower levels of outdoor air supply and IEQ complaints. Among office workers, the relative risk for short-term sick leave was 1.53 (95% confidence 1.22-1.92) with lower ventilation, and 1.52 (1.18-1.97) in areas with IEQ complaints. The results imply that among those exposed to lower outdoor air supply rates the risk of short-term sick leave attributable to lower ventilation was 35% and that of total sick leave 57 percent.

Table IV.6 - Association of Suspected Risk Factors with Sick Leave		
Risk Factor	Percent Change (95% Confidence Limits)	
	Total Sick Leave	**Short-Term Sick Leave**
Lower Ventilation Rate	+130%	+53%
Humidification	+96%	N/A
Complaint Area	N/A	+52%
Crowding	-46%	N/A
Source: Kumar S. and Fisk W., *The Role of Emerging Energy-Efficient Technology in Promoting Workplace Productivity and Health: Final Report* , IHP Project, Feb. 2002		

This study also goes further to explore the cost and benefits of increasing ventilation by 25 cfm, compared to the recommended ventilation rates of ~20 cfm per occupant for offices. The results are net savings of $400 per employee per year for total savings in the order of $38 billion for the U.S. economy.

Table IV.7 - Potential Economic Costs and Benefits of Increasing Ventilation Rate by 25 cfm per Person	
Outcome	**Annual Cost (Saving) per Employee***
Ventilation Energy Costs ($3.22/cfm/year)	$80
Sick Leave Costs (Avoided 1.5 days per W.)	$480
Net Savings	$400
* Assumes hourly compensation of $40	

3- Seppanen OA, Fisk WJ, Mendell MJ (1999), *Association of Ventilation Rates and CO2 Concentrations with Health and other Human Responses in Commercial and Institutional Buildings*. Indoor Air, 9(4): pp. 226-52:

This study reviews published papers on the associations of ventilation rates and carbon dioxide concentrations in office buildings with health and other human outcomes. Forty-one studies, with around 60,000 subjects, were analyzed and then summarized (20 and 21 studies analyzed ventilation rates and carbon dioxide concentration respectively).

Almost all studies found that ventilation rates below 10 Ls^{-1} per person (~21 cfm) in all building types were associated with statistically significant worsening in one or more health or perceived air quality outcomes. Some studies determined that increases in ventilation rates above 10 Ls^{-1} per person (~21 cfm), up to approximately 20 Ls^{-1} per person (~42 cfm), were associated with further significant decreases in the prevalence of SBS symptoms or with further significant improvements in perceived air quality. The carbon dioxide studies support these findings. About half of the carbon dioxide studies suggest that the risk of sick building syndrome symptoms continued to decrease significantly with decreasing carbon dioxide concentrations below 800 ppm (0.08% by mass). The ventilation studies reported relative risks of 1.5 - 2 for respiratory illnesses and 1.1 - 6 for sick building syndrome symptoms for low compared to high ventilation rates[10].

Table IV.8 - Association of IEQ Characteristics with SBS	
IEQ Characteristic	**Outcome**
Ventilation Rate below 10 Ls^{-1} per Person	Significant Amount of SBS and CRI Sympt.
Ventilation Rate around 20 Ls^{-1} per Person	Decrease in SBS Sympt. - Better Perc. IAQ
Low Vs. High Ventilation	1.5 vs. 2 RR* for CRI
	1.1 vs. 6 RR for SBS
CO_2 Concentration Below 800 ppm	Significant Decrease in SBS Sympt.
* Relative Risk	

The following table summarizes the major findings of the 41 studies analyzed in this paper.

Table IV.9 - Summary of Major Findings			
Outcome	**Number of Studies**	**Number Finding Worse Outcome at Lower V. Rate**	**Increase in Outcome at Lower Ventilation Rates**
CRI or Short-Term Abs.	4	4	51%, 53%, 94%, 120%-370%
SBS Symptoms	27	20	10%-100% with >80% in 9 Stud.
Perceived Worst IAQ	8	7	60% to 180%
Source: Kumar S. and Fisk W., IHP Project, Feb. 2002			

4- Sieber WK, Staynor LT, Malkin R, Petersen MR, Mendell MJ, Walligford KM, Crandall MS, Wilcox TG, Reed L (1996), *The National Institute for Occupational Safety and Health Indoor Environmental Evaluation Experience, Part Three: Associations between Environmental Factors and Self-Reported Health Conditions*, Applied Occupational and Environmental Hygiene, 11(12): pp. 1387-92:

In this study, associations between environmental factors and work-related health conditions were assessed using regression techniques. Environmental and health data was collected from 2435 respondents in 80 office buildings initially included in the National Institute for Occupational Safety and Health (NIOSH), Health Hazard Evaluation (HHE) program. The health conditions that were included in the study were lower respiratory symptoms, allergic symptoms and asthma diagnosed after beginning work in the building. From another side, four categories of environmental variables were included: HVAC system design, HVAC maintenance, building design, and building maintenance.

Certain respondent characteristics (gender, age) showed increased relative risks (RR) for each health condition; the regression models were adjusted for gender and age.

RRs of multiple lower respiratory symptoms were increased for fifteen variables in the HVAC design and maintenance categories, with the highest RR for presence of debris inside the air intake [RR=3.1, confidence interval (C1) =1.8, 5.2] and for poor or no drainage from drain pans (RR= 3.0, C1= 1.7, 5.2).

Table IV.10 - Variation in health Outcomes due to HVAC and Maintenance Variables

Category	Variable	Increase in Lower Respiratory Symptoms	Increase in Allergic Symptoms	Increase in Asthma Diagnosed after Beginning Work in B.
HVAC	*Outdoor Air Intake within 25 ft. of:*			
Design	Standing Water	+130%	---	---
	Exhausts Vents	+140%	---	---
	Sanitary Vents	+120%	---	---
	Cooling Tow er	---	-70%	---
	Vehicle Traffic	+80%	---	---
	Trash Dumpster	+110%	---	---
HVAC	*No Scheduled Air Handler Inspect.*	+100%	---	---
Maintenance	*No Testing and Balancing Rprt. Av.*	---	+80%	---
	Particulate Filtration System:			
	Filters not secure in Place	+120%	---	---
	Dirty Filters	+90%	---	+100%
	HVAC Cleanliness	+80%	+30%	---
	HVAC Condition:			
	Debris Inside Air Intake	+210%	---	+100%
	Residue/Dirt in Drain Pans	+60%	---	---
	Poor or No Drainage from Pans	+200%	---	---
	Dirty Ductw ork	+110%	---	---
	Presence of Moisture in HVAC Sys	+120%	---	---
	Air Ductwork Never Cleaned	+180%	+80%	-40%
Building	*Daily Surface Cleaning w/Solution*	---	---	-50%
Maintenance	*Daily Vacuuming*	-50%	---	---
	Daily Surface Dusting	-40%	+30%	-50%
	Interior Pesticides Applied	-50%	+50%	---
	Floor Waxing and Striping Monthly	-60%	---	---
	Renovation of Wall within 3 Weeks	---	---	+150%

Source: Kumar S. and Fisk W., IHP Project, Feb. 2002

Elevated RRs of allergic symptoms were found for variables in three of the four environmental categories, with the highest for presence of suspended ceiling panels (RR=2.3, CI= 1.0, 5.5). The RR of asthma was highest if recent renovation with new drywall had been performed (RR = 2.5, CI=1.4, 4.5). This analysis is particularly useful, for determining factors that may be associated with development of health conditions in the work environment and which might be considered in any building plan to reduce IAQ problems. Table IV.10[11] is a summary of those associations.

5- Apte MG, Fisk WJ, Daisey JM (2000), *Associations between Indoor CO2 Concentrations and Sick Building Syndrome Symptoms in U.S. Office Buildings: An Analysis of the 1994-1996 BASE Study Data*, Indoor Air 10(4): pp. 246-57:

This study also analyzes the correlation between low ventilation rates represented by carbon dioxide concentration and SBS symptoms in office buildings. It uses multivariate logistic regression (MLR) analyses for data collected from a probability sample of 41 U.S. office buildings. It constructed two CO_2 metrics: average workday indoor minus average outdoor CO_2 (dCO_2, range 6-418 ppm), and maximum indoor 1-h moving average CO_2 minus outdoor CO_2 concentrations ($dCO_{2\ MAX}$). MLR analyses quantified dCO_2/SBS symptom associations, including adjustments for personal and environmental factors. A dose-response relationship ($p < 0.05$) with odds ratios per 100 ppm dCO_2 ranging from 1.2 to 1.5 for different SBS symptoms was observed. The dCO_{2MAX}/SBS regression results were similar.

Table IV.11 - Association of CO_2 Concentration with SBS Symptoms

IEQ Characteristic	**Productivity**
100 ppm Increase in CO_2 Concentration	20% - 50% Increase in SBS

6- Mendell M, *Non-Specific Symptoms in Office Workers: A review and Summary of the Epidemiologic Literature*, Proceedings of Indoor Air, 3: pp. 27, ISSN 0905-6947:

This study concentrates on the causes of non-specific health symptoms among office workers, by studying 37 potential factors through the analysis of 32 relevant publications. Among the IAQ factors assessed, findings consistent with the previous studies showed substantial linkage to HVAC design and maintenance, carpets, crowdedness, VDT use, and especially ventilation rates below 10 Ls^{-1} per person. Furthermore, decreases in symptoms were associated with the use of high ventilation rate, short-term humidification, negative ionization, and improved office cleaning. Some of the studies also found a correlation between increased symptoms and high temperature and low humidity.

7- Sundell J (1994), *On the Association between Building Ventilation Characteristics, Some Indoor Environmental Exposures, Some Allergic Manifestations, and Subjective Symptom Reports*, Indoor Air, Suppl. 2: pp. 1-49:

The aims of this study are 1) to assess the associations between ventilation characteristics of indoor spaces, and dust mite infestation and allergy among occupants; 2) to assess the association between ventilation characteristics and occurrence of SBS-related symptoms among office workers; 3) to study changes in total volatile organic compounds (TVOC) or formaldehyde concentration from outdoor to indoor air and to study the associations between SBS symptoms and concentrations of TVOC and formaldehyde in indoor air. The results from 3 studies were analyzed.

The first study tackled the issues of allergic diseases among children and is not very relevant to office buildings and adult workers. The second, an office illness study on associations between ventilation characteristics (measuring TVOC and formaldehyde) and occurrence of SBS symptoms among office workers. The third study was a technical and chemical field study on the possible re-entrainment of indoor air pollutants (formaldehyde) via rotary heat exchangers. The results are summarized in Table IV.12:

Table IV.12 - Association of IEQ Characteristic with SBS Symptoms

IEQ Characteristic	Correlation with SBS Symptoms
Ventilation Operating Hours (<10 hours)	High
Presence of Photocopiers/Video Display	High
Low Rating of Psycho Social Conditions	High
Asthma and Skin Sensivity to Sunlight	High
Type of HVAC System	None
Recirculation of Air	None
Presence of Rotary Heat Exchangers	None
TVOC	N/A
Perception of Dry Air	Average

8- Wargocki P, Wyon DP, Fanger PO (2000), *Pollution Source Control and Ventilation Improve Health, Comfort, and Productivity*. Proceedings of Cold Climate HVAC 2000, Sapporo, Japan; pp. 445-450:

Three independent studies were analyzed in this paper. Using similar procedures, they showed that increasing IAQ by doubling ventilation rates or decreasing the source of indoor pollution two-fold can improve the performance of office work. The results confirm that good IAQ improves the performance of text typing (P=0.0002), addition (P=0.056), and proof-reading (P=0.087). Subsequently, performance will increase on average by 1.5% when the proportion of occupants dissatisfied with the IAQ is decreased by 10% (in the range where IAQ is causing 25% - 70% of occupants to be dissatisfied). The doubling of ventilation rates or two-fold decrease in pollution sources yielded results of 1.9% increase in productivity.

