GREEN CITY BUILDINGS: APPLYING THE LEED™ RATING SYSTEM

Prepared for

Portland Energy Office
Portland, Oregon

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We would like to thank Rich Attridge, Dick Ragland, and Mike Speck who helped us obtain the data on each City building needed for this study. In particular, we appreciate the insights provided by Rich on the specifics of the 1900 Building and the time he dedicated to reviewing the details of our analyses. We also thank Steve Sivage for providing a thorough review and comments on the draft report.

Other City personnel deserve special mention for contributing to various parts of this study. Jeff Sandberg of the Water Bureau provided an analysis of the East Precinct's water using equipment, water use data for the buildings, and rates data. Kim Gates took the time to provide a walkthrough of the East Precinct. Jim Hagerman provided additional information on stormwater and water treatment costs.

Finally, we would like to express a special appreciation for the efforts of Commissioner Dan Saltzman who provided the leadership needed to institute the Green Building Initiative. We also thank the City Council for its on-going support for the Initiative and the research and implementation activities needed to make it a reality.

This report was prepared by Allen Lee, Geoffrey Syphers, and Tami Rasmussen at XENERGY, Inc., and Alan Scott at SERA Architects. For information on the details of the study, please contact Allen Lee at 503-226-6179 or alee@xenergy.com.

S EXECUTIVE SUMMARY

During 1999, the City of Portland, Oregon, conducted a public process to investigate options open to the City to promote the construction and operations of green buildings. This process led to development of the City's *Green Building Initiative*, which has two overarching principles:

1. Expand market demand by educating building industry professionals and the public about the benefits of green building; and
2. Make green building practices easier to implement by developing technical services and resources for building industry professionals.

Two of the main issues raised during development and early implementation of the Initiative were what constitutes "green building" and the costs and benefits of building green. This report discusses a study conducted to provide initial answers to these questions.

S.1 STUDY OBJECTIVES AND APPROACH

S.1.1 Objectives

The study had the following primary objectives:

1. Determine how "green" three recently built City buildings are.
2. Assess how each City building **could have been built** to qualify as "green" and determine the costs and benefits that would have occurred.

Table S-1 summarizes the characteristics of the three City buildings included in our study.

S.1.2 Building Ratings

Our approach for determining the "greenness" of each building was to evaluate each one based on an appropriate green rating system. We used the rating system developed by the U.S. Green Building Council (USGBC). The Leadership in Energy and Environmental Design (LEED™) green building rating system available at the time of our study was created for rating new commercial buildings.[1] It provides the following set of categories within which specific measures or performance requirements are defined:

- Sustainable Sites

[1] We used the LEED™ commercial building rating system , Version 2, that was undergoing public review early in 2000. The final version was issued just as this study was concluded. The final version probably would not change our overall findings, but it would have allowed the redesigned buildings to qualify as "Silver-rated," rather than at the lowest certification level.

- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality

Table S-1
Study Building Characteristics

Building	Type	Number of Stories	Floor Area, sq. ft.	Year Built	Number of Occupants
1900 Building	Office	7	143,200 (office space)	1999	550
East Precinct Community Police Station	Mixed use, police station and community space	2	23,000	1997	46*
Fire Station 17	Fire station	2	4,900	1994	17**

*We were informed that 30 people work 8-hour shifts in the police station 5 days per week and 5 people work in the building the remainder of the time. On the average, this would be equivalent to 46 employees in the station for a single shift, 5 days per week.
**Based on 4 per shift, 24 hrs/day, 7 days/week.

To rate a building, it receives one or more points for meeting individual requirements specified in the rating system. The total of all points constitutes the building's rating and, based on the rating, the building can be classified into one of four certification levels (such as the Gold Level), which are defined based on a range of points (or the building can fail to meet the requirements of the minimum certification level).

S.1.3 Selecting Measures to Meet LEED™ Requirements

We assessed each building and analyzed ways in which the original design could have been changed to qualify the building under the LEED™ approach. We used two economic criteria—lowest first cost and lowest life cycle cost—to select changes to the original design. First cost was used as one criterion because of questions raised during the development of the Green Building Initiative about how much, if any, construction costs would increase for green buildings. Life cycle cost was used as the other criterion because of the importance of taking into account the future benefits that were likely to be derived from green buildings. We strove to be conservative in our analysis of the three City buildings so that benefits would not be overestimated or costs underestimated.

S.1.4 Costs and Benefits

We applied different perspectives to assess the costs and benefits of the green options considered.

- The *direct* perspective captures the direct costs and benefits that fall upon the operator/owner and building occupants.
- The *regional system* perspective accounts for impacts on regional ratepayers, which depend on marginal costs.[2]
- The *societal* perspective takes a more global view and adds externalities to the regional system costs and benefits. Unfortunately, many external impacts are not readily quantified or monetized.

There are several fundamental parameters that were needed to calculate life cycle impacts. These are listed below along with the value that we used:

- life cycle time horizon = 25 years,
- inflation rate = 2.8% (but analysis was done in real terms), and
- discount rate (used to derive present discounted value of future costs and benefits) = 5.8% nominal, 3% real.

For every option included, it was necessary to document the following:

- incremental first cost compared to the measure employed in the as-built building,
- incremental operating and maintenance costs over the life cycle of the building, and
- all other significant incremental benefits and costs including changes in occupant productivity, changes in air emissions, and changes in other environmental impacts.

S.2 MAJOR FINDINGS

It is important to note that our findings are based on analyses of buildings that were constructed before the LEED™ system was available. Consequently, there was no accepted way of defining green buildings or systematically selecting green options when these buildings were designed and built. As a result, these findings should be viewed as providing insights into how future City practices could lead to green buildings and what the costs and benefits will be. They should not be viewed as an assessment of past practices.

S.2.1 LEED™ Ratings

Table S-1 shows that all three buildings fell short of the 32 points required for basic LEED™ certification.[3] Generally, the LEED™ categories in which the biggest percentage gaps existed

[2] Despite a comprehensive effort to quantify marginal costs to use in our study, we were unable to obtain reliable estimates of marginal costs in any relevant category and, therefore, could calculate no differential between the direct and regional system effects. The distinction between direct impacts, however, is an important one.

[3] The requirement has been reduced to 26 points in the final Version 2 of LEED™.

between the rating and points possible were Water Efficiency, Energy and Atmosphere, and Materials and Resources.

Table S-1
LEED™ Ratings of Three City Buildings

Building	Total Points Scored As Built
1900 Building	20
East Precinct	12
Fire Station 17	17
Points Required = 32	

S.2.2 Upgrading to Meet LEED™

Although these three buildings fell short of the required point total, our analysis showed that they could have been designed to meet the requirements for a relatively small (if any) increase in first cost as shown in Table S-2.

Table S-2
Summary of Costs Required to Qualify as LEED™ Certified

Building	% Increase in First Cost	
	Lowest First Cost Approach	Lowest Life Cycle Cost Approach
1900 Building	0.3%	1%
East Precinct	1.3%	2.2%
Fire Station 17	-0.3%	0%

Figure S-1 summarizes the economic cost and benefit results for redesigning the largest of the three buildings studied to meet the LEED™ requirements. The pattern of the results was similar for the two smaller buildings, but the magnitudes were less.

For the relatively small increases in first costs, the life cycle costs to the City would have decreased for each building. Taking into account only the "hard" future costs (such as utilities, maintenance, etc.), future savings over 25 years would have more than offset the initial investment costs. Table S-3 presents the difference between the life cycle cost (first cost plus future discounted costs) for each building if it had been designed to meet LEED™ and the life cycle cost estimated for the building as built. These results were calculated over the first 25 years. The life cycle costs would have decreased primarily due to reductions in energy and potable water consumption and stormwater runoff. The use of salvaged materials in some cases also offered both first cost and life cycle cost savings opportunities.