Table IV.13 - Association of IEQ Characteristic with Productivity Increase

IEQ Characteristic	Productivity Increase
Doubling Ventilation Rates	1.90%
Two-Fold Decrease in Pollution	1.90%
Reduction of 10% in the Proportion of Occupants Dissatisfied with IAQ	1.50%

9- Wyon DP (1996), *Indoor Environmental Effects on Productivity*, Proceedings of IAQ '96: Paths to Better Building Environments, pp. 5-15:

Thermal conditions and IAQ are factors that can affects human efficiency such as reading, thinking, and arithmetic, by 5% to 15%, according to this study. Temperature differences are analyzed within the thermal comfort zone and vertically where they cause IAQ problems at head height and can cause headache. The individual control of thermal conditions, tackled in other studies, becomes an important tool to provide productivity increases in the workplace. The rest of the study evaluates the different approaches to analyze the correlation of IAQ and physical features of a space with human performance.

10- Wyon DP (1974), *The Effects of Moderate Heat Stress on Typewriting Performance*, Ergonomics, 17(3): pp. 309-18:

In this study, four experiments examined the correlation between typewriting performance and air temperature differences. Twenty-four subjects worked for ten days in different thermal conditions (20°C and 24°C). After raw data collection, using non-parametric statistical methods established that subjects performed considerably better at 20°C than at 24°C on the typewriting task. Even though the results of this study are simple and don't say a lot on the optimal thermal conditions, it reveals that they are in the vicinity of 20°C for typewriting and other office work.

11- Wyon DP (1993), *Healthy Buildings and Their Impact on Productivity*, Proceedings of Indoor Air '93, 6: pp. 3-13:

Healthy Buildings are achieved when special considerations are given to heat and cold stress, humidity, airborne particulates and VOCs to which their occupants are exposed. A recent ASHRAE workshop identified specific useful measures of productivity. This study analyzes the effect of IAQ factors, temperature and vertical temperature differences on these measures, as well as on SBS and sensations of dryness. Direct effects of IAQ and thermal climate parameters on productivity are treated separately. Individual control of the microclimate at the workstation is proven to be a cost-effective method of maintaining high levels of human performance. Finally this study concludes that generally, there is enough evidence and recorded measures that healthy buildings do affect productivity levels. The results, sometimes as high as 50% productivity increase, are more usually in the range of 5% to 15%.

12- Fisk WJ, Price P, Faulkner D, Sullivan D, Dibartolomeo D, Federspiel C, Liu G, Lahiff M, *Worker Productivity and Ventilation Rate in a Call Center: Analyzes of Time-Series Data for a Group of Workers*, Lawrence Berkeley National Laboratory, 2001:

This paper describes part of a productivity study performed in a call center of a health maintenance organization. The rates of outside air ventilation were manipulated while indoor air temperature, humidity and CO_2 concentrations were monitored. Worker performance data was collected and analyzed via multivariate linear regression to look for an association between ventilation rates and productivity.

The results suggest that there is very little effect of ventilation on performance (between 0% and 1%). Although the range of ventilation rates applied was wide enough (12 Ls^{-1} to 48 Ls^{-1}), there was only small evidence that there might be around 2% increase in productivity at very high levels (when CO_2 concentrations exceed outdoor concentration by less than 75 ppm). This result was due in part to the fact that a health maintenance organization has initially a lower level of indoor pollutants than a regular office building, which stresses even more our approach on the source of those pollutants (this will be the subject of the following sections).

This paper also mentioned a case study of an insurance office by Kroner and Stark (1992) that suggested that individual temperature control increased productivity by approximately 2%[12].

Lighting - Daylighting: Fixtures, Windows, and Skylights

1- Fisk WJ (2000), *Health and Productivity Gains from Better Indoor Environments and their Relationship with Building Energy Efficiency*, Annual Review of Energy and the Environment 25(1): pp. 537-566:

This paper mostly tackling the issues of HVAC design and ventilation, as well as thermal comfort, also provided evidence of linkage between lighting and human performance. The review of many published papers and studies approached the subject of lighting more on the qualitative level than quantitative. It advances the amount of 6% increase in performance due to a lighting retrofit; however it tackles more the technical side of lighting by examining lighting levels, light tones, spectrum, intensity, as well as lighting systems and fixtures. It also correlates the type of lighting system with energy efficiency and occupant satisfaction. It also relates a study of Daylighting in schools with 7% to 18% increases in performance.

Finally, it concludes that the reviewed literature suggests 2% to 20% increases in performance. These results were divided by two assuming that the change will involve only half the occupants in an office. It was further divided by two because the variation in lighting is unrealistic and few offices would achieve such results. The final number advanced would be 0.5% to 5% increases in productivity due to lighting retrofits with peaks up to 10% for exceptional projects.

2- Heschong L, *Daylighting in Schools: an Investigation into the Relationship between Daylighting and Human Performance*, 1999 and Heschong L, *Skylighting and Retail Sales: an Investigation into the Relationship between Daylighting and Human Performance*, 1999:

This study examines the effect of Daylighting on human performance. It focuses the approach on skylighting, since it isolates daylight from other qualities inherent to windows such as views. This study tries to establish a statistically significant association between Daylighting and student performance as well as the effect of skylights on retail sales.

Data was collected from test performance of over 21,000 students in three different school districts. After reviewing architectural plans, aerial photographs and maintenance records, Daylighting conditions were classified in over 2000 classrooms. The study used multivariate linear regression analysis to control for other influences on student performance.

After comparing twelve elaborate models (four for each district), the result was that students with the most Daylighting in their classrooms progressed 20% faster on math tests and 26% on reading tests in one year than those with the least. Similarly, larger window areas were responsible for a progression 15% faster in math and 23% faster in reading. A well-designed skylight, one that diffused the daylight throughout the room with teacher's control of the amount of daylight entering the room, also improved performance by 19-20%.

Another window-related effect was also observed in classrooms where windows could be opened; students were found to progress 7% - 8% faster than those in classrooms with fixed windows. This result suggests that natural ventilation has an effect additional to Daylighting (not in parallel), which adds the performance benefits even further.

Table IV.14 - Association of Daylighting with Human and Sales Performance

Daylighting Characteristic	Performance
Abundant Daylighting in Schools (Skylight)*	20% - 26% Increase
Large Windows in Schools*	15% - 23% Increase
Well-Designed Skylight (Diffuser, Control)	Additional 19% - 20% Increase
Openable Windows	Additional 7% - 8% Increase
Skylighting in Retail Space	40% Increase in Sales
* In comparison to National Average	

The results of this study on student performance, along with those of the parallel study showing the positive effect of skylighting on retail sales, strongly support the thesis that these performance benefits from Daylighting can be translated to other building types and human activities, for instance, office buildings.

3- Boyce PR, Beckstead JW, Eklund NH, Strobel RW, and Rea MS (1997), *Lighting the Graveyard Shift: The Influence of a Daylight-Simulating Skylight on the Task Performance and Mood of Night-Shift Workers,* Lighting Research and Technology, 29(3), pp. 105-134:

Working overnight (between 0:00AM and 08:00AM) shifts is difficult for most people because their body is arranged to sleep rather than work. This paper reviews an experiment studying the effect of bright light, provided by a daylight-simulating skylight, on performance and mood of night-shift workers. The results are positive; productivity in some tasks is improved substantially (while others not). Subsequently, exposure to bright light can be plausibly linked to mood and performance of workers.

4- Newsham GR and Veitch JA (2001), *Lighting Quality Recommendations for VDT Offices: A New Method of Derivation,* Lighting Research and Technology, 33(2): pp. 115-143:

This paper analyzed an experiment performed in a mock-up office space. It gave occupants control over dimmable lighting circuits after working the whole day in random lighting conditions. The study resulted that the lighting conditions experienced during the day influenced the chosen illuminance at the end of the day, even though these allowed for screen glare. Regression of these end-of-day choices relative to the illuminance experienced during the day yielded a preferred illuminance in the range of 200 lx to 500 lx. Interestingly, the variation between participants' lighting preferences and the lighting they experienced during the day was a significant forecast of participant mood and satisfaction.

5- Hodgson MJ, Frohliger J, Permar E, Tidwell C, Traven ND, Olenchock SA, Karpf (1991), *Symptoms and Micro-Environmental Measures in Non-Problem Buildings,* Journal of Occupational Medicine, 33(4): pp. 527-33:

This study analyzes the correlation between SBS symptoms and thermal parameters, VOC pollution, CO and CO_2 concentrations, as well as noise and light intensity. Although this study will be the subject of the next sections, it suggests that SBS symptoms may have specific environmental causes, including lighting.

Building Envelope: Fighting Dampness and Mold Growth

1- Brunekreef B (1992), *Associations between Questionnaire Reports of Home Dampness and Childhood Respiratory Symptoms*, The Science of the Total Environment 127: pp. 78-89:

This paper analyzes a questionnaire (80% response rate) assessing dampness and respiratory symptoms including around 1,000 children from 5 Dutch towns (Brunekreef, 1992). The occurrence of damp stains in the surveyed homes was 14.8% while the occurrence of mould growth on indoor surface was 9.1%. Another questionnaire done later, where the prevalence of symptoms was identical, reported a higher occurrence of damp stain and mould spots (23.6% and 15%). However, in both studies, a significant association between dampness/mould growth and respiratory symptoms like cough, wheeze and asthma could be drawn.

Table IV.15 - Association of Dampness and Mould Growth with Respiratory Symptoms

Association	AOR*
Cough / Damp Stains	1.97 (CI**: 0.8 - 4.41)
Cough / Mould Spots	3.06 (CI: 1.29 - 7.26)
Wheeze / Mould Spots	1.5
Asthma / Mould Spots	1.9
* Adjusted Odds Ratio	
** Confidence Interval	

2- Cooper K, Demby S, Hodgson M (1997), *Moisture and Lung Disease: Population-Attributable Risk Calculations*, IAQ 97/Healthy Buildings: Design, Construction, and Operation of Healthy Buildings, 1: pp. 213-8:

According to this paper, moisture, mostly due to bad building envelope practices and faulty HVAC system design and maintenance, is associated with pulmonary disease in at least 15 studies. These studies were reviewed in an attempt to get to an estimate of the risks of airways and interstitial disease due to moisture. The result was that a significant reduction in moisture problems could reduce airways and interstitial pulmonary disease by 25% and 60% respectively.

3- Dales RE, Zwanenburg H, Burnett R, Franklin CA (1991), *Respiratory Health Effects of Home "Dampness" and Molds among Canadian Children*, American Journal of Epidemiology 134: pp. 196-203:

This is a questionnaire based study on the health effects of the IEQ in 30 Canadian communities, focusing on the association between the respiratory health of occupants (especially children) and home damp and mould spots. The housing stock was divided as follow: 81% were one-family detached homes, 6% were one-family attached homes, and 13% were buildings for two or more families. Molds were reported in 32.4%, flooding in 24.1%, and moisture in 14.1% of the homes. This information might give us an insight on the relation between the building envelope configuration and moisture problems. Respiratory symptoms were consistently higher in homes with reported mold and dampness. The percentage of homes with dampness or molds problems (37.8%) indicates that it is an important public health issue. The same results can be easily transposed to office buildings or other building types.

Table IV.16 - Association of Dampness and Mould Growth with Respiratory Symptoms (2)

Health Hazard	**AOR***
Bronchitis	1.32 (CI**: 1.06 - 1.39)
Cough	1.89 (CI: 1.58 - 2.26)
* Adjusted Odds Ratio	
** Confidence Interval	

4- Peat JK, Dickerson JL (1998), *Effects of Damp and Mould in the Home on Respiratory Health: a Review of the Literature*, Allergy: European Journal of Allergy and Clinical Immunology, 53: pp. 120-8:

This study investigates whether there is a direct or indirect association between moisture (causing damp and mould spots) in the home and respiratory health problems. Theoretically, dampness is considered to have health effects because of allergenic factors such as the proliferation of dust, mites and moulds. Studies conducted in children are probably the most reliable because of the absence of confounding factors such as smoking or other exposures. The results show an increased risk of cough and wheeze with the presence of damp and mould spots in the order of 1.5 – 3.5. This range is consistent with the measured effects of other environmental exposures which are considered important to health, such as tobacco smoke or outdoor air pollutants. However, in this study, the potential benefits of reducing mould in the home have not been investigated nor has a cost-benefit analysis been performed. But the result does imply that houses or buildings in general, need to be specifically designed for prevention from indoor allergen proliferation.

Building Materials: VOCs, Formaldehyde, and Other Emissions

A careful choice finishing materials such as carpets, paints, and false ceiling should be made in order to reduce the emission of volatile organic compounds (VOC), formaldehyde and other particulates. Most studies dealing with the issue of indoor pollution sources approach the subject by the question of ventilation, since it is the agent that gets VOC emissions to affect the occupants. This is why, most of the issues regarding VOC emissions were discussed in previous sections.