Figure S-1
Summary of 1900 Building Costs and Benefits

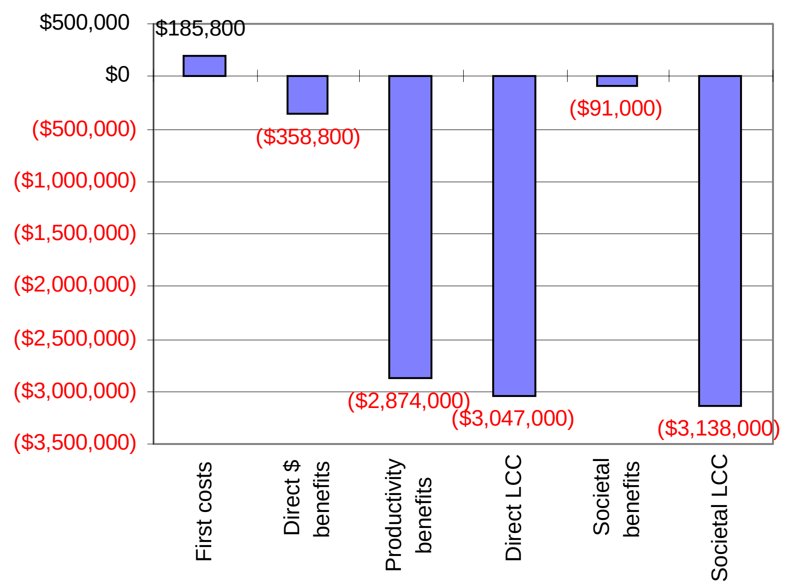


Table S-3
Change in Life Cycle Cost (Neglecting Productivity Increases), Lowest Life Cycle Cost Alternative

Building	Change in Life Cycle Cost (no productivity benefits included)
1900 Building	-$173,000
East Precinct	-$36,000
Fire Station 17	-$13,100

The biggest potential payoff for the City, however, would be probable improvements in productivity of the building occupants. These would result from better lighting, air flow, indoor air quality, etc., which would improve worker comfort and reduce complaints, absenteeism, and health problems. Table S-4 shows that, taking the productivity benefits into account, the life cycle cost savings would have been increased by a factor of about 10 to 15 (over 25 years) compared to the "hard" cost savings above. Because it was not possible to measure actual productivity changes, we based our calculations on conservative estimates from prior research. For all three buildings, the life cycle savings would have been about 15% of the original construction cost.

Table S-4
Summary of Estimated Direct Life Cycle Cost Savings Including Productivity Benefits

Building	Change in Life Cycle Cost	(Life Cycle Savings)/(Construction Cost)
1900 Building	-$3,047,000	16%
East Precinct	-$516,000	14%
Fire Station 17	-$101,900	13%

Other than options that increase productivity, the primary opportunities to reduce life cycle costs were the following:

- measures to improve energy efficiency,
- measures that reduce water consumption, and
- use of salvaged materials.

These results showed that low cost ways to improve energy efficiency should always be investigated, even for buildings that are designed to perform better than required by code. A life cycle cost analysis should be conducted to select efficiency measures that have the largest payoff.

Water consumption, both in the building and for landscaping, often can be reduced through measures that have little or no incremental costs. For example, native vegetation can eliminate the need for irrigation, thus reducing *both* first cost and future costs, as well as earning credits under LEED™.

The use of salvaged materials, another option that receives LEED™ green building credits, offers opportunities to reduce first cost and overall life cycle costs.

Our analysis also revealed that green roofs were preferred options for two of buildings from the City's life cycle cost perspective. The largest economic effect of green roofs comes from eliminating the requirement to replace conventional roof materials as often as every 12 years. Green roofs also provide life cycle benefits from reduced energy consumption and stormwater runoff, and provide difficult to quantify, but important, aesthetic and heat island benefits. In general, it would appear to be worthwhile to evaluate a green roof option on a case-by-case basis.

Measures that target improvements in indoor air quality, reduced use of toxic materials, and decreased negative environmental impacts also should be emphasized, even though their direct life cycle economic impacts may be difficult to quantify.

S.2.3 Application of a Green Rating System

Our results show that using a system, such as LEED™, to broaden the objectives used in the design/build process can produce significant benefits that are not likely to result from standard practices. As stressed earlier, evaluating measures based on their life cycle costs can produce significant long-term benefits for the building owner and occupants. Explicitly recognizing societal impacts can lead to decisions that also have significant payoffs beyond the building owners. In addition, an integrating framework such as LEED™ can promote the use of measures that have multiple benefits, such as green roofs.

Our case studies illustrated the necessity to develop criteria to guide the selection of measures to comply with the requirements of LEED™. The minimum first cost criterion was applied successfully to a wide range of feasible options to select those that could have been packaged together to achieve LEED™ certification at lowest first cost. The minimum life cycle cost criterion also was applied successfully, leading to a slightly different combination of measures that would minimize the life cycle cost of meeting the LEED™ requirement. In keeping with the intent of the City's Green Building Initiative and the fundamental principles underlying the concept of green buildings, we believe that using the life cycle cost criterion is the preferred approach.

S.2.4 Building Commissioning

Our approach assumed that the measures analyzed were installed and operated correctly. Based on the extensive studies that have been conducted, commissioning should be implemented to ensure the proper performance of buildings, particularly green buildings. A recent report indicates that full commissioning costs range from about 0.5% to 1.5% of total construction cost. We estimated commissioning costs based on these data and information from the City about its construction quality assurance practices. Without a rigorous analysis of each building and its systems, however, it is uncertain what the actual commissioning costs would have been, but we believe our estimates were realistic and relatively conservative.

Since no formal, systematic commissioning process has been established by the City, using an approach patterned after the commissioning process LEED™ defines could lead to a formalized and consistent approach for all new City buildings.

S.2.5 Societal and Non-quantified Impacts

Our analyses provided estimates of some of the societal benefits of designing green buildings. In particular, we estimated the economic value associated with air quality impacts from reduced electricity generation. We were unable, however, to estimate the economic value of several other benefits, including improved health of building occupants and improved fish and wildlife habitat.

Table S-5 presents the value of the life cycle cost impacts that we were able to estimate that would fall on society at large. These impacts are often referred to as externalities. Although these impacts are not extremely large compared with the cost of the buildings, they are very comparable to the direct life cycle economic benefits (excluding productivity effects) that would have accrued to the City if the buildings had been designed to meet LEED™.

Table S-5
Change in Estimated Externalities,
Lowest Direct Life Cycle Cost Alternative

Building	Change in externalities
1900 Building	-$91,000
East Precinct	-$31,000
Fire Station 17	-$1,200
Note: Direct costs on building owner/occupants are not included.	

If the societal impacts, rather than the direct impacts on the building owner/occupants, were used to select green building options, a somewhat different set of measures would have been chosen for each building. These choices would have produced larger societal and environmental benefits, and pursuing them would be consistent with the City's commitment to environmentally sound policies. The purchase of green power is one example where the benefits to society could be increased substantially, although the direct life cycle costs to the City would be higher. The recent decision by the City to purchase green power demonstrates the City's commitment to improving the environment and fulfilling its public role. By specifying purchases of green power for green buildings, the City would fulfill this commitment and receive credit under LEED™.

S.3 RECOMMENDATIONS

The major recommendations to the City from this study are the following:

1. Develop and implement a green building rating system starting with LEED™, and modify it, as needed, to take into account conditions unique to this region and environment.
2. Develop an evaluation tool to complement the rating system to assist the City and the building community in selecting among measures and documenting their probable impacts.
3. Develop tools for assessing the operating impacts of buildings and to provide guidance on decisions made during the operational life of buildings.
4. Implement the key steps remaining in the Green Building Initiative.
5. Begin including in specifications for new commercial buildings green measures based on those included in LEED™.
6. Document experiences gained from green building projects.
7. Identify differences between current City practices and the requirements of full commissioning and define consistent practices for commissioning new City buildings. Conduct research on the costs and benefits of commissioning.
8. Conduct a detailed study of potential productivity benefits from green buildings.

1 INTRODUCTION AND OVERVIEW

This section describes the context in which this study was conducted and the study objectives. It also summarizes the characteristics of the buildings included in the study.

1.1 BACKGROUND AND CONTEXT

The City of Portland, Oregon, has a national and international reputation for successfully balancing community development, growth management, and environmental stewardship. In recent years, the City has wrestled with how to restore and maintain its environment as the region experiences unprecedented growth. A major source of environmental impacts is buildings, both during their construction and throughout their life cycle. Faced with forecasts of continued population growth and the construction and operation of a growing inventory of commercial and residential buildings, City planners believed that the time was right to improve the quality and performance of buildings while simultaneously reducing the stresses they placed on the environment.

In the early 1990s, local governments such as those in Austin, Texas, and Boulder, Colorado, initiated green building programs to promote the construction and operation of buildings in ways that would reduce their negative impacts on the environment. In recent years, such efforts have expanded to include regional and national organizations, such as the U.S. Green Building Council, and other jurisdictions, such as Seattle, Los Angeles, Santa Monica, and Denver. At the local level, such programs often have been part of comprehensive policies and programs to promote sustainability.

The innovative building and siting techniques that can realize these goals—typically referred to as "green building"—are gaining currency in the design and construction industry. The spread of these practices is hindered, however, by

- a lack of information,
- regulatory disincentives, and
- financial barriers.

Because of the current rapid pace of construction and development in Portland, the sooner these obstacles are removed, the greater will be the economic, social, and environmental benefits that can be achieved through green buildings. By leveraging new resources and developing innovative partnerships to provide training, outreach, and technical resources, Portland's policy makers believe they can accelerate the adoption of green building practices throughout the residential and commercial building sectors.

During 1999, the City conducted a public process to investigate options open to the City to promote the construction and operations of green buildings. This effort was spearheaded by the Sustainable Portland Commission (SPC), a public body appointed to advise the City Council on issues related to sustainability. The Portland Energy Office provided technical and staff support to the SPC. This process led to development of the City's *Green Building Initiative*, which has two overarching principles:

1. **Expand market demand** by educating building industry professionals and the public about the benefits of green building; and
2. **Make green building practices easier to implement** by developing technical services and resources for building industry professionals.

Portland's Green Building Initiative is an integrated effort to promote non-polluting and resource-efficient building and site design practices throughout the City. The effort coordinates the expertise and resources of six City bureaus—Energy, Environmental Services, General Services, Planning and Development Review, Portland Development Commission, and Water—to deliver comprehensive services to the development and building community, building owners and occupants, businesses, and the City's own project and facilities managers.

Two of the main issues raised during development and early implementation of the Initiative were what constitutes "green building" and the costs and benefits of building green. This report discusses a study conducted to provide initial answers to these questions.

1.2 STUDY OBJECTIVES

Through a competitive process, the City selected XENERGY and its subcontractor, SERA Architects, to conduct this study. The study was funded by the City and the Northwest Energy Efficiency Alliance. The study focuses on three recently constructed City buildings.[1]

The study has the following primary objectives:

1. Determine how "green" the buildings are.
2. Assess how each City building **could have been built** to qualify as "green" and determine the costs and benefits that would have occurred.

Our approach for determining the "greenness" of each building was to evaluate each one based on an appropriate green rating system. For the three buildings, we used the rating system developed by the U.S. Green Building Council (USGBC). The Leadership in Energy and Environmental Design (LEED™) green building rating system available at the time of our study

[1] A study also was conducted as part of this effort to assess the performance of a renovated multifamily, low-income residential complex. Because of the residential nature of this project, the emphasis on renovation, and a different study approach, the results of this study are reported in a separate report.

was created for rating new commercial buildings.[2] It provides a very comprehensive set of categories within which specific measures or performance requirements are defined. The categories cover broad areas, such as increased water efficiency or improved indoor environmental quality, in which environmental goals can be specified. To rate a building, it receives one or more points for meeting individual requirements specified in the rating system. The total of all points constitutes the building's rating and, based on the rating, the building can be classified into one of four certification levels (such as the Gold Level), which are defined based on a range of points (or the building can fail to meet the requirements of the minimum certification level).

It is important to clarify that our objective for this study was to revisit each building and assess ways in which the original design could have been changed to qualify the building under the LEED™ approach**—it was not to examine how the building could have been retrofit to meet the requirement**. We took this approach because of widespread interest in how green building design and construction are likely to affect the first cost and life cycle cost of *new buildings*.

It is important to stress that *we strove to be conservative in our analysis of the three City buildings*. There are two major factors that influenced our use of a conservative approach.

First, the retrospective nature of our study and its limited scope precluded us from conducting the type of comprehensive analysis that would have been possible *if the approach had been implemented from the very beginning* of the design, site selection, and planning stages. For example, LEED™ provides credits for building on brownfield sites, but it was beyond our scope to reconsider the original siting decision and determine what brownfield site options were available and what the costs and impacts of choosing one would have been. In addition, we took the basic characteristics of each building as given, and did not start with a blank slate and consider entirely new designs. Our approach was to start with the fundamental building characteristics and evaluate the most reasonable changes that could have been implemented to the materials, equipment, construction process, and design without requiring a significantly different building design. This approach was necessitated by limitations in the scope of our study. Because of these necessary constraints, the reader should recognize that there are probably ways that each building could have been designed from the very beginning to be green, but with lower first and life cycle costs than our retrospective analysis suggests.

The other factor making our approach conservative is that, where we had choices or had to make assumptions about costs and benefits, we tried to pick values that did not underestimate the likely costs or overestimate the likely benefits. We did so primarily to increase the defensibility of our findings and reduce the possibility of overstating the net benefits of applying green building practices.

[2] We conducted informal ratings of the buildings for informational purposes related to this study only. Our research team is very familiar with the LEED™ methodology, but we did not conduct a formal certification.

1.3 DESCRIPTION OF BUILDINGS INCLUDED IN STUDY

Table 1-1 summarizes characteristics of the three City commercial buildings included in our study.

Table 1-1
Study Building Characteristics

Building	Type	Number of Stories	Floor Area, sq. ft.	Year Built	Number of Occupants
1900 Building	Office	7	143,200 (office space)	1999	550
East Precinct Community Police Station	Mixed use, police station and community space	2	23,000	1997	46*
Fire Station 17	Fire station	2	4,900	1994	17**

*We were informed that 30 people work 8-hour shifts in the police station 5 days per week and 5 people work in the building the remainder of the time.[3] On the average, this would be equivalent to 46 employees in the station for a single shift, 5 days per week.
**Based on 4 per shift, 24 hrs/day, 7 days/week.

1.4 REPORT CONTENTS

The remainder of this report describes the analyses that we conducted and our findings and recommendations. Section 2 discusses the methodologies used. It first describes the methodology used to rate the buildings and then presents the methodology used to assess how the buildings could have been designed to qualify as green buildings.

Sections 3 through 5 present the analyses conducted for each of the three buildings analyzed. Each section describes a specific building. The as-built building ratings are presented first, followed by the results of our analysis of the upgrade options proposed to qualify each as a green building. Note that we were asked to structure the sections describing the results for each building as much as possible so they could be considered as standalone case studies. Consequently, some descriptive information is repeated across these three sections.

Section 6 summarizes the key finding from our analysis. It also present recommendations intended to be useful to the City in implementing its Green Building Initiative and recommendations directed at a broader audience. The references used in this study are presented in Section 7.

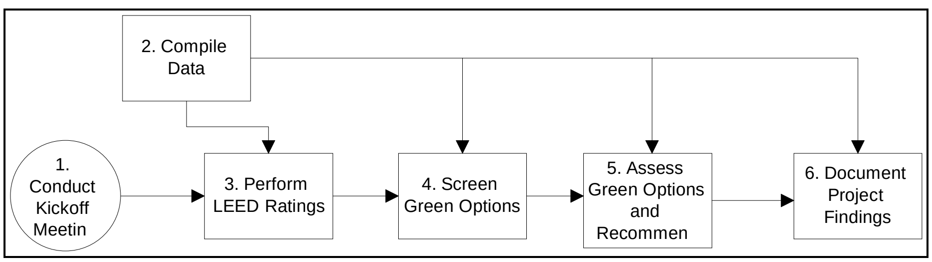
3 Personal communication, Kim Gates, East Precinct Administrative Supervisor, June 12, 2000.