1- Garrett MH, Hooper MA, Hooper BM (1996), *Low Levels of Formaldehyde in Residential Homes and a Correlation with Asthma and Allergy in Children*, Proceedings of Indoor Air, 1: pp. 617-22:

This paper tries to define an association between levels of formaldehyde in indoor spaces with the occurrence of asthma and allergy symptoms in young children. For this purpose, 80 households in Victoria, Australia, were studied. Formaldehyde was measured using passive samplers for four consecutive days on four separate seasons. Skin prick tests were then performed on the children.

The indoor mean of formaldehyde was 12.5 ppb (0 ppb – 108 ppb). The results are summarized in the following table:

Table IV.17 - Association of Formaldehyde Levels with Asthma Symptoms

Formaldehyde Level	% of Homes with Asthmatic Child
< 16 ppb	16%
16 - 40 ppb	39%
> 40 ppb	43%

The formaldehyde level of 40 ppb was associated with asthma with an AOR of 2.78 (95% confidence interval (CI) = 1.49 – 3.2). Homes in excess of 40 ppb were significantly associated with atopic children (one or more positive skin prick tests) with an AOR of 2.3 (CI = 1.32 – 2.30).

The bottom line is that formaldehyde may be implicated in the rise in asthma, respiratory and allergic symptoms in building occupants (all ages), especially sensitive individuals. Guidelines should be set to select building materials and systems that reduce the emissions of formaldehyde.

2- Gyntelberg F, Suadicani P, Nielsen JW, Skov, PS, Valbjørn O, Nielsen PA, Schneider T, Jørgensen T, Wolkoff PW, Wilkins CK, Gravesen S, and Norn S (1994), *Dust and the Sick Building Syndrome*, Proceedings of Indoor Air, 4: pp. 223-38:

This is a questionnaire-based study performed in twelve Danish town halls (870 persons) to find out whether biologically active components in dust or absorbed organic gazes and vapors in the indoor environment may be responsible in part for SBS symptoms. For this purpose, dust samples were collected and their organic, inorganic and human contents were determined.

The results of the analysis showed a significant correlation between the prevalence of gram-negative bacteria in the indoor dust and SBS symptoms (Correlation Coefficient (CC) = 0.73) and mucous membrane / upper respiratory tract symptoms (CC = 0.76). There was also a correlation between the total amount of volatile organic component (TVOC) and lack of concentration (CC = 0.85) and headache (CC = 0.72). The remaining results are all summarized in the following table:

Table IV.18 - Association of Indoor Pollutants with SBS and Other

Indoor Pollutant	**Consequence with CC***
Prevalence of Gram-Negative Bacteria	SBS - 0.73
	Mucous Memb./Upper Respiratory - 0.76
Prevalence of Particles in the Dust	Mucous Memb. - 0.81
Prevalence of TVOC	Lack of Concentration - 0.85
	Headache - 0.72
Macromolecular Dust	Headache/Dizziness - 0.66
Histamine Emission by Dust	Malaise/Dizziness - 0.65
* Correlation Coefficient	

Maintenance Practices and Occupant Behavior

1- Park JH, Gold DR, Spiegelman DL, Burge HA, Milton DK (2001), *House Dust Endotoxin and Wheeze in the First Year of Life*, American Journal of Respiratory Critical Care Medicine, 163(2): pp. 322-8:

This study analyzed the correlation between endotoxin exposure and wheezing in children. The endotoxin settled with dust was measured. It was found that there is a significant association of elevated endotoxin (higher or equal to 100 EU/mg) in family room dust with an increased risk of wheeze (Relative Risk = 1.29, 95% CI: 1.03 – 1.62). Another multivariate model including factors such as cockroach allergen, lower respiratory illness, smoking during pregnancy, or maternal asthma yielded a multivariate relative risk (RR) = 1.33 (95% CI: 1.00 – 1.76). In the multivariate model, elevated endotoxin in family room dust was also associated with an increased risk (RR = 1.56, 95% CI: 1.03 – 2.38) of repeated wheeze.

These results suggest that home endotoxin exposure may increase risk of any wheeze and repeated wheeze during the first year of life for children. Even if this doesn't apply directly to the office indoor environment (no study on this subject has been done), the results might suggest some correlation. Proper maintenance practices and dust removal should be performed to get rid of endotoxin accumulation.

2- Raw GJ, Roys MS, Whitehead C (1993), *Sick Building Syndrome: Cleanliness is Next to Healthiness*, Proceedings of Indoor Air, 3: pp. 237-245:

Theoretically, it is believed that SBS symptoms are caused, in part, by indoor surface pollution (ISP): pollutants such as dust, fibers, and micro-organisms deposited and settled on indoor surfaces. This study tried to evaluate the amplitude of each of four possible causes of SBS symptoms, by performing these procedures in turn: Ventilation system cleaning, air-filtration, hot-water extraction cleaning of chars and carpets, and high grade fiber vacuuming and dusting as well as dust mite treatment (using liquid nitrogen).

After applying each of the four measures, only the last two brought significant decreases in the occurrence of SBS symptoms. This concludes that cleaning, which effectively reduces ISP can also reduce SBS symptoms. This also leads to the issue of monitoring; if ISP and the temporary local pollution levels created by it are a problem, then monitoring of ambient conditions cannot always identify the source of the problem. Indoor design and furniture layout should be rethought to make cleaning easier. Moreover, better cleaning practices should be specified.

3- Skulberg KR, Skyberg K, Kruse K, Huser PO, Levy F, Djupesland P (1999), *Dust, Allergy and Health in Offices: An Intervention Study on the Effect of Cleaning*, Proceedings of Indoor Air, 1: pp. 92-3:

This study analyzes the effects of intensive cleaning in offices where the occupants have a high number of reported mucosal irritation symptoms. About a hundred employees were divided into two groups: study and control groups. The control group received a superficial office cleaning (placebo) while the study group received a thorough cleaning. Airborne dust concentration and health indicators were measured, including a screening test for common allergies (Phadiatop test).

The study's result was that intensive cleaning dramatically reduced dust levels (especially in offices with levels > 50 mg/m^3). The study group also witnessed a greater reduction in mucosal irritation symptoms than the control group.

Another similar study by the same author used rhinometry to measure nasal volume. The reduction of mucosal symptoms was in the order of 27%, while nasal dimensions increased by 15%, compared to 2% and 6% respectively for the control group. Nasal volume is significantly associated with allergy status. The implication of this study is that thorough office cleaning can provide health benefits in the form of reduced mucosal irritation, particularly for sensitive individuals, with the potential for reduced complaints and improved productivity.

Table IV.19 - Association of Surface Cleaning and Mucosal Irritation	
Indoor Surface Cleaning	**Consequence**
Thorough Cleaning	Mucosal Irritation Symptoms Decrease - 27%
	Nasal Dimension Increase - 15%
Superficial Cleaning	Mucosal Irritation Symptoms Decrease - 2%
	Nasal Dimension Increase - 6%

4- Oseland N, *To What Extent does Workplace Design and Management Affect Productivity*, Johnson Controls, 1999, **posted on:** Office Productivity Network: Improving Workplace Productivity, Design, and Management, Dec. 2001:

Table IV.20 - Effect of the Workplace on Staff Productivity			
Design / Operations and Maintenance Issue	**Source**	**Productivity**	**C***
Mean total downtime due to poor facilities, eg. Walking to/ waiting at faxes and copiers	Oseland and Barlett	-12.5%	2
Increased illuminance from 550 to 1100 lx for paper-based work	Barnaby	+2.8%	2
Increased lilluminance from 100 to 1100 lx in a textile factory	Cabak	+20%	2
Introduction of up-lighting for VDU work	Hedge et al	+3%	2
Lighting refurbishement in aircraft production	Romm & Browning	+20%	2
Lighting refurbishement in designer's office	Romm & Browning	+15%	2
Increasing noise by 10 dB in post room	Kourigin & Mikheyen	-25%	3
Reducing noise (using ear plugs) for industrial weavers	Weston & Adams	+12%	1
Reducing noise in assembly room	Kryter	+68%	1
Introducing sound absorbing material into wall of typing pool	Wilson	+29%	1
Extreme temperatures in munitions factories	Fox	-30%	2
Warm temperatures in summer months of tin-plate manufacturer	Vernon et al	-10%	2
High temperature in coal mine	Vernon et al	-27%	2
Introducing AC into utility company	Schweisheimer	+50%	1
Introducing AC into leather manufacturer	Schweisheimer	+8.5%	1
Introducing AC into electrical manufacturing	Schweisheimer	+3.5%	1
Uncomfortable conditions in typing pool	Wyon	-40%	1
Increasing fresh air intake to dilute pollutants	Kemp & Dingle	+3%	1
Bringing offices up to current IAQ standards	Dorgan	+4%	1
Moving from Natural Ventilation (NV) to AC office	Sterling	-6%	1
Comparison of NV versus AC offices	Oseland	+3%	1
Control over environmental conditions	Drake et al	+9%	2
Control over environmental conditions	Kroner et al	+2.8%	3
Office refurbishement	Kroner et al	+12.9%	3
Office refurbishement and restructuring	Sullivan	+67%	2
New furniture	Sullivan	+15%	3
Properly designed workstation	Springer	+10%	1
Increasing privacy through cellular offices	Brill et al	+12.3%	1
Voice response systems in call-up centers	Lewis	+10%	2
* Confidence: min. (1) and max. (3)			

This article reviews the subject of workplace productivity; after presenting issues such as workers performance and productivity measurement, it studies the impact of organizational factors on workplace productivity. The approach is based on an elaborate literature review, with a summary and evaluation of each paper. The following table (Table IV.20), prepared by Dr. Oseland (Oseland, 1999), summarizes the effect of the workplace on staff productivity:

Association of Workplace Attributes with Health and Productivity

Summary of findings

"It is common knowledge that factors other than workplace design and management affect productivity. Organizational factors and individual factors have the largest influence on productivity. Organizational factors include hierarchy, culture, reward system, and leadership. Individual factors include motivational issues such as aspiration, rewards, loyalty, self-motivation, and ability such as aptitude, experience and training. So is it a valuable exercise to measure the impact of workplace (environmental factors) on productivity?"

Dr. Nigel Oseland[13]

After an elaborate review of more than 27 relevant papers, with most of them being an appraisal of many studies, we can assertively answer the question raised by Dr. Oseland affirmatively. It is generally accepted that typically the workplace design and operation can have up to a 15% effect on performance (Wyon, 1993; Brill et al, 1984). A quick evaluation of an average for productivity increases due to IEQ strategies would give a 4% - 8% range. This number is by no means negligible, especially that an increase of 1% is enough to cover all the operations and maintenance bills of an office.

The results demonstrated by the studies in the previous sections are very scattered, with incompatible measurement units. However they all share the same characteristic of associating a physical attribute of a workplace feature or the performance of a certain system with health and productivity outcomes. In turn, the possible health hazards can be divided into broad categories, and themselves can be translated into their impact on productivity. This will allow us to set the guidelines for five matrices, one for each of the broad categories defined in the previous sections. Each matrix will relate ranges of possible actions (IEQ strategies) with their respective health and productivity outcomes.

However, joining all the reviewed studies in one set of guidelines raises an important question: What are the credentials of each study? In fact, some issues like natural ventilation for instance, were thoroughly scrutinized by many experiments, while others were stated with a high level of uncertainty, or through poorly designed tests. Although this problem was resolved in part in the initial screening of the selected papers, it still exists. For this reason, the resulting matrices would yield results in ranges representing the optimistic and pessimistic figures. Moreover, the structure of each matrix would accommodate for future research, for this field of study is still fresh and many new experiments and analyzes are surfacing daily.

Another very important issue is also raised when joining the results of the previous studies: How to add the results of each intervention. For example, if strategy (A) yields an increase in productivity of 4% while strategy (B) results in a 5% improvement; would the implementation of (A) and (B) together, result in a 9% increase or a result somewhere between 5% and 9%? Moreover, sometimes some strategies work against each other or cooperate to achieve even better results. This brings up the need for a method, annexed to the matrices, to add up their effect. The source for this information would be existing case studies where one or more strategies were implemented. The results, bearing in mind uncertainties, would help us understand the way different IEQ strategies work together.

The next section will present a paper, *"Greening the Building and the Bottom Line: Increasing productivity through Energy-Efficient Design"*, by Joseph Romm and William Browning from the Rocky Mountain Institute[14]. This work analyzes and compares six case studies and evaluates their health benefits and productivity increases. Comparing their findings and those of the tables from the previous sections would bring us one step closer to understanding the additive process of the results.

Case Studies

Retrofit Case: Reno Post Office, Reno, Nevada

The 1986 lighting and energy retrofit of the Main Post Office in Reno, Nevada, made it the most productive of all mail sorters in the Western part of the United States. The post office was a modern warehouse with high ceilings and black floors, along with two huge noisy mail sorting machines. The retrofit, initially aiming to reduce energy use, included the redesign of the roof and lighting. The lower ceiling made the room easier to heat and cool along with better acoustics. The ceiling was also sloped to enhance indirect lighting now replacing a harsh direct down lighting.

The cost of the retrofit was around $300,000, while the energy savings came to about $22,400 per year, with additional annual savings of $30,000 due to less frequent repainting. The $300,000 investment yielded a six-year payback period.

From another side, the retrofit also produced productivity gains of 6% for the value of $400,000 to $500,000 per year, which would pay for the entire costs in less than a year. However it is interesting to look at the six percent figure (as well as the 0.1 percent rate of sorting errors) suggested by this example and compare it to the findings of the previous sections. According to (Fisk, 2000) and (Heschong, 1999), lighting retrofits could yield up to 5% or 6% increases in productivity. However, from another side, (Oseland, 1999) suggests increases between 12% and 25% due to 10dB decrease in noise. However, according to this example and due to the nature of the retrofit and machines used, we could estimate that lighting improvements were responsible of two third of the result (4% due to lighting and 2% due to better acoustics). Since the two attributes are completely diverse, their effects can be considered to be 100% additive, hence the 6% result.

Retrofit Case: Boeing Energy-Efficient Lighting, Seattle, Washington

The aircraft manufacturer Boeing is participating in the U.S. EPA's "Green Lights" program promoting energy-efficient lighting. It has already retrofitted 12.5% of its 8 million square feet assembly space near Seattle. Through various lighting upgrades, Boeing has reduced lighting electricity usage by 90%, which yields an overall Return-on-Investment (ROI) of 53%. However, due to better work conditions and employee satisfaction (better IEQ), the facility managers estimate that the productivity increases (although not quantified) and drops in error rates are worth at least as much as the energy savings. A good estimate would put these at around 2 percent. Even though this example doesn't apply directly to office environments, it helps in giving a scale to productivity increases due to lighting retrofits.

Retrofit Case: Pennsylvania Power and Light, Pennsylvania

This early 1980s lighting retrofit of the drafting engineers' studio of the Pennsylvania Power & Light is a good example of a successful investment in IEQ strategies that yielded returns up to 540 percent. The draftsmen were experiencing veiling reflections, a form of indirect glare due to the reflection of light on the working surface. The utility used high-efficiency lamps and ballasts, along with a full reconfiguration of the lighting scheme, focusing more on the drafting surface than other spots such as circulation. In other terms, this resulted into less general illuminance but a more intelligent lighting.

The total net cost of changes amounted to $8,362 and resulted in a drop of 69% in energy use and 73% in total annual operating costs ($2,800 to $765). The direct savings alone would have paid back the investment in 4.1 years, i.e. ROI equal to 24%. However, the lighting re-design increased the productivity of workers by 13.2 percent (0.163 drawings per hour vs. 0.144 drawings per hour). This gain, worth $42,240 per year, would pay back the whole investment in 69 days; the resulting ROI would be 540%. Moreover, the rate of sick-leave dropped by 25 percent and the employee morale was boosted significantly. According to the facility manager, if we were to count the value of the reduced rate of error, we would add another $50,000 per year, increasing the ROI to more than 1,000 percent.

Compared to the papers analyzed in the previous section about lighting, we find that this case study yielded results even higher than the expectations. This may be due in part, to the poor condition in which the studio was before the retrofit. However, it may also help us prove that the numbers advanced by the reviewed studies are rather conservative and represent the lower end of the range.

New Building Case: Lockheed Building 157, Sunnyvale, California

This case study involves interventions at two levels: Lighting and occupant's behavior, more specifically acoustics. This new office 600,000 square feet building, commissioned in 1979 and finished in 1983, houses 2,700 engineers and support people for the Lockheed Missiles and Space Company. The lighting strategies consist of introducing daylight deep in the building and make it the major source of lighting. Furthermore, it was complemented by workstation lighting controllable by each employee, as well as general fluorescent lighting controlled by daylight sensors. On the other side, the whole office layout, as well as materials were designed and selected for better acoustics. All post-occupancy surveys showed a high level of satisfaction of employees with their workplace.

The IEQ strategies implemented increased the $50 million cost of the building by $2 million. The 75% savings on the lighting bill as well as savings on the HVAC energy bill (Daylighting absorbs less heat than regular lighting) totaled $500,000 a year. The improvements paid for themselves in little over than 4 years. The manager of the Facility Interior Development assured that productivity increased since absenteeism went down; however, no official numbers were published by Lockheed. Later on, many Lockheed officials gave some figures: 15% drop in absenteeism along with 15% increase in productivity. These results go in line with the expected 5% for better lighting and 10% for a better designed workstation including improvements in acoustics (Oseland, 1999).

New Building Case: West Bend Mutual Insurance, West Bend, Wisconsin

The West Bend Mutual Insurance Company's new 150,000-square-foot headquarters in West Bend, Wisconsin, built in 1991, incorporates green strategies resulting in health and productivity benefits. It also has perhaps the most carefully documented increases in productivity due to green design. The building has a number of IEQ features, including energy-efficient lighting (task lighting and occupancy sensors), better windows, shell insulation, and an efficient HVAC system. Moreover, the workers benefit from an Environment Responsive Workstation (ERW) with individual control over temperature and airflow along with controlled task lighting and white-noise levels reduction. These measures allowed the owner to get utility rebates and keep the project within its budget of $90 per square foot.

The new annual electricity costs are $1.32 per square foot (versus $2.16 per square foot in the old building). Detailed studies of productivity, both in the old and new buildings, were conducted by the Rensselaer Polytechnic Institute (RPI) in Troy, New York. The implemented IEQ strategies (ERWs and other) yielded a 16% increase in productivity from the old building. Further studies showed that the ERWs alone, were responsible for a 2.8% increase in productivity (some other studies advance a figure of 4% to 6%) worth $364,000 per year. These figures are compatible with the 2% - 3% range proposed in the previous reviews.

Certification System and Building Commissioning

The information about the associations between IEQ strategies and health and productivity benefits is conveyed through highly technical and complicated language. Even though design practitioners and builders are familiar with most of it, developers and building owners may not always grasp it. Moreover, this chapter only sets the guidelines for analyzing IEQ/health/productivity associations, for this field is very wide and varied. Therefore, we find the need for a certification system adapted for IEQ.

An IEQ Certification System (IEQ-CS) would evaluate the impact of a set of strategies implemented in a building and would evaluate the resulting health and productivity benefits. In other terms, without going into the technical specifications of building systems, a developer would be able to make decisions based on the cost of specific systems and relate them directly to tangible outcomes. The IEQ-CS would be administered by a qualified third party that would work in parallel with the consultants during design, construction and operation of a building project.

On the other hand, most of the IEQ strategies analyzed in this chapter involve increasingly sophisticated HVAC systems, energy conservation equipment, lighting systems, and mechanized thermal control devices that rely on electronics. The increasing reliance on advanced technology makes it more frequent for one or many systems not to perform properly or as expected. This would result in energy-efficiency losses, occupant complaints about IEQ, high initial investment and operating costs with very little return. Buildings designed to meet a specific return on investment would fail to achieve their target and the risk of liability would increase for building owners, operators, employers, and design professionals. For this reason, a very important issue should be raised with the introduction of complicated building upgrades: Building Commissioning.

Building commissioning (BC) involves examining and approving building systems to verify that they function (or will function) as intended. This task is usually performed by a qualified third party during design, construction, and post occupancy, with major milestones at the completion of the project and one year after putting it in service. Joining the tasks of administering an IEQ-CS and BC seems natural in this case, for reasons of trust and liability. It should be said that the success of the IEQ-CS would rely in part on the worth and sincerity of the BC.

The next chapter, which will describe the structure and content of a certification system adapted for IEQ, will deal with the issue of building commissioning extensively. After elaborating on this IEQ-CS, which is a way of creating an incentive for developers to upgrade their IEQ strategies, the chapter to follow will experiment with a real-life simulation to show the process as well as the advantages and disadvantages of this system. The case study will involve mostly the financial aspect of a building project in the perspective of the developer, in order to evaluate the potential benefits of IEQ green strategies.

Notes

[1] United States Green Building Council, *LEED™ Reference Guide 2.0, Section 5: Indoor Environmental Quality*, Paladino Consulting LLC, June 2001

[2] Gottfried D, *Sustainable Building Technical Manual: Green Building Design, Construction, and Operations - Chapter 1: The Economics of Green Buildings*, Public Technology, Inc., 1996

[3] Health benefits and lower liability risk were neglected in this example for simplicity.

[4] **Excerpts from:** Bernheim A, *Sustainable Building Technical Manual: Green Building Design, Construction, and Operations – Chapter 13: Indoor Air Quality*, Public Technology, Inc., 1996

[5] Hansen S, *Managing Indoor Air Quality* (Englewood Cliffs, NJ: Fairmont Press, Distributed by Prentice Hall, 1991), 43, 44, 76

[6] Ibid

[7] Fiedler N, Maccia C, and Kipen H, *Evaluation of Chemically Sensitive Patients*, Journal of Medicine 34, no.5 (May 1992)

[8] National Science and Technology Council (NSTC), *Indoor Health and Productivity Project (IHP)*, www.IHPCentral.org

[9] Romm J, and Browning W, *Greening the Building and the Bottom Line: Increasing Productivity through Energy Efficient Design*, Rocky Mountain Institute, 1998

[10] **Excerpts from:** Kumar S, and Fisk WJ, *The Role of Emerging Energy-Efficient Technology in Promoting Workplace Productivity and Health: Final Report*, IHP Project, NSTC, Feb. 2002

[11] Ibid

[12] Kroner WM, Stark-Martin JA (1992), *Environmentally Responsive Workstations and Office Worker Productivity*, Ed. H Levin, Proc. Indoor Environment and Productivity, June 23-26, Baltimore, MD, ASHRAE, Atlanta

[13] Oseland N, *To What Extent does Workplace Design and Management Affect Productivity,* Johnson Controls, 1999, **posted on:** Office Productivity Network: Improving Workplace Productivity, Design, and Management, Dec. 2001

[14] Romm J. and Browning W., *Greening the Building and the Bottom Line: Increasing Productivity through Energy Efficient Design*, Rocky Mountain Institute, 1998

CHAPTER V
IEQ CERTIFICATION SYSTEM

Developing a Certification System Adapted to IEQ

After reviewing a substantial amount of papers and studies relevant to the subjects of associating IEQ improvement strategies and health and productivity benefits, it is important to think of a tool that would convey part of these rewards to the developer. In fact, we have already seen that health and productivity benefits, if well analyzed and quantified, could be transferred to monetary values. In other terms, if the developer invests in IEQ strategies, the user of the space will get the estimated benefits. However, it goes without saying that the developer would not invest unless he gets enough returns himself. This raises the question of a partnership that should be formed between the developer and his client. Subsequently, the benefits should be divided between both parties for the deal to go through. The tenant would not pay an increased rent equal to the value of the productivity benefits, while the developer would not undertake any improvements unless they are rewarding enough.

However, this raises an even bigger problem represented in a conflict of interest between the developer and his tenant. In fact, productivity speculation and measurement has a high level of uncertainty due to the complexity of the subject in itself. For this reason, the involvement of a neutral and qualified third party should be envisaged. This third party should administer a certification system adapted to the association between IEQ strategies and their health and productivity outcomes. Working with the design and construction teams all through design, construction and building commissioning phases, this sustainability controller would assign a health and performance rating for the building. His responsibilities would even go further to test and measure productivity through questionnaires and studies once the building is occupied and through the life of the building. In other terms, the earned rating for each building would have to be re-checked and maintained at different time intervals to make sure that the systems are working properly.