2 METHODOLOGY

This section describes the methodology used to conduct this study. The first subsection discusses the LEED™ rating system used to rate the three commercial buildings. It then discusses how this system was applied in this study. The second subsection describes our approach for assessing how each of the City buildings could have been upgraded to qualify as green. The values of major input variables used in this study are presented at the end of this section.

The overall study methodology applied to the City buildings is shown in Figure 2-1. The study started with a kickoff meeting involving the City building project managers, bureau representatives, and Energy Office staff. The meeting introduced the City personnel to the analysis method, data needs, and products. Data collection was then initiated to collect several types of information including building and site characteristics, and measure costs and benefits. The rating for each building was generated based on the features incorporated in the building and the characteristics of the site and construction process.

Figure 2-1
Overall Study Methodology



2.1 APPLICATION OF LEED™ TO RATE THE BUILDINGS AS BUILT

This subsection describes the overall methodology used to rate each building based on its existing features.

2.1.1 Overview of LEED™

We applied the Leadership in Energy and Environmental Design (LEED™) green building rating system to assess the three buildings in our study. The rating system was developed by the U.S. Green Building Council (USGBC). As shown in Table 2-1, it provides a very comprehensive set of categories within which specific measures or performance requirements are defined.

Table 2-1
LEED™ Rating System Point Categories and Possible Points

	Category	Possible Points
Sustainable Sites.		
	Erosion and Sedimentation Control	0
1	Site Selection--not developed on environmentally inappropriate site	1
2	Urban Redevelopment--sited in high density area	1
3	Brownfield Development--developed on brownfield site	1
4	Alternative Transportation	4
5	Reduced Site Disturbance	2
6	Stormwater Management	2
7	Landscape and Exterior Design to Reduce Heat Islands	2
8	Light Pollution Reduction--meet IESNA exterior lighting requirements AND eliminate direct-beam illumination from building	1
Water Efficiency.		
1	Water Efficient Landscaping	2
2	Innovative Wastewater Technologies--reduce potable water for sewage by >50% OR treat all wastewater to tertiary standards	1
3	Water Use Reduction	2
Energy and Atmosphere.		
	Fundamental Building Systems Commissioning—implement standard commissioning	0
	Minimum Energy Performance--meet ASHRAE 90.1-1999 or local code if more stringent	0
	CFC Reduction in HVAC&R Equipment--use no CFC refrigerants in major systems and water coolers, spot coolers, etc.	0
1	Optimize Energy Performance (new bldgs.)	10
2	Renewable Energy	3
3	Best Practice Commissioning—include 3rd party review of commissioning documents	1
4	Elimination of HCFCs and Halons--eliminate in HVAC&R and fire suppression systems	1
5	Measurement and Verification—install monitoring equipment for lighting, motor loads, VFDs, chillers, cooling load, economizers, air distribution system, boilers, etc.	1
6	Green Power-- 2 yr. contract for at least 30% green power	1
Materials and Resources.		
	Storage & Collection of Recyclables--ground-floor recycling center	0
1	Building Reuse	3
2	Construction Waste Management	2
3	Resource Reuse	2
4	Recycled Content	2
5	Local/Regional Material	2
6	Rapidly Renewable Materials (5%)	1
7	Certified Wood (min. of 50% of wood-based materials)	1
Indoor Environmental Quality (IEQ).		
	Minimum IAQ Performance—meet ASHRAE 62-1989 Standard	0
	Environmental Tobacco Smoke (ETS) Control—prohibit smoking or provide ASTM approved smoking facility	0
1	Carbon Dioxide (CO2) Monitoring--provide system and specify parameters to maintain CO2 at <530 ppm higher than outdoors	1
2	Increase Ventilation Effectiveness--involve >90% of room/zone in air flow	1
3	Construction IAQ Management Plan	2
4	Low-Emitting Materials	4
5	Indoor Chemical and Pollutant Source Control—permanent entryway systems to capture dirt etc. and separate outside venting/negative pressures for chemical use areas and drains for disposal of liquid waste where water/chemical mixing occurs	1
6	Controllability of Systems	2
7	Thermal Comfort	2
8	Daylight and Views	2
Innovation Credits and Design/Build Process.		
1	Innovation Credits	4
2	Accredited Professional	1

Notes: The points possible for each option are shown in the rightmost column. Major option categories are shown between solid lines. Prerequisites are shaded and are awarded no points. Options are numbered within each major category.

We applied the LEED™ system, Version 2: Ballot Version, published in January 2000 by the USGBC. The final version of this system had not been adopted when we began preparing this report, but it was published as this report was being completed. Several minor changes were made in the final version; the most significant change was a reduction in the number of points required for LEED™ certification. Time did not permit reanalyzing the buildings using the final version, but a preliminary review suggested that the major findings and conclusions would be unchanged. However, the building modifications we proposed would come close to qualifying the buildings for a Silver rating, rather than the basic certification. The reader should note that our analysis was not intended to provide an official rating of the buildings although we were very familiar with the LEED™ system.

2.1.2 Applying the Rating Process

As shown in Table 2-1, LEED™ organizes green building measures into these six categories:

- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation Credits and Design/Build Process

To rate a building, it is necessary to determine which of several specific requirements it meets within each of the six major categories. In many cases, this is a simple exercise to determine whether the building has a certain type of equipment or whether certain practices were implemented during siting and construction.

In other cases, a more complicated process is required. For example, for the energy efficiency options included under the Energy and Atmosphere category, it is necessary to analyze the energy consumption of the building as-built and compare the estimated usage with what it would have been had the building been built to just meet ASHRAE Standard 90.1-1999. If the consumption is estimated to be less than it would have been under the Standard, then the percent improvement is used to determine the number of points the building would receive for this subcategory. In the case of several options under the Materials and Resources category, it is necessary to determine the cost of components that might qualify for a specific option, such as recycled content, and compare their cost to the overall building materials cost. The percent of total cost that these materials constitute determines how many points the building would earn for this option.

The Innovation and Design/Build Process category is slightly different. It allows the building to receive credit for innovative performance in categories not specified in the system or receive credit for having a project team member who has completed the LEED™ Accredited Professional exam successfully.

The points that the building receives in each category are then added up to determine the total that would be awarded to the building. The rating system has a total of 64 core points; core points exclude the points possible in the Innovation and Design/Build Process category. The total received by the building gives the building's point score rating and the building can be classified into one of five certification levels depending on the number of points it receives—uncertified (less than 32 points), Certified (32-38 points), Silver (39-45 points), Gold (46-51 points), or Platinum (52 points or more).

It is important to note that LEED™ was designed to cover a very wide range of nonresidential building situations and provide opportunities for buildings to be certified without having to override major siting and construction constraints. For example, although building on a brownfield site would earn a point in one category, a building that was not built on a greenfield site could still earn a point in another category if sustainable practices were followed. For several of the options, the number of points earned varies by the extent to which a certain characteristic is improved. Examples include the percent that energy efficiency is increased, the percent of an existing building that is reused, and the percent of energy supplied by renewable resources.

2.1.3 Data Needs and Data Collection

At the beginning of this project, we developed a list of materials that would be needed to conduct the ratings accurately. Data were obtained through site visits, interviews with project staff, and documents requested from each building's City project manager. Table 2-2 presents the list of information requested from the project managers.

Table 2-2
Information Requested to Conduct Rating

As-built drawings
Construction documents (hard copy and electronic)
Reflected ceiling plan
Architectural shell drawings
Construction details on windows, walls, floors and ceilings
Final landscaping plan, including placement and type of vegetation and type of irrigation system
Project manuals (specifications)
General HVAC system characteristics
Material lists for construction details (finishes)
Code compliance forms
Energy
Storm water calculations
General contractor's bid and/or final estimate
Product and system submittals from general contractor and subcontractors
General contractor's Construction Waste Management Plan
Building operating schedules
O&M manuals
Water and energy usage reports

We were able to obtain many of the materials, but there were significant gaps in the information that we were able to obtain. These included the following:

- as-built drawings for the two older buildings;
- electronic copies of construction documents for one of the buildings;
- detailed general contractor's bid data for one building;
- detailed waste management plans for all three buildings; and
- energy usage data for the largest (and newest) building.

The information gaps were due, in some cases, to the amount of time that had passed since construction was completed. In other cases, the missing information was not routinely requested and had never been obtained by the City. As a result of these information gaps, we had to develop reasonable professional estimates and assumptions. The detailed building studies presented later identify where and how we filled in missing information.

2.2 City Green Buildings Analysis

Once the basic rating of each City building was completed, the next step was analyzing ways that the building *could have been constructed* to qualify as LEED™ certified. To conduct this analysis, we had to develop criteria and a process for selecting among possible green options, and we needed to analyze the impacts of the measures selected.

2.2.1 Overview

Criteria for Selecting Green Options

Viewing buildings in terms of their "greenness" is considerably more complicated than analyzing them in terms of one criterion, such as energy efficiency, alone. Because the green perspective encompasses a wide range of impacts, numerous criteria are available to use to select among green measures. Energy impacts, CO_2 emissions, water runoff, embodied energy, health effects, solid waste generation, air emissions, and their associated first cost and life cycle costs and benefits are all likely criteria.

In theory, measures could be selected based on optimizing one or more of these potential costs and benefits. A number of generic tools and methodologies have been developed for analyzing multiple attributes and using weighting techniques to select the optimum combination of measures that satisfy multiattribute criteria (see for example, Norris and Marshall 1995). In recent years, tools have been developed that apply such a comprehensive framework and data to the selection of building materials based on sustainability criteria (see for example, Lippiatt 1998). Because such a comprehensive analysis was beyond the scope of this study, however, we decided to focus our analysis by assessing different measures based on specific individual criteria that were consistent with the study scope and objectives.

We chose two criteria to use in selecting green measures. Because this research was motivated, in part, by concerns about the first costs of green buildings, we used *least first cost* as one selection criterion. Because the Green Building Initiative was predicated on the understanding that most green building benefits would accrue over the life of the building, we chose *least life cycle cost* as the second criterion for selecting an optimum mix of measures.

Costs and Benefits Included in Analysis

Many green building options require an up-front investment that produces benefits spread out over the life cycle of a building. It is critical, therefore, to take a life cycle perspective in analyzing the costs and benefits of green buildings. Consequently, our analysis was designed to quantify the magnitude of the initial investment in a green option, as well as incremental costs and benefits associated with the option over the building's lifetime.

One critical issue in any cost-benefit analysis is which actors should be included when assessing costs and benefits. Prest and Turvey (1974, p.76) note the importance of "the wide class of costs and benefits which accrue to bodies other than the one sponsoring a project, and the equally wide issue of how far the sponsoring body should take them into account" in cost-benefit analysis.

The principle underlying green buildings is based on an inherently broad and long-term perspective of costs and benefits. In addition, city and other government buildings represent the public interest and they should, therefore, be evaluated from a broadly public and long-term perspective. Consequently, we sought an approach that considered impacts as broadly as possible within the study constraints.

In this study, we adopted a framework similar to that often used in cost-benefit studies of utility energy-efficiency programs to identify the actors included in the cost-benefit analyses. The utility program approach traditionally considers several cost-benefit tests including, among others, the participant, nonparticipant, and societal tests. Our selected cost-benefit categories were similar to these, as shown in Table 2-3. The table shows the three perspectives we used for defining costs and benefits and presents examples of each cost and benefit type. Note that all costs and benefits are determined on an incremental basis relative to the building as built.

Table 2-3
Categories of Costs and Benefits Included in Analysis

	Direct	Regional System	Societal
Definition	Monetary costs/benefits incurred directly by building owner/operator or occupants: based on average costs	Direct monetary costs/ benefits plus any added costs imposed on the regional system: based on marginal costs of supplying utilities such as energy, potable water, and water treatment	Regional system costs/benefits plus monetary and non-monetary externalities that impact society
Examples	• First cost of green measures • Maintenance costs of measures • Electric utility bills	• System marginal costs of electricity • System marginal costs of water treatment	• First costs of green measures • Monetized CO_2 impacts • Non-monetized environmental impacts

By presenting these three cost-benefit perspectives, our framework is relatively comprehensive. The *direct* perspective is most relevant to the building operator/owner in that it captures the direct costs and benefits that fall upon the operator/owner and building occupants. We limit this category to those impacts that can be readily monetized.

The *regional system* perspective accounts for the fact that increased demands for regional services impact the cost of providing those services overall. Impacts on ratepayers depend on marginal costs, although the direct rate impacts on the building occupant usually are based on system average costs. Consequently, this perspective assesses system costs and savings in terms of the marginal costs of supplying services where appropriate.

We note here that we attempted to identify marginal costs to be used in the regional system impacts analysis. Despite a comprehensive effort to quantify marginal costs to use in our study, we were unable to obtain reliable estimates of marginal costs in any relevant category and, therefore, could calculate no differential between the direct and regional system effects. This issue is discussed later in this section.

The *societal* perspective takes a more global view and adds externalities to the regional system costs and benefits. This final perspective is very important given that the environmental impacts of green buildings affect a population larger and more expansive than the building's owner/operator and occupants and populace living in the metropolitan area. Because some of these impacts are not readily monetized, the analysis also includes non-monetary impacts (e.g., tons of pollutants). Some impacts are not even quantifiable, given current knowledge and information, yet they are important; in these cases the impacts are described, even though they're not presented numerically.

In virtually all cost-benefit studies, practical limits make it is necessary to restrict the breadth of costs and benefits included. It is important to note that we *did not attempt* to apply a full Life Cycle Assessment (LCA) approach in our study. As stated by the International Organization for Standardization:

> *LCA studies the environmental aspects and potential impacts throughout a product's life (i.e., cradle-to-grave) from raw material acquisition through production, use and disposal.*[1]

Assessing the cradle-to-grave impacts of every material or product that we considered was far beyond the scope of this project. Although our analysis was not this comprehensive, it is reasonable to assume that methods such as LEED™, which we applied to the commercial buildings studied, already reflect this viewpoint, to a degree, in their ratings. Overall, we relied on the study scope and objectives to place reasonable bounds on the costs and benefits that we included in our analysis.

Green Option Selection Process

We started with all the options included in the LEED™ rating system and conducted an initial screening to reduce them to a set of feasible options for further consideration. This initial screening was based on professional judgment, prior analyses, and preliminary cost and benefit data. We took into account the following criteria:

- excessive first costs or potentially large life cycle costs compared to potential benefits and the respective costs of other measures;
- inapplicability or lack of feasibility for the site;
- requirements for major redesign or siting changes (e.g., major construction changes to accommodate daylighting or relocation to a Brownfield site); and
- unresolved ecological benefits for the site (e.g., elimination of HCFCs and Halons[2]).

Once we had identified a set of options to consider for further analysis, the selection process was relatively direct. In the case where we selected options for the three City buildings based on lowest first cost, we simply listed the options in the order from lowest to highest based on their first cost per LEED™ credit (if any resulted in cost reductions, they were at the top of the list and

[1] International Organization for Standardization. 1997. *ISO 14040 Environmental Management—Life Cycle Assessment—Principles and Framework*. Switzerland.

[2] This measure is controversial because of the confusing message it conveys that switching to the use of HCFC refrigerants is ecologically beneficial. In our opinion, the most ecological way to meet this requirement is to eliminate mechanical cooling entirely, and that option was not considered because of the necessity to significantly alter the building designs.

showed negative effects on the cost). We then selected the measures in order until the green options included led to a building that met the LEED™ certified level.