This chapter will present and explain the functioning of the IEQ Certification System (IEQ-CS). It will also define the role and responsibilities of the third party in charge of administering this IEQ-CS. After raising some issues associated with measuring productivity, the next sections will present the structure and content of the IEQ-CS, along with a small sample case study.

Productivity Measurement

The success of a certification system adapted to IEQ relies partially on the ability to measure and quantify productivity and convert it to a monetary value. This task gets even more complicated since very few companies monitor their staff performance, let alone using the information to full effect. In a study by Oseland and Barlett (1999)[1], it was found that only 20% of the companies they visited had productivity monitoring among their daily practices. For this reason, productivity measurement methods should be analyzed, to find which is best to evaluate the impact of IEQ on human performance.

There are many ways of measuring productivity and these vary widely according to the structure of the organization in question. According to another study by Oseland (1999)[2], there are many generic measure of business performance that can be grouped into four categories: Operating ratios, business targets, HR measures, and process efficiency. He also raises two important issues about (a) the relevance of the measure to organizational levels within the company, and (b) the ability to generalize the measure across companies. The generic measures of performance are summarized in Table V.1 below:

Table V.1 - Generic Measures of Performance

Group Measure	**Specific Measure**
Operating Ratios	Share Value
	Annual Turnover / Revenue
	Utilisation Rates, Average Charge Out Rate, Overhead Costs
	Customer Satisfaction
Business Targets	Outside Interest, Number of Visitors and Partnerships
	Self-Assessment of Performance (Using Questionnaires)
	Number of Enquiries Answ ered and Resulting Income
	New Business / Projects and Resulting Income
	Staff Attendance (Absenteism, Unpaid Overtime)
	Peer and Management Assessment
HR Measures	Annual Staff Appraisal, Performance Related Pay / Bonus
	Personal Aw ards and Achievements
	Staff Attitude, Job Satisfaction and Commitment
Process Efficiency	Response Time to Carry Specific Requested Duties
	Time to Carry Out Specific Activity

According to the same study, it is easier to quantify productivity increases at the level of the whole company (Operating Ratios and Business Targets), but very difficult to associate with specific improvements to IEQ. Similarly, at the individual level, it is easy to evaluate productivity, but it remains difficult to apply it to the group/team performance. Usually, businesses focus on the latter through their improvements to IEQ.

Another challenge is that office work in itself does not provide a tangible outcome that can be easily measured; unlike manufacturing companies which produce a quantifiable output/product. In some cases, a company would develop an in-house measure relevant to its business e.g. claims processed in an insurance company or average call-waiting time in a call center. In all cases, productivity consultants should be able to select specific criteria that would more or less effectively associate productivity variations to IEQ strategies. The accuracy of the measurements would vary from case to case but ultimately, it would be enough to show the benefits of IEQ improvements.

The need for a qualified third party to measure productivity and certify new and refurbished buildings becomes imminent. The next section will assess the responsibilities of this party and will envision steps for measuring productivity and certifying building projects.

IEQ Consulting and Certification Process

Measuring increases or decreases in productivity due to the quality of workplace can't be done but in comparison to the productivity of the tenant in other office locations. For this reason, pre and post-move performance should be measured and then subtracted. Another important issue is that the tenant is most of the time not present at the time of design/construction or issuing of the certification rating. Therefore, there is a need for a more complex certification process. This section will describe the different phases of the IEQ-CS and the role of the IEQ Consultant in each.

The first role the IEQ Consultant should assume is very close in concept to the traditional building commissioning task, but applied on IEQ strategies only. In other terms, the IEQ Consultant should work with the design, construction and operation teams to make sure that the building systems affecting IEQ are well designed and constructed. In the design phase, they should assist the designers in setting priorities and goals for a projected IEQ. During construction, they perform routine quality checks. At the end of the project, the IEQ Consultant, assisted by a building committee representing the A/E, contractor and developer, should make sure that the building meets the specifications set forth at the beginning. The IEQ Consultant should also perform routine performance checks after the building is in operation.

The IEQ-CS process also starts early on: During the (1) design phase, the IEQ Consultant coordinates with the designer and developer to determine the target rating. Then, all through design and construction, the IEQ Consultant awards a certain rating based on the expected productivity and health benefits. Productivity increases are measured by comparison to industry standards. The high uncertainty at this level makes the rating inaccurate; however, it can be used as a marketing tool by the developer.

The next major step happens at the (2) substantial completion of the project. The IEQ Consultant can now measure the exact performance of the implemented systems, and award a rating that reflects more or less the productivity and health benefits in comparison to similar buildings on the market. This rating constitutes the basis for discussion between the developer and a prospective tenant.

The third level of certification is awarded (3) a year after the building has been occupied. The systems improving IEQ can now be tested in real life through a series of employee surveys and questionnaires. A productivity analysis is also performed by the IEQ Consultant to learn more about the impact of IEQ improvements on human performance. The rating will be re-evaluated annually (or at a set interval) and either maintained or down-graded. Such measure would make sure that the benefits are always realized and that operations and maintenance are carried out as planned. Moreover, the annual re-evaluation of the building rating can be done along (or connected contractually) with the rent negotiation. This is normal since the rent is defined in association with the projected benefits.

It should be noted that the IEQ Consultant's responsibilities are varied and extend over a long period of time; their reward should be substantial. However, with the value of the estimated increases in productivity, the cost of such commodity shouldn't be a problem.

The next section will discuss the structure of the IEQ-CS. After setting the framework of the system i.e. issues such as flexibility, graded categories and pre-requisites, and addition/subtraction of credits, it will reformulate the findings of the literature review from the previous chapter into IEQ improvement guidelines. It should also be noted that the system presented is based on limited research and is only trying to set the framework for a certification system; not a complete and accurate technical manual.

Structure and Content of the IEQ-CS

Structure

The backbone of the IEQ-CS is the research currently going on in the field of IEQ and its association with health and productivity. This field is very wide, complicated, and the research in it is still at its early stages. Consequently, the design of the IEQ-CS should be flexible and expandable, allowing for new research results. Later versions of this IEQ-CS should be more accurate and comprehensive. The experience of the IEQ Consultant administering the certification process is also very important in updating and developing later versions of the system.

The structure of the IEQ-CS should be straightforward with criteria easy to evaluate by design and construction professionals. It should relate physical descriptions of systems or outcomes (according to the case) to a grading system. In other terms, a list of IEQ strategies should be provided, along with the maximum and minimum grading for each. The next step would be to relate the earned grades to health and productivity benefits.

The selected criteria would represent any IEQ factor that has an effect on health and productivity. A good way of regrouping them would be following the sub-division of building systems from the previous chapter. The five major categories of criteria are: (1) HVAC Systems, (2) Lighting and Daylighting, (3) Building Envelope, (4) Building Materials, and (5) Maintenance Practices and Occupant Behavior (including acoustics).

Moreover, there should be a set of pre-requisites for each category. These characteristics add some gain to the performance of the building without justifying their cost, and focus on the environmental benefits. By including them as pre-requisites, the IEQ-CS would be using some of the value of added productivity to promote the environment.

On the other side of the scale, there would be four separate grading scales. Each of the scales would represent the size of the benefits in terms of one of the following four outcomes: (1) Productivity Increase, (2) SBS Symptoms Decrease, (3) BRI Symptoms Decrease, and (4) MCS Symptoms Decrease. The productivity losses or gains due to health symptoms would be included. After evaluating the building systems performance, the grades should be added to evaluate the performance of the whole building.

It should also be noted that the grading may include negative numbers if the systems fail to meet a minimum performance. It has been proven through many studies, that poor IEQ could also have a negative impact on health and performance. In other terms, it would not be very useful to invest heavily in one category while overlooking others. The negative impact of some strategies can be substantial, resulting in a negative total even with a large investment in other strategies. For this reason, with the help of the IEQ Consultant, a balancing of the IEQ strategy design should be done in order to avoid a negative result.

The next section will present the criteria and pre-requisites of each category of the IEQ-CS. A small sample case would be discussed afterwards to show the way points are added or subtracted.

Content: Criteria and Pre-Requisites of the IEQ-CS

The following five tables are a proposal of what could be the basis for the IEQ-CS discussed in the previous sections. Each table represents the criteria and pre-requisites for a broad category. A positive grade unit under the "Productivity" column represents a 0.1 percent increase in productivity, while each unit under the remaining columns represents a 1 percent decrease in the occurrence of the health symptom in question. It should also be noted that any similarities of the proposed system with the IEQ section of the U.S. Green Building Council's LEED™ Rating System are unintentional and purely by accident.

Table V.2 - IEQ-CS Category I: HVAC Systems

Type	IEQ Strategy	SBS*	BRI*	MCS*	Prod.
P1	Meet the minimum requirements of ASHRAE Standard 62-1999	---	---	---	---
C1	Install a permanent CO_2 monitoring system and maintain ΔCO_2 (Int.-Ext.) level less than (500; 250; 0) ppm	2;4;6	---	---	10;20;30
C2	Ventilation rate per person: (10; 15; 20; 25) Ls^{-1}	0;2;4;6	0;2;4;6	---	-20;0;10;20
C3	Rely on w indow s for ventilation for more than 50% of time	6	4	2	10
C4	Individual controllability of ventilation (±3°C)	10	5	---	50
C5	HVAC System air intake beyond 25ft. of pollution source	10	5	2	10
C6	Implementing enough IAQ strategies to reduce the number of IEQ complaints by 10%	8	4	1	15
SBS	Sick-Building-Syndrome				
BRI	Building Related Illness				
MCS	Multiple Chemical Sensitivities				

Table V.3 - IEQ-CS Category II: Lighting and Daylighting

Type	IEQ Strategy	SBS*	BRI*	MCS*	Prod.
P1	Provide a direct line of sight to w indow s (view s) from 90% of regularly occupied spaces	---	---	---	---
C1	Achieve a Daylight factor of (2%; 4%; 6%) in more than 75% of regularly occupied spaces	2;4;6	---	---	10;20;40
C2	Skylight introducing (low , medium, high) Daylighting	2;4;6	---	---	10;20;30
C3	Well-designed skylight (abundant Daylighting, diffuser, control)	2	---	---	20
C4	Individual controllability of lighting (one lighting ctrl. zone per 200sq.ft.)	10	---	---	50
C5	Daylight simulating skylights for night shifts	30	---	---	20
C6	Maintain illumination level betw een 400 and 500 lx through the use of sensors	20	---	---	10
C7	Skylighting in retail spaces	---	---	---	40

Table V.4 - IEQ-CS Category III: Building Envelope

Type	IEQ Strategy	SBS*	BRI*	MCS*	Prod.
C1	Insure proper building envelope practices to minimize the risk of dampness and mould grow th	3-6	2-4	---	10;30
C2	Proper HVAC system maintenance	1	---	---	5

Table V.5 - IEQ-CS Category IV: Building Materials

Type	IEQ Strategy	SBS*	BRI*	MCS*	Prod.
P1	Use of design softw are for material selection w ith low VOC emission	---	---	---	---
C1	Use of permanent monitoring device for VOC and TVOC levels	8	4	5	30
C2	Keep formaldehyde levels below (60; 40;16) ppb	1.5;4;5	1;2;3	2;3;4	10;20;25

Table IV.6 - IEQ-CS Category V: Maintenance Practices and Occupant Behavior					
Type	IEQ Strategy	SBS*	BRI*	MCS*	Prod.
P1	Provide thorough cleaning practices of all indoor surfaces	---	---	---	---
P2	Provide proper building systems performance check (esp. HVAC)	---	---	---	---
C1	Proper HVAC maintenance	15	10	5	40
C2	Noise Reduction through insulation, better design and operations	8	---	---	60
C3	Using natural ventilation (w indow s) for more than 50% of time	3	1	1	15
C4	Poor facilities design (location and operation of photocopiers, fax, etc	5	---	---	60

The table would then be used to evaluate the IEQ strategies implemented, by the grades given to each category. Each non-satisfied category would have a negative grade equal to half its grade value. The totals should give the increase in productivity in percentage as well as the decrease in risk of occurrence of each health symptom category. These can then be translated into monetary value after a quick analysis of the tenant's organizational structure and type of activity taking place in the office in question.

The next section will provide a sample case that administers the IEQ-CS for an office building. The result will be used in the next chapter to evaluate green building finance from the developer's perspective.