In the lowest life cycle cost case, we followed the same approach, but ordered the measures in terms of their effect on life cycle cost. In both cases, the measures were selected based on direct costs and benefits only, but we estimated and documented the regional system (although, as noted before, we were unable to estimate a regional system cost differential) and societal costs and benefits as well.

2.2.2 Data and Calculation Procedures

There are several fundamental parameters that were needed to calculate life cycle impacts. These included the following:

- life cycle time horizon,
- inflation rate, and
- discount rate.

For every option that we included in our analysis, it was necessary to document the following:

- incremental first cost compared to the measure employed in the as-built building,
- incremental operating and maintenance costs over the life cycle of the building,[3] and
- all other significant incremental benefits and costs.

Finally, a life cycle analysis needs to account for uncertainties. For this analysis, uncertainty is particularly important in assessing future costs and benefits because projections of both can be very inaccurate if basic assumptions about the future are incorrect.

The following subsections discuss each of these topics.

Life Cycle Time Horizon

Ideally, a life cycle analysis extends over the entire life cycle of a building, from design, through construction, operations, and demolition and salvage. For the buildings we studied, the applicable life cycle period can be 50 years or more.

In practice, however, several factors led us to conduct our analysis over a shorter period. These factors included the following:

[3] Technically, a salvage value should be determined for each measure at the end of the life cycle period. In most cases, there would be only a negligible difference in salvage values so this was ignored and this tended to be consistent with our intent to conduct a conservative analysis.

- Projections of key inputs such as energy prices and the impacts of CO_2 are either unavailable or extremely uncertain beyond a 10- to 20-year period.
- One of the basic tenets of our study was to conduct a conservative analysis that has little chance of overstating the benefits of green buildings. Consequently, it is prudent to project benefits of green buildings over a period short enough that they can be readily justified.[4]
- Because of discounting, future costs and benefits become decreasingly significant over time when discounted to their present value. For example, using a discount rate of 3%, energy savings in the 25th year have a present value of only 48% of their current value and savings in the 50th year are discounted to only 23% of their current value. Consequently, including costs and benefits far into the future is less critical if a discount rate greater than zero is applied. Excluding costs and benefits far into the future also was consistent in general with our conservative analysis approach.
- More options are likely to become available as time passes that would make the study assumptions about future costs and benefits less reliable. For example, the costs of solar cells might decrease substantially in the future, making installation or replacement of cells in the future very cost-effective.

Taking these factors into account, we selected a **life cycle period of 25 years**. This period balances the expected life of these buildings against the fact that projections of most key inputs are available for only about 10 years or less. The consequence of this assumption is that our estimates of green building impacts, in most cases, are likely to understate the benefits.

Inflation Rate

The inflation rate accounts for general price increases in products and services. The inflation rate can differ for various categories of products or services. An inflation rate of 2.8% was published recently for energy life cycle analysis purposes.[5] This value was projected to apply over a 10-year horizon. For our study, rather than attempt to account for inflation and deal with different rates for different products, we have conducted our analyses in **constant, or real, price terms**. In effect, price inflation has been eliminated from the study.

Discount Rate

Future economic costs and benefits are typically adjusted to convert them to their equivalent values from today's perspective. This is done by applying a time preference rate or discount rate.[6] The discount rate takes into account the fact that a dollar invested today can earn a rate of

[4] We note that some green options, such as purchasing green power, might have costs that exceed their direct benefits in the future, so terminating the analysis at any point in time might understate their net costs.

[5] National Institute of Standards and Technology (NIST). 2000. *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - Annual Supplement to NIST Handbook 135 and NBS Special Publication 709.* Gaithersburg, Maryland.

[6] Layard, Richard (ed.). 1974. *Cost-Benefit Analysis*, p. 29. Great Britain. Penguin Books.

return based on the interest rate and be worth $(1+the interest rate) a year from now. Determining the appropriate discount rate in cost-benefit analysis can be complicated by issues such as what alternative investments are available, whether the investment is a private or public one, whether the discount rate should vary from year to year, the inflation rate, risk, and whether a different rate should be applied to different types of costs or benefits. Furthermore, many economists and analysts have argued that future costs that affect subsequent generations should not even be discounted if the intergenerational impacts are to be accounted for equitably.

Discount rates used in economic studies have ranged from 0% to over 20%. Since this study focuses primarily on the City's perspective, a social discount rate is probably most appropriate and these rates are near the low end of the range. In this study, we use **a real discount rate of 3%**. This is comparable to long-run real discount rates used in most analyses of government investments. We note also that, accounting for inflation, the nominal discount rate would be 5.8%, which is comparable to the cost of City borrowing through bonds and the bond rate is often used in cost-benefit analyses as the nominal discount rate.

Incremental First Costs

The first cost associated with each option included in our analysis is a critical component of the cost-benefit analysis. Because our analysis addresses changes in the building relative to the building as-built, the first costs of interest were the incremental costs compared to the costs of the measures or practices employed in the building as-built. Generally, first costs would be included in the *direct* cost-benefit perspective defined earlier because they would be incurred by the building owner/operator.

First cost impacts that we anticipated analyzing on an incremental basis included at least the following:

- higher (or, in some cases, lower) costs of more energy-efficient equipment or materials,
- higher (or, in some cases, lower) costs of water conserving equipment,
- reduced costs of hauling and landfilling construction materials,
- higher (or, in some cases, lower) costs of recycled, local, and environmentally certified materials,
- higher costs of less polluting, less harmful materials, and
- building system commissioning costs.

Key sources of first cost data included databases available to XENERGY and SERA. We also obtained cost data for certain options from vendors and other databases.

Incremental Operating and Maintenance Costs

To calculate life cycle cost, first costs are combined with the recurring costs of operating and maintaining equipment or systems over the life cycle period analyzed. As with the first cost, we focused on the changes in these costs compared to the as-built building. Generally, these cost impacts would be included in the *direct* cost-benefit perspective, as defined earlier; however, those impacts that would affect the costs of providing service to system-wide ratepayers should be estimated from the *regional system* perspective, as well, when relevant data are available.

Two of the most obvious and significant operating costs affected by green options are the costs of energy use and water use. Several green options have the potential to affect energy use and, consequently, energy costs of operating the building. Energy costs can be calculated by multiplying electric and natural gas (and any other form of energy used in the building) rates by the amount of energy used and adding any fixed energy costs. Because the impacts are expected to be related to the changes in quantities consumed, the fixed costs (for example, monthly service charges) are not likely to be relevant in this analysis, so the effects can be calculated by multiplying rates times the change in energy consumption. This calculation produces the monetary effect on the building occupant or owner, and this is the *direct* effect.

In the 1970s and 1980s, the marginal costs of providing energy were higher than the average costs and, when an additional unit of energy was required, the marginal cost of providing that unit increased the total cost of providing energy by an amount greater than the average energy price. Over the long run, marginal costs are likely to exceed average energy prices and this relationship should be taken into account. Consequently, from the *regional system* perspective the marginal energy costs should be used to calculate the impacts. We investigated this by examining forecasts of electricity and natural gas marginal costs in Portland. The available projections, however, suggested that marginal costs were likely to remain relatively constant over the next 20 years and were unlikely to increase system-wide average costs. Therefore, without a time horizon well beyond 20 years, we could not justify estimating a *regional system* energy cost impact different from the *direct* impact based on average energy prices.

Both Portland General Electric (PGE) and PacifiCorp provide electricity to the City of Portland. Approximately 78% is provided by PGE.[7] To simplify our analysis, we used PGE electricity rates and projections (as well as emissions estimates) rather than a weighted average. In all cases, this tended to be a conservative approach..

The purchase of green power is another option included in LEED™ and it affects operating cost. PGE recently implemented a green power program that offers green power for a slightly higher rate per kWh. The incremental electricity costs can be estimated by multiplying the electricity consumption times the incremental electricity rate.