IEQ-CS Case Study

A Typical 100,000 Sq. Ft. Office Building Incorporating Green IEQ Strategies

The following case study evaluates the IEQ strategies implemented in an office space, and quantifies productivity and health benefits. The building has incorporated the IEQ strategies described hereafter. The initial grading report is represented in Table V.7.

On the level of the HVAC system, a CO_2 monitoring device is installed, with a notification system whenever the difference in Carbon dioxide level between interior and exterior exceeds 250 ppm. A ventilation rate of 20 Ls^{-1} per person is provided, and windows are opened more than 50 percent of the time for natural ventilation purposes. Provision is made for future implementation of individual ventilation control systems allowing for ±3°C thermal comfort range per person. The building being located in the downtown, providing HVAC air intake beyond 25 feet from a pollution source was difficult and deemed cost inefficient, therefore neglected.

Due to the surrounding buildings, only a 2 percent daylight factor was achievable. Well designed skylights were provided for 20% of the office spaces. Individual controllability of lighting was also provided for, and sensors maintained an optimal illumination levels.

Proper building envelope practices such as waterproofing and vapor barriers were provided, as well as design features for ease of maintenance. No monitoring system for VOCs was provided but materials were selected using the BEES software, for environment friendly finishing materials. All possible planning and construction features were provided for the ease of future general maintenance.

The results are that the conceived office building would help boost productivity by 15 percent, while reducing SBS, BRI and MCS symptoms by 54.6%, 10%, and 2% respectively. It remains to see how much those building upgrades are costing and compare it to the value of the productivity and health savings. The latter would be translated into monetary value once the tenant is known and its staff and operations analyzed. This falls under the subject of the next chapter.

Table V.7 - IEQ-CS Case Study Grading

Cat.	Criteria	SBS	BRI	MCS	Prod.	Cat.	Criteria	SBS	BRI	MCS	Prod.
I	P1	Y	Y	Y	Y	III	C1	5	3	1	25
I	C1	4	---	---	20	III	C2	---	---	---	---
I	C2	4	4	---	10	III	**SubTota**	5	3	1	5
I	C3	6	4	2	10	IV	P1	Y	Y	Y	Y
I	C4	5	2	---	25	IV	C1	-4	-2	-3	-15
I	C5	-5	-3	-1	-5	IV	C2	2	1	2	10
I	C6	---	---	---	---	IV	**SubTota**	-2	-1	-1	-5
I	**SubTotal**	14	7	1	60	V	P1	Y	Y	Y	Y
II	P1	Y	Y	Y	Y	V	P2	Y	Y	Y	Y
II	C1	2	---	---	10	V	C1	2	1	1	5
II	C2	1.2	---	---	6	V	C2	1	---	---	5
II	C3	0.4	---	---	4	V	C3	1	---	---	10
II	C4	10	---	---	40	V	**SubTota**	4	1	1	20
II	C5	---	---	---	---		**TOTAL**	54.6	10	2	150
II	C6	20	---	---	10	The building w ould boost productivity by 15%,					
II	C7	---	---	---	---	SBS, BRI and MCS w ould be reduced by 54.6%, 10%					
II	**SubTotal**	33.6	---	---	70	and 2% respectively.					

Notes

[1] Oseland N A & Bartlett P, _Improving Office Productivity: A Guide for Business and Facilities Managers_, Harlow: Longman, 1999

[2] Oseland N, _To What Extent does Workplace Design and Management Affect Productivity,_ Johnson Controls, 1999, **posted on:** Office Productivity Network: Improving Workplace Productivity, Design, and Management, Dec. 2001

CHAPTER VI
CASE STUDY: REGULAR VS. GREEN OFFICE DEVELOPMENT

Case Study Description

Having developed the IEQ Certification System, it would be useful to apply the findings in comparing a regular office development to the same development but implementing IEQ green strategies. The analysis will be done in the perspective of the developer; the results would constitute an evidence of the benefits of green buildings and perhaps, the IEQ-CS would become an incentive for developers.

The following chapter will develop this case study, by first describing the project in question. Then, it will provide an analysis of the regular office building finance approach using the Discounted Cash Flow (DCF) method. The next section will study the structure of the tenant's organization to be able to quantify the value of productivity benefits described in the case study of the previous chapter. Then the green building financial analysis will be described, showing the role of the IEQ Consultant as well as the phases of the IEQ-CS. The chapter will conclude by comparing the Internal Rate of Return (IRR) resulting from the two DCF analyzes.

The Developer

For this example, we are considering a small size development company, ABC Development, Inc., analyzing possible alternatives for an office building project. ABC owns a piece of land in the downtown (no specific city is considered) worth $3 million. It is considering two alternatives: (1) a 100,000-square-feet office building to be leased to one tenant, contracted with for a variable period of time. The contract is signed before the substantial completion of the building. The second alternative, (2) is an office building incorporating IEQ enhancing green strategies (same gross area and general design). ABC would then contract with an IEQ Consultant to take care of the IEQ-CS process. Initial equity investment is not a very important issue, as long as both alternatives provide the same gross area. The choice will be based on the Internal Rate of Return (IRR) of the proposed project.

The Project

The project is a typical 100,000 square feet office building located in a downtown area. It is planned that the project will be built in two years spending 40 percent of the construction cost in the first year and 60 percent in the second. The lease agreement would include all the operations and maintenance expenses on the developer. In other terms, the developer also acts in this case as a property manager. The prospective tenant is only expected to pay a fixed rent per square foot per year. The rent escalation will be provided for in the lease agreement.

The project will be financed through two loans. The first is a construction loan, and will finance the construction of the project. The second is a long-term loan amortized over 30 years; it will repay the first loan and will be repaid over ten years. At the end of the ten-years operating period, the developer plans to sell the property at its residual value and make a balloon payment to repay the remaining balance on the long-term loan. In both proposals, the loan amounts will be equal to the maximum amount approved by the lending institution.

For the Construction loan, the lending institution would use a Loan-to-Cost (LTC) Ratio of 70 percent. The long-term loan amount is more complicated to determine: They first calculate the value of the building by dividing the Net Operating Income (NOI) over the Capitalization Rate (Cap Rate) which in our case is estimated to be equal to 10 percent. Then, they apply a Loan-to-Value (LTV) Ratio of 70 percent which will give them a certain loan amount A. They then calculate the cost of the investment, equal to the cost of construction plus the cost of the land and any other miscellaneous expenses. They apply an LTC Ratio of 78 percent and they get another loan amount B. They compare A and B and decide on the lower loan amount. This method is applied for both the regular and green proposals.

Proposal I: Regular Office Building Development

Description of the Discounted Cash Flow Model

The budget for the construction costs is $120 per square foot paid for in two years (40 and 60 percent respectively). The total construction costs are $12 million for which the developer borrows $8,400,000 for two years at a 14% annual interest rate. The expected rent is $25.5 per square foot with an estimated vacancy rate of 7 percent. The annual expenses are estimated to be equal to $7.11 per square foot (check breakdown of expenses in Appendix B). The resulting NOI would be $1,660,500 per year what gives a $16,605,000 property value. The long-term loan amount would be equal to $11,623,500 (compared to $11,700,000 for the construction cost by 78% LTC Ratio). This loan is amortized over 30 years with a 10 year period and a 9.5% fixed interest rate. The fixed mortgage payment is $1,181,884.27 per year, with a $10,415,215.84 balloon payment at the end of the ten-year period. Both operations and maintenance and rent have an escalation rate of 2 percent.

Results

At the end of the 10-year period, the property is sold for its value (NOI/Cap Rate) of $20,241,402.34. The resulting IRR is 13.72 percent (13.7155%) which is slightly below average for a similar project. The project requires an initial equity investment of $4,070,400 over two years, in addition to the $3 million piece of land. The second part of this chapter will be devoted to the second proposal: an office building implementing green IEQ strategies.

Proposal II: Green Office Building Development

The Tenant: Valuing Health and Productivity Benefits

Using the example from the previous chapter, the proposed IEQ improvements yielded the following results: Productivity increase of 15% and SBS, BRI and MCS symptoms reduction of 54.6%, 10% and 2% respectively. Let us now approximate the composition of the possible tenant and the impact of 15 percent productivity increase on its operation.

Due to the uncertainty in the numbers at this stage of the analysis, i.e. number of employees of the tenant and their salaries and benefits, the developer would include the worst case scenario, using figures higher than the average. We consider that the space per employee is 180 square feet (instead of the 150 square feet industry average). This raises the number of building occupants to 556. Estimating the average employee salary and benefits is also very difficult if the tenant is unknown. For this exercise, we consider an average annual salary of $35,000 per employee; added to this are the healthcare benefits of $4,000[1] and other benefits of $1,000. The total salaries and benefits paid by the tenant would be as high as $22,240,000 which is approximately equal to $222.4 per square foot.

The value of 15% increase in productivity is equal to $3,336,000 per year or $33.36 per square foot. Since only BRI and MCS are known illnesses causing health care expenditure, we estimate that the health care costs would be reduced by 12% yielding another benefit of $266,880 per year or $2.67 per square foot. The estimated total value of IEQ improvements is $36.27 per square foot. However, these figures are still more or less uncertain, especially in respect to the tenant who might relate the productivity benefits to internal improvements to the company's organization and process efficiency. For this reason, the landlord-tenant partnership dividing these benefits would be closer to a 30%-70% split of the reward. In other terms, the tenant would get to keep $3,336,000 worth of annual benefits by only paying a $10.88 per square foot premium to the rent (totaling $1,088,100 per year). With $2,538,900 worth of net annual benefits, including all the approximations favoring the tenant, it is definitely a good choice for the tenant to go for a green office space.

Impact of Green Strategies on the Financial Analysis

The IEQ improvements proposed in the previous chapter are estimated to cost an additional $30 per square foot[2] raising the total budget to $150 per square foot ($15 million for the whole project. The complexity of the new systems in place is also expected to raise the repairs and maintenance bill by 20 percent. The operations and maintenance escalation is also raised to 2.5% (instead of 2%) for the systems are expected to deteriorate more rapidly. From another side, some of the implemented systems like HVAC and lighting retrofit are also expected to lower total electricity and heating energy usage by 40% and 30% respectively. The resulting total annual operations and maintenance bill would be equal to $6.24 per square foot (lowered by 13 percent).

The construction loan amount is now raised to $10.5 million, however, since the project now costs more per square foot ($150 versus $120), the lending institution deems the project riskier and decides to raise the interest rate from 14% to 16%. The same happens with the long term loan. The amount is first selected based on total project costs with an LTC Ratio of 78 percent; the amount is $14,040,000 versus $21,098,000 using the building value (V = NOI/Cap Rate) with an LTV ratio of 70%. The interest rate is set at 10.5% after the IEQ Consultant's report for the first level of IEQ-CS Rating is reviewed. A year after the building is occupied and the second level of the IEQ-CS Rating is presented, the interest rate is expected to be lowered to 8.5%. In other terms, the long-term loan will be refinanced one year after the building is occupied. The agreement between the developer and the lending institution also includes that the developer should maintain the second level rating over the life of the project or the interest rate would be raised back to the 10.5% figure.

After the agreement is negotiated with the tenant, both parties agree to raise the rent by $10.88 resulting in a rent of $36.38 per square foot. The substantial advantages given to the tenant are expected to lower the vacancy rate to 5%. The IEQ Consultant, whose initial work is performed during the first three years of the project but still continues during the remainder of the project, will be compensated at the rate of $3 per square foot for the initial period and $2 for the remaining life of the project. This amount would cover the expenses of the IEQ Consultant (knowledge, labor) and protect him (liability costs) from failures in the Certification System.

Results and Comparison

At the end of the ten-year period, the property value (NOI/Cap Rate) would be equal to $31,715,753.46, approximately 56% higher than the regular office development's value. It would be sold, to cover in part the long-term loan balloon payment of $12,259,074.12. The Discounted Cash Flow (DCF) Analysis of the project yields an IRR of 30.5 percent (30.5215%), requiring an initial equity investment of $5,772,000 over two years, in addition to the $3 million piece of land. Compared to the IRR of 13.72 percent of the regular office development project, the green office building presents clear and substantial advantages for the developer. The same can be said in respect to the tenant, IEQ Consultant, and all the parties involved in this project.