The same concepts that apply to energy use also apply to water use and water treatment. The *direct* impact can be calculated by applying the average price to the change in consumption or discharge. The *regional system* impact would be based on the marginal cost of providing additional fresh water supplies or treating sewage. A recent empirical study in Canada estimated

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[7] Peters, Lon and Robert Young. 1999. *An Assessment of Portland Electricity Loads and Infrastructure*. Prepared for the Portland Energy Office by Northwest Economic Research, Portland, Oregon.

that the price charged for fresh water was only one-third to one-half the long-run marginal supply cost, and the prices charged for sewage were only about one-fifth the long-run marginal cost of sewage treatment.[8]

It was relatively easy to access current and near-term projections of customer water prices in Portland. Both longer-term water rates and the marginal cost of water supplies, however, were more difficult to obtain. Portland benefits from adequate fresh water supplies for the near term. Although additional water supplies will have to be developed if consumption continues to increase, the Portland Water Bureau was unable to provide projections of the marginal cost of supplying water over the 25-year time horizon we analyzed. Consequently, we used the average current prices and projections to calculate both the direct impacts and regional system impacts.

The situation was similar for sewer and stormwater runoff impacts. We were able to obtain current sewer and stormwater rates, but no data were available on the marginal costs of treating sewage and runoff.[9]

Despite the fact that we did not have data available to quantify the regional system impacts of reducing water consumption and demand for sewage treatment we believe that future studies of green building impacts should attempt to incorporate the long-run marginal costs associated with reducing the consumption of fresh water and demands on the sewage/stormwater treatment system.

Maintenance cost impacts should capture incremental changes in the costs of maintaining green building options. Because life cycle costs are central to this analysis, any incremental equipment or material replacement costs also should be included. We included these costs (both increases and decreases) in the life cycle stream of costs where this was possible. Generally, we calculated the incremental maintenance costs by determining the average annual incremental cost and multiplying it by the number of years included in our analysis. These costs all fall into the category of *direct* impacts.

Incremental salvage costs at the end of the life of green options we considered also should be included. However, any differences between the original and green option salvage costs were likely to be much less significant than the incremental first costs and incremental operating costs and, therefore, we neglected them in this analysis.

Commissioning building systems is intended to ensure that systems perform as desired and, in the case of energy or water efficiency measures, ensure that the predicted resource savings are achieved. When savings are estimated under the assumption that energy or water efficiency

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[8] Russell, L.S. and B.S. Shin. 1996. "Public Utility Pricing: Theory and Practical Limitations," in *Marginal Cost Rate Design and Wholesale Water Markets*, D.C. Hall (ed), JAI Press, Greenwich, Connecticut.

[9] Sewer and stormwater costs are further complicated by the fact that flows are not easily metered and prices charged to customers are not well linked to changes in actual use of the water treatment system. Portland recently proposed new rate designs intended to link prices paid by customers more closely to demands placed on the system.

measures perform as designed, however, it is not appropriate to credit commissioning with additional savings or impacts. One of the prerequisites under the LEED™ system is fundamental building systems commissioning, for which the building receives no rating credits. Consequently, our approach was to not attribute additional energy or water savings to commissioning by itself. Furthermore, we assumed that "best practice" commissioning and ongoing measurement and verification (both of which earn LEED™ credits) would be conducted in conjunction with the prerequisite commissioning process, and we have attempted to reflect this by assuming relatively high commissioning costs.

Other Categories of Significant Costs and Benefits

Many of the benefits of green buildings are not included in standard life cycle cost calculations, yet they are very important. One group is those benefits that are often overlooked because conventional life cycle cost studies are too narrowly focused. This group includes changes in worker productivity that translate into higher output or reduced labor costs. A second group is those benefits that are distributed across society as a whole, for example, the effects of reduced air pollution, which can have impacts worldwide.

Increased worker productivity is a particularly important benefit of green buildings that is receiving increasing attention. A recent study notes that "The current argument for green buildings promotes the idea that investments will pay off in the long run due to enhanced health and productivity of the workforce..."[10] This same paper also points out that direct measures of productivity may be inadequate to encompass the effect of green buildings on performance; for example, customer satisfaction, employee retention, and employee attitudes about work and the company may be less tangible, but nevertheless important dimensions of green building effects. For this study, we relied on case studies and other sources that estimated the effects of various green-building related improvements in work environments. Much of this literature addresses the effect of lighting quality and intensity on productivity, but LEED™ focuses primarily on lighting controls, indoor air quality, comfort, and daylighting. Consequently, we rely primarily on sources that assess productivity effects of the options covered by LEED™. We treat the impacts on productivity as *direct* because they affect the costs of the organization that occupies the building. Because productivity benefits are tied to the overall functioning of the building and systems, it is virtually impossible to attribute them to individual measures. The approach that we use is to link productivity benefits to the comprehensive commissioning process described above.

Reduced global warming resulting from diminished CO_2 generation is a potential benefit of green buildings that is associated most directly with reduced energy use. While a reduction in electricity consumed by a building saves the building occupant an economic amount based on the average price charged per kWh, society benefits by an additional amount that is related to the quantitative reductions in emissions of CO_2, SO_2, and other pollutants. For reduced electricity consumption, the benefits are proportional to the change in consumption times the amount of pollution generated per unit of electricity. As noted earlier, we used the characteristics of the

[10] Heerwagen, Judith, Nancy Durbin, and Jennifer Macaulay. 2000. "Assessing the Human and Organizational Impacts of Green Buildings," Pacific Northwest National Laboratory. Seattle, Washington.

PGE system to estimate impacts; this assumption tended to be conservative with regard to the environmental benefits of reduced energy consumption, as well as direct utility bill savings.[11] Effects on global warming and other effects that extend over a wide area are treated from the *societal* perspective.

Another potential effect of green buildings is a reduction in automobile travel for commuting. The impacts are not usually included in life cycle cost analyses because they do not fall on the building owner. However, facilitating the use of bicycles or public transit can reduce the travel costs faced by employees and the external impacts of automobile travel. We classify the former as a *direct* impact because it affects the building occupants and we classify the latter as *societal* impacts because they affect society at large. These impacts could be calculated by estimating how many building occupants switch from automobile use to bicycles or public transit, and multiplying the reduction in vehicle miles traveled times the average costs and impacts associated with automobiles.

Table 2-4 describes several costs and benefits that we included in our study where they were relevant. It identifies to whom the costs and benefits would accrue, describes the calculation method, and presents key inputs required for the analysis.

[11] This is primarily because the City acquires electricity from both PacifiCorp and PGE, and the pollutants generated by PGE facilities per unit of electricity are less than those produced by the PacifiCorp facilities.

Table 2-4
Description of Typical Costs and Benefits and Calculations

Quantifiable Cost or Benefit	To Whom Benefit or Cost Accrues	Calculation Methodology	Inputs
Energy bill savings	Direct: building owner/ occupant pays less for energy due to improved efficiency	Decrease in energy consumption due to efficiency increase * price per unit of energy	• baseline energy use • energy use after efficiency improvements • energy price per unit
Decrease in workers commuting	Direct: cost savings for employees	# employees who no longer commute * [average commute miles/year * avg mpg * cost per gallon of gas + parking costs/ employee/year + maintenance costs/ vehicle/year]	• # employees who no longer commute • average commute miles/year • avg mpg cost per gallon of gas • parking costs/ employee/year • maintenance costs/vehicle/year
	Society: decrease in CO_2 emissions	pounds of CO_2/gallon of gas * # employees who no longer commute * avg mpg * avg commute miles/year	• pounds of CO_2/ gallon of gas • # employees who no longer commute • avg mpg • avg commute miles/year
Increased worker output	Direct: building operator experiences increased productivity among workers leading to lower labor costs for same output	# employees affected by improved conditions * increase in productivity/ worker due to improved conditions * average wage	• # employees affected by improved conditions • % increase in productivity/ worker • average wage rate

Uncertainties and Risk

There are several key uncertainties and risks that could affect the magnitude of the costs and benefits associated with greening the City buildings. Although most uncertainties involve future costs and benefits, it is important to note that there are uncertainties in the first costs estimated for some of the options considered. For example, no major green roof has been installed on a large commercial building in this area, so the estimated green roof costs are not based on actual local projects. For other options, unanticipated costs might be incurred for certain measures if they were actually installed in the buildings we studied. On the other hand, it is likely that some of the first costs would be lower than our estimates if the options had been included during the initial design phase, rather than retrospectively.