In conclusion, this case study is only based on approximations; the numbers vary substantially from case to case as well as with geography, location, developer, tenant, and building design and operation. By using the same model and varying the rent amount between $20 and $30, we get a range of IRRs between roughly, 20% and 35% (Table VI.1). In all cases, these figures are higher than the average expected IRR of 15% for a regular office development. With these results, we can easily state that green development makes sense financially for the developers, and that the use of a certification system adapted to IEQ is an incentive for them to turn to green workplaces.

Table VI.1 - Sensitivity of IRR to Rent Amount	
Rent Amount	**IRR**
$40	35.28%
$38	32.71%
$36.38	30.52%
$34	27.09%
$32	23.97%
$30	20.53%

Notes

[1] Atlantic Information Services, Inc., AISHealth.com: Specialized Business Information for Health Care Managers, http://www.aishealth.com/MarketData/DataSummaries/AverageAnnual.html
[2] All estimations are done using previous examples, personal judgment and experience, and RS Means: Construction Costs Information, http://www.rsmeans.com/

CONCLUSION

Summary of Findings

This thesis attempted to frame an approach to creating incentives for developers to turn to green development. However, the field being so wide, diverse and complicated, the findings remained at a relatively shallow level, only setting guidelines instead of discussing issues in details. Starting at the level of policies and incentive programs provided by the Government, the thesis then went into the particularities of green development at the level of the project's finances. The latter was discussed at two levels; first by presenting the material benefits of green strategies usually discussed extensively in previous studies, and then by expanding on the intangible benefits, which most of the time are disregarded or under-estimated. These become the core of the subject, and are developed in three chapters. A method to quantify these benefits in monetary value is proposed and tested in a comparative case study.

The approach at the macro-scale level presented evidence that the Government is a major player in the effort towards a greener construction industry. However, it also established that Government provided incentives are not compelling enough to turn green. Moreover, Government action may also have a drawback, since it might prove green buildings uneconomical by providing independent incentives. For this reason, the Government's involvement in green buildings should be carefully and delicately balanced to help in creating a public awareness without becoming a handicap.

At the micro-scale, a review of previous studies showed that green strategies do make sense economically. However, their benefits are very close to the break-even point that they are not enough to initiate the green revolution the building industry needs so much. However, the solution could be found in the intangible benefits of better health and productivity.

After a thorough literature review, this thesis sets the guidelines for the analysis of published papers and studies in the fields of Indoor Environmental Quality (IEQ), health and productivity. It also opens the way for future studies as well as a method to evaluate future research findings. Moreover, it proposes the major outline for a certification system, which is one option of practically applying the research findings on the market. This system is presented as a summary of the reviewed studies' results. The system's process is also described and tested on a figurative case study.

The results of the case study are clear and compelling, even when using the worst case scenario. According to the approach adapted by this thesis as well as the proposed approximations, productivity and health benefits due to IEQ green improvements hold in them the success of promoting effectively green development.

Future Research

This thesis, having adopted an approach that remains at a broad level, opens the way for numerous fields of research. According to the findings stated above and the personal experience of the author, the following possible subjects of research are crucial for the promotion of green buildings:

- Understanding the role of the Government in providing incentives for green development. Analyzing the cost and benefits of green buildings from the Government's perspective.

- Analyzing the U.S. Policy regarding energy and environmental issues, and proposing solutions at the level of Federal and State Government policies.

- Understanding the associations between the workplace physical attributes and the health and productivity of building occupants. Applying these on many building sectors other than office/commercial development (i.e. industrial, residential, and institutional).

- More research and development on the proposed certification system applied to IEQ is needed, as well as testing the results on more case studies and proposing alternative solutions.

APPENDICES

Appendix A – Reviewed Papers and Studies

Appendix B – Regular Office Development DCF Model

Appendix C – Green Office Development DCF Model

Appendix D – Abbreviations

APPENDIX A

Reviewed Papers and Studies

Source: IHP Project

1- Apte MG, Fisk WJ, Daisey JM (2000), *Associations between Indoor CO2 Concentrations and Sick Building Syndrome Symptoms in U.S. Office Buildings: An Analysis of the 1994-1996 BASE Study Data*, Indoor Air 10(4): pp. 246-57

2- Boyce PR, Beckstead JW, Eklund NH, Strobel RW, and Rea MS (1997), *Lighting the Graveyard Shift: The Influence of a Daylight-Simulating Skylight on the Task Performance and Mood of Night-Shift Workers,* Lighting Research and Technology, 29(3), pp. 105-134

3- Brunekreef B (1992), *Associations between Questionnaire Reports of Home Dampness and Childhood Respiratory Symptoms*, The Science of the Total Environment 127: pp. 78-89

4- Cooper K, Demby S, Hodgson M (1997), *Moisture and Lung Disease: Population-Attributable Risk Calculations,* IAQ 97/Healthy Buildings: Design, Construction, and Operation of Healthy Buildings, 1: pp. 213-8

5- Dales RE, Zwanenburg H, Burnett R, Franklin CA (1991), *Respiratory Health Effects of Home "Dampness" and Molds among Canadian Children*, American Journal of Epidemiology 134: pp. 196-203

6- Fisk WJ (2000), *Health and Productivity Gains from Better Indoor Environments and their Relationship with Building Energy Efficiency*, Annual Review of Energy and the Environment 25(1): pp. 537-566

7- Garrett MH, Hooper MA, Hooper BM (1996), *Low Levels of Formaldehyde in Residential Homes and a Correlation with Asthma and Allergy in Children*, Proceedings of Indoor Air, 1: pp. 617-22

8- Gyntelberg F, Suadicani P, Nielsen JW, Skov, PS, Valbjørn O, Nielsen PA, Schneider T, Jørgensen T, Wolkoff PW, Wilkins CK, Gravesen S, and Norn S (1994), *Dust and the Sick Building Syndrome*, Proceedings of Indoor Air, 4: pp. 223-38

9- Heschong L, *Daylighting in Schools: an Investigation into the Relationship between Daylighting and Human Performance*, 1999

10- Hodgson MJ, Frohliger J, Permar E, Tidwell C, Traven ND, Olenchock SA, Karpf (1991), *Symptoms and Micro-Environmental Measures in Non-Problem Buildings*, Journal of Occupational Medicine, 33(4): pp. 527-33

11- Mendell M, *Non-Specific Symptoms in Office Workers: A review and Summary of the Epidemiologic Literature*, Proceedings of Indoor Air, 3: pp. 27, ISSN 0905-6947

12- Milton DK, Glencross PM, Walters MD (2000), *Risk of Sick Leave Associated with Outdoor Ventilation Level, Humidification, and Building Related Complaints*, Indoor Air, 10(4): pp. 212-21

13- Newsham GR and Veitch JA (2001), *Lighting Quality Recommendations for VDT Offices: A New Method of Derivation,* Lighting Research and Technology, 33(2): pp. 115-143

14- Park JH, Gold DR, Spiegelman DL, Burge HA, Milton DK (2001), *House Dust Endotoxin and Wheeze in the First Year of Life*, American Journal of Respiratory Critical Care Medicine, 163(2): pp. 322-8

15- Peat JK, Dickerson JL (1998), *Effects of Damp and Mould in the Home on Respiratory Health: a Review of the Literature*, Allergy: European Journal of Allergy and Clinical Immunology, 53: pp. 120-8

16- Raw GJ, Roys MS, Whitehead C (1993), *Sick Building Syndrome: Cleanliness is Next to Healthiness,* Proceedings of Indoor Air, 3: pp. 237-245

17- Seppanen OA, Fisk WJ, Mendell MJ (1999), *Association of Ventilation Rates and CO2 Concentrations with Health and other Human Responses in Commercial and Institutional Buildings,* Indoor Air, 9(4): pp. 226-52

18- Sieber WK, Staynor LT, Malkin R, Petersen MR, Mendell MJ, Walligford KM, Crandall MS, Wilcox TG, Reed L (1996), *The National Institute for Occupational Safety and Health Indoor Environmental Evaluation Experience, Part Three: Associations between Environmental Factors and Self-Reported Health Conditions*, Applied Occupational and Environmental Hygiene, 11(12): pp. 1387-92

19- Skulberg KR, Skyberg K, Kruse K, Huser PO, Levy F, Djupesland P (1999), *Dust, Allergy and Health in Offices: An Intervention Study on the Effect of Cleaning*, Proceedings of Indoor Air, 1: pp. 92-3

20- Sundell J (1994), *On the Association between Building Ventilation Characteristics, Some Indoor Environmental Exposures, Some Allergic Manifestations, and Subjective Symptom Reports*, Indoor Air, Suppl. 2: pp. 1-49

21- Wargocki P, Wyon DP, Fanger PO (2000), *Pollution Source Control and Ventilation Improve Health, Comfort, and Productivity*, Proceedings of Cold Climate HVAC 2000, Sapporo, Japan; pp. 445-450

22- Wyon DP (1996), *Indoor Environmental Effects on Productivity*, Proceedings of IAQ '96: Paths to Better Building Environments, pp. 5-15

23- Wyon DP (1993), *Healthy Buildings and Their Impact on Productivity*, Proceedings of Indoor Air '93, 6: pp. 3-13

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Source:
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1- Natl. Electr. Manuf. Assoc. 1989, *Lighting and Human Performance: A Review*, Washington, DC: NEMA

2- Fisk WJ, Rosenfeld AH, 1997, *Estimates of Improved Productivity and Health from Better Indoor Environments*, *Indoor Air* 7:158-72

3- IPMVP IEQ Committee, 1999, *Indoor Environmental Quality: Introduction, Linkage to Energy Efficiency, and Measurement and Verification: Appendix to the 1999 Version of the International Performance Measurement and Verification Protocol*, http://www.ipmvp.org/info/download.html

4- Brundage JF, Scott RM, Lednar WM, Smith DW, Miller RN, 1988, *Building-Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees*, *JAMA* 259 (14):2108-12

5- Dixon RE, 1985, *Economic Costs of Respiratory Tract Infections in the United States*, *Am. J. Med.* 78(6B):32-37

6- U.S. Dep. Health Hum. Serv. 1994, *Vital and Health Statistics, Current Estimates from the National Health Interview Survey, Series 10: Data from the National Health Survey No. 189*, DHHS Publ. No. 94-517

7- Katzev R, 1992, *The Impact of Energy-Efficient Office Lighting Strategies on Employee Satisfaction and Productivity*, *Environ. Behav.* 24(6):759-78

Source: Other

1- Heschong L, *Skylighting and Retail Sales: an Investigation into the Relationship between Daylighting and Human Performance*, 1999

2- Oseland N, *To What Extent does Workplace Design and Management Affect Productivity*, Johnson Controls, 1999, **posted on:** Office Productivity Network: Improving Workplace Productivity, Design, and Management, Dec. 2001

3- Fisk W, Federspiel C, *Worker Productivity and Ventilation Rate in a Call Center: Analyses of Time-Series Data for a Group of Workers*, Lawrence Berkeley National Laboratory, Berkeley, CA, 2002

4- Fisk W, *Health and Productivity Gains from Better Indoor Environments and Their Implications for the U.S. Department of Energy*, Lawrence Berkeley National Laboratory, Berkeley, CA, 2002

APPENDIX B

Case Study: Regular Office Development DCF Model

Variables Used for the Model

Variables		
Construction Cost ($/SF)	$120.00	
IEQ Strategies ($/SF)	$0.00	
Construction Loan Rate	14.00%	
Long-Term Loan Rate	9.50%	
Long-Term Loan Rate (2)	9.50%	
Amortization (Years)	30	
Term (Years)	10	
Rent ($/SF)	$25.50	
Vacancy Loss	7.00%	
Rent Escalation	2.00%	
Operations & Maintenance	$7.11	
Energy (Heating) ($/SF)	$1.81	
Electricity ($/SF)	$1.53	
Repair and Maintenance ($/SF)	$1.37	
Real Estate Taxes ($/SF)	$2.40	
O&M Escalation	2.00%	
Land Cost	$3,000,000.00	
Long-Term Debt Amount	$11,623,500.00	$11,700,000.00
Net Operating Income (NOI)	$1,660,500.00	
Loan-to-Value Ratio (LTV)	70.00%	
Capitalization Rate (Cap Rate)	10.00%	
Value of Building (V)	$16,605,000.00	
Total Building Cost	$15,000,000.00	
LTC Ratio	78.00%	
Construction Loan Amount	$8,400,000.00	
Loan-to-Cost Ratio (LTC)	70.00%	
Construction Costs	$12,000,000.00	

Discounted Cash Flow Model

Regular Office Development	Year 0	Year 1	Year 2
Expenses			
Land Cost	($3,000,000.00)		
Construction Costs	($4,800,000.00)	($7,200,000.00)	
Construction Debt Servicing		($470,400.00)	($1,176,000.00)
Construction Debt Repayment			($8,400,000.00)
Long-Term Debt Servicing			($1,181,884.27)
Long-Term Loan Balloon Payment			
Operations & Maintenance			($711,000.00)
TOTAL	($7,800,000.00)	($7,670,400.00)	($11,468,884.27)
Income			
Rent			$2,371,500.00
Construction Loan Disbursement	$3,360,000.00	$5,040,000.00	
Total Construction Loan Disburs.	$3,360,000.00	$8,400,000.00	
Long-Term Loan Disbursement			$11,623,500.00
Long-Term Loan Balance			$11,545,848.23
Property Re-Selling			
TOTAL	$3,360,000.00	$5,040,000.00	$13,995,000.00
Cash Flow	($4,440,000.00)	($2,630,400.00)	$2,526,115.73
Net Present Value **NPV**	$7.89		
Internal Rate of Return **IRR**	13.7155%		

DCF Model (Continued 1)

Year 3	Year 4	Year 5	Year 6	Year 7
($1,181,884.27)	($1,181,884.27)	($1,181,884.27)	($1,181,884.27)	($1,181,884.27)
($725,220.00)	($739,724.40)	($754,518.89)	($769,609.27)	($785,001.45)
($1,907,104.27)	($1,921,608.67)	($1,936,403.16)	($1,951,493.54)	($1,966,885.72)
$2,418,930.00	$2,467,308.60	$2,516,654.77	$2,566,987.87	$2,618,327.62
$11,460,819.53	$11,367,713.12	$11,265,761.59	$11,154,124.67	$11,031,882.24
$2,418,930.00	$2,467,308.60	$2,516,654.77	$2,566,987.87	$2,618,327.62
$511,825.73	$545,699.93	$580,251.61	$615,494.33	$651,441.90

DCF Model (Continued 2)

Year 8	Year 9	Year 10	Year 11	Year 12
($1,181,884.27)	($1,181,884.27)	($1,181,884.27)	($1,181,884.27)	
			($10,415,215.84)	
($800,701.48)	($816,715.51)	($833,049.82)	($849,710.82)	($866,705.03)
($1,982,585.75)	($1,998,599.78)	($2,014,934.09)	($12,446,810.92)	
$2,670,694.18	$2,724,108.06	$2,778,590.22	$2,834,162.03	$2,890,845.27
$10,898,026.78	$10,751,455.05	$10,590,959.00	$10,415,215.84	
			$20,241,402.34	
$2,670,694.18	$2,724,108.06	$2,778,590.22	$23,075,564.37	
$688,108.42	$725,508.28	$763,656.13	$10,628,753.45	

Long-Term Loan Amortization Schedule

Long Term Debt Amortization Schedule (Yearly Payments)					
Year	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**
Payment (PMT)	$1,181,884.27	$1,181,884.27	$1,181,884.27	$1,181,884.27	$1,181,884.27
Interest	$1,104,232.50	$1,096,855.58	$1,088,777.86	$1,079,932.75	$1,070,247.35
Amortization	$77,651.77	$85,028.69	$93,106.42	$101,951.53	$111,636.92
Balance	$11,545,848.23	$11,460,819.53	$11,367,713.12	$11,265,761.59	$11,154,124.67

Y7	**Y8**	**Y9**	**Y10**	**Y11**
$1,181,884.27	$1,181,884.27	$1,181,884.27	$1,181,884.27	$1,181,884.27
$1,059,641.84	$1,048,028.81	$1,035,312.54	$1,021,388.23	$1,006,141.11
$122,242.43	$133,855.46	$146,571.73	$160,496.04	$175,743.17
$11,031,882.24	$10,898,026.78	$10,751,455.05	$10,590,959.00	$10,415,215.84

APPENDIX C

Case Study: Green Office Development DCF Model

Variables Used for the Model

Variables (Green Building)		
Construction Cost ($/SF)	$120.00	
IEQ Strategies ($/SF)	$30.00	
Construction Loan Rate	16.00%	
Long-Term Loan Rate (1)	10.50%	
Long-Term Loan Rate (2)	8.50%	
Amortization (Years)	30	
Term (Years)	10	
Rent ($/SF)	$36.38	
Vacancy Loss	5.00%	
Rent Escalation	2.00%	
Operations & Maintenance	$6.24	
Energy (Heating) ($/SF)	$1.27	
Electricity ($/SF)	$0.92	
Repair and Maintenance ($/SF)	$1.65	
Real Estate Taxes ($/SF)	$2.40	
O&M Escalation	2.50%	
IEQ Consultant Annual Fees	$2.00	
IEQ Consultant Initial Fees	$3.00	
Land Cost	$3,000,000.00	
Long-Term Debt Amount	$14,040,000.00	$21,098,000.00
Net Operating Income (NOI)	$3,014,000.00	
Loan-to-Value Ratio (LTV)	70.00%	
Capitalization Rate (Cap Rate)	10.00%	
Value of Building (V)	$30,140,000.00	
Total Building Cost	$18,000,000.00	
LTC Ratio	78.00%	
Construction Loan Amount	$10,500,000.00	
Loan-to-Cost Ratio (LTC)	70.00%	
Construction Costs	$15,000,000.00	

Discounted Cash Flow Model

Green Office Development	Year 0	Year 1	Year 2
Expenses			
Land Cost	($3,000,000.00)		
Construction Costs	($4,800,000.00)	($7,200,000.00)	
Construction Debt Servicing		($672,000.00)	($1,680,000.00)
Construction Debt Repayment			($10,500,000.00)
Long-Term Debt Servicing			($1,551,819.88)
Long-Term Loan Balloon Payment			
Operations & Maintenance			($624,000.00)
IEQ Consultant Fees	($300,000.00)	($300,000.00)	($300,000.00)
TOTAL	($8,100,000.00)	($8,172,000.00)	($14,655,819.88)
Income			
Rent			$3,456,100.00
Construction Loan Disbursement	$4,200,000.00	$6,300,000.00	
Total Construction Loan Disbursement	$4,200,000.00	$10,500,000.00	
Long-Term Loan Disbursement			$14,040,000.00
Long-Term Loan Balance			$13,962,380.12
Property Re-Selling			
TOTAL	$4,200,000.00	$6,300,000.00	$17,496,100.00
Cash Flow	($3,900,000.00)	($1,872,000.00)	$2,840,280.12
Net Present Value **NPV**	($3.34)		
Internal Rate of Return **IRR**	30.5215%		

DCF Model (Continued 1)

Year 3	Year 4	Year 5	Year 6	Year 7
($1,299,207.50)	($1,299,207.50)	($1,299,207.50)	($1,299,207.50)	($1,299,207.50)
($13,962,380.12)				
($639,600.00)	($655,590.00)	($671,979.75)	($688,779.24)	($705,998.72)
($200,000.00)	($204,000.00)	($208,080.00)	($212,241.60)	($216,486.43)
($16,101,187.62)	($2,158,797.50)	($2,179,267.25)	($2,200,228.35)	($2,221,692.66)
$3,525,222.00	$3,595,726.44	$3,667,640.97	$3,740,993.79	$3,815,813.66
$13,962,380.12				
$13,849,974.93	$13,728,015.29	$13,595,689.09	$13,452,115.16	$13,296,337.45
$17,487,602.12	$3,595,726.44	$3,667,640.97	$3,740,993.79	$3,815,813.66
$1,386,414.50	$1,436,928.94	$1,488,373.72	$1,540,765.44	$1,594,121.00

DCF Model (Continued 2)

Year 8	Year 9	Year 10	Year 11	Year 12
($1,299,207.50)	($1,299,207.50)	($1,299,207.50)	($1,299,207.50)	
			($12,529,074.12)	
($723,648.69)	($741,739.91)	($760,283.41)	($779,290.49)	($798,772.76)
($220,816.16)	($225,232.48)	($229,737.13)	($234,331.88)	($239,018.51)
($2,243,672.36)	($2,266,179.90)	($2,289,228.04)	($14,841,904.00)	
$3,892,129.94	$3,969,972.54	$4,049,371.99	$4,130,359.43	$4,212,966.61
$13,127,318.63	$12,943,933.21	$12,744,960.03	$12,529,074.12	
			$31,751,753.46	
$3,892,129.94	$3,969,972.54	$4,049,371.99	$35,882,112.88	
$1,648,457.58	$1,703,792.64	$1,760,143.94	$21,040,208.89	

Long-Term Loan Amortization Schedules

Long-Term Debt (1) Amortization Schedule (Yearly Payments)										
Year	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
Payment (PMT)	$1,551,819.88	$1,551,819.88	$1,551,819.88	$1,551,819.88	$1,551,819.88	$1,551,819.88	$1,551,819.88	$1,551,819.88	$1,551,819.88	$1,551,819.88
Interest	$1,474,200.00	$1,466,049.91	$1,457,044.07	$1,447,092.61	$1,436,096.24	$1,423,945.26	$1,410,518.42	$1,395,681.77	$1,379,287.27	$1,361,171.35
Amortization	$77,619.88	$85,769.97	$94,775.81	$104,727.28	$115,723.64	$127,874.62	$141,301.46	$156,138.11	$172,532.61	$190,648.54
Balance	$13,962,380.12	$13,876,610.15	$13,781,834.34	$13,677,107.06	$13,561,383.42	$13,433,508.80	$13,292,207.34	$13,136,069.23	$12,963,536.62	$12,772,888.09

Long-Term Debt (2) Amortization Schedule (Yearly Payments)										
Year	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
Payment (PMT)		$1,299,207.50	$1,299,207.50	$1,299,207.50	$1,299,207.50	$1,299,207.50	$1,299,207.50	$1,299,207.50	$1,299,207.50	$1,299,207.50
Interest		$1,186,802.31	$1,177,247.87	$1,166,881.30	$1,155,633.57	$1,143,429.79	$1,130,188.68	$1,115,822.08	$1,100,234.32	$1,083,321.60
Amortization		$112,405.19	$121,959.63	$132,326.20	$143,573.93	$155,777.71	$169,018.82	$183,385.42	$198,973.18	$215,885.90
Balance	$13,962,380.12	$13,849,974.93	$13,728,015.29	$13,595,689.09	$13,452,115.16	$13,296,337.45	$13,127,318.63	$12,943,933.21	$12,744,960.03	$12,529,074.12

APPENDIX D

Abbreviations

AOR	Adjusted Odds Ratio
BC	Building Commissioning
Cap Rate	Capitalization Rate
CC	Correlation Coefficient
Cfm	Cubic Feet per Minute
CI	Confidence Interval
CRI	Communicable Respiratory Illness
BRI	Building Related Illness
DCF	Discounted Cash Flow
EIA	Energy Information Administration
ERW	Environment Responsive Workstation
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HVAC	Heating, Ventilating, and Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
IEQ-CS	Indoor Environmental Quality Certification System
IHP P	Indoor Health and Productivity Project
IRR	Internal Rate of Return
LBNL	Lawrence Berkeley National Laboratory
LEED™	Leadership in Energy and Environmental Design
LTC	Loan-to-Cost Ratio
LTV	Loan-to-Value Ratio
lx	Lux (Illuminance)
MCR	Market Capitalization Rate
MCS	Multiple Chemical Sensitivities
MLR	Multivariate Logistic Regression
NCEE	National Center for Environmental Economics
NEP Init.	National Energy Policy Initiative
NIOSH	National Institute for Occupational Safety and Health
NOI	Net Operating Income
NPV	Net Present Value
NRDC	National Resources Defense Council
NSTC	National Science and Technology Council
O&M	Operations and Maintenance
ppb	Parts per Billion
ppm	Parts per Million
PV	Photovoltaic (system)

RMI	Rocky Mountain Institute
ROI	Return on Investment
RR	Relative Risk
SBS	Sick Building Syndrome
Sq. Ft.	Square Foot
TVOC	Total Volatile Organic Compound
US DOE	United States Department of Energy
US EPA	United States Environmental Protection Agency
V	Value (Building)
VOC	Volatile Organic Compound

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