The major uncertainties in this study, however, involve the estimated future benefits. The most important uncertainties include the following factors that are inputs to the benefits calculations:

- customer costs for electricity and natural gas and the marginal costs of supplying energy,
- customer costs for potable water and the marginal costs of supplying water,
- customer rates for sewage and runoff treatment and the marginal costs of treatment,
- environmental regulations that could impose significant restrictions on a wide range of activities and their environmental damages, and
- environmental impacts of CO_2 emissions and other air pollutants.

Another important factor is the risk associated with different types of monetary flows. It has been pointed out that the present value of highly variable cash outflows that are counter-cyclical relative to the economy should be calculated with a reduced discount rate.[12] Energy costs tend to fall into this category, so one way of addressing the risk inherent in future energy costs is to discount energy expenditures at a lower rate than other types of cash flows, thus increasing the present value of future energy savings.

For most categories of uncertainties and risk suggested above, including them in our analysis would increase the benefits attributable to green buildings. We were not able to conduct a thorough uncertainty analysis and incorporate the effects here; by not including them, our analysis tends to be conservative with respect to the effects of green buildings.

2.2.3 Selection of Green Building Options

As noted earlier, we developed two sets of green options for each building using two different criteria: least first cost and least life cycle cost. Green options were selected for each set based on the relevant criterion. As we developed the selected sets of options, we took into account the fact that some options could complement each other and that some could provide green benefits in multiple categories.

The minimized first cost approach was used to demonstrate the results of focusing on first costs over all other possible criteria. As described previously, this approach neglects the broad and long-lasting benefits of building green because of its near-term emphasis.

[12] Awerbuch, Shimon. 1993. “The Surprising Role of Risk in Utility Integrated Resource Planning,” in *The Electricity Journal*, 6(3), pp. 20-33.

The minimized life cycle cost approach is more consistent with the objectives of building green. At a minimum, it recognizes that green buildings are investments that typically pay long-term dividends.

Neither approach, however, is as encompassing as the concept of building green demands. There are alternative criteria that could be used to select green building options in ways more in line with the intent of building green. For example, green options could be selected based on their societal impacts. From a global perspective, this approach would be preferred, but for the building owner/operator this criterion could lead to increases in first costs that would be unacceptable, and using this approach could undermine efforts to promote green buildings.

Although we use two fairly limited criteria to develop our sets of green building options, the resulting costs and benefits can provide broader insights about the process of selecting green building options and their consequences. What we learned from our analyses and the implications of different selection criteria are discussed later in this report.

2.3 INPUT VARIABLES

The key variables that we used in our cost-benefit analysis are presented in Table 2-5. A description of the variable is presented in the first column. The values that we used are presented in the second column and the sources are shown in the third column.

Table 2-5
Values of Key Variables Used in Cost-Benefit Analysis

Variable	Value(s)	Source(s):
Building commissioning benefits	Estimated benefits of commissioning systems include reduced costs to correct design deficiencies, correct system operational problems, and obtain proper performance and productivity enhancements/cost reductions due to reduced complaints, reduced absenteeism, improved output, better health, etc. We did not attempt to include construction and operating cost benefits. Productivity increases of 20% or more have been estimated in prior studies. Values used here vary by building and are described in text.	Oregon Office of Energy: www.energy.state.or.us/bus/comm/bldgcx; www.betterbricks.com; www.energyideas.org; Heerwagen, Durbin, and Macaulay 2000; Romm and Browning 1998; *Environmental Building News*, February 2000.
Building commissioning costs	Estimates range from 0.5-1.5% of total construction cost to commission all systems. Values selected vary by building and usually include best practices commissioning and monitoring/verification.	*Building Commissioning Guide, V. 2.2*, US GSA and DOE, July 30, 1998, from Portland Energy Conservation Inc.; *Environmental Building News*, February 2000

Table 2-5 (cont.)
Values of Key Variables Used in Cost-Benefit Analysis

Productivity effects of better ventilation	Productivity Improvement due to improved IAQ have been estimated to be 3.5% or approximately $980 per employee - year for government buildings. The National Energy Management Institute estimates productivity benefits of 1.5% for generally healthy buildings and 6% for "sick" buildings.	OSHA: www.osha-slc.gov/FedReg_osha_data/FED19940405; National Energy Management Institute (NEMI). 1999. "Productivity and Indoor Environmental Quality Study." Alexandria, Virginia.
Average commercial electricity price	For PGE, 6.24 cents/kWh first 5000 kWh/mo., 4.15 cents/kWh above 5000 kWh/mo., if demand<30 kW. If demand >30 kW, 6.05 cents/kWh for first 5000 kWh/mo., 3.53 cents/kWh above 5000 kWh/mo. Use rate based on highest consumption.	Personal communication, Portland General Electric
Avoided cost of electricity	Based on PGE projections, use constant real prices	Personal communication, Portland General Electric
CO_2 emissions from electric generation	1,650 Lbs/MWh based on PGE fossil fueled powerplants	Natural Resources Defense Council, Inc. at www.nrdc.org/nrdc/nrdcpro/util/index.html#figures
Other externalities from electric generation	No_x=2.8 Lbs/MWh, SO_2=3.5 Lbs/MWh based on PGE fossil fueled powerplants	Natural Resources Defense Council, Inc. at www.nrdc.org/nrdc/nrdcpro/util/index.html#figures
Natural gas average commercial price	$0.61735/therm	Northwest Natural Gas: Dec. 01, 1999 Price Schedule
Avoided cost of natural gas	Use constant real prices based on forecast of wellhead prices provided by Northwest Natural Gas	Personal communication, John Hanson - Director of Integrated Resource Planning, Northwest Natural Gas - March 3, 2000
Average fresh water prices	$0.98/100 cu.ft. in 2000; escalate at 6%/yr nominal.	Spreadsheet and graphs provided by Portland Water Bureau, March 2000
Fresh water avoided costs	No data are publicly available; use average price.	Personal communication, Jim Burke, Portland Water Bureau, March 29, 2000
Average wastewater (sewer) costs	$3.41/unit (100 cu.ft.); escalation rate in the near term averages about 7% per year (nominal); extend this escalation over analysis period.	www.enviro.ci.portland.or.us/hasrc.htm
Wastewater treatment avoided cost	No information was available; use average prices	
Average miles driven by city employees to work	Assume 20 miles round-trip	
Average and fixed driving costs	Average cost of driving: $.37/mile paid by driver, $.28/mile paid by society, $.05/mile subsidized by government. Society cost includes environmental externalities.	*An Expensive Love Affair.* Oregon Environmental Council.
CO_2 emissions from cars	Average passenger car 0.8 pounds per mile - average miles traveled 12,500 per year.	Aalbers, Steve. *Telephone Interview.* Oregon Department of Environmental Quality. 6 March 2000

Table 2-5 (cont.)
Values of Key Variables Used in Cost-Benefit Analysis

Cost of bicycle facilities	$100-$600 per bike space; facilities cost $1,400 per rider	Portland Bike Program Master Plan, http://www//trans.ci.portland.or.us/ Traffic_Management/Bicycle_Program/Bike MasterPlan/endtrip.htm#Current; May 1996
Stormwater discharge charge	$4.01/1000 sq.ft. (of impermeable surface); escalate at water treatment escalation rate	www.enviro.ci.portland.or.us/hasrc.htm
CO_2 externality value	$10/ton	Personal communication, Sam Sadler, Oregon Energy Office, based on ORA 345001-0010, paragraph 33, April 23, 2000
SO_2 externality value	$890/ton	Derived from Oregon NOx value and average SO2/NOx ratios in Mintzer, Miller, and Serchuk. 1996.
NO_x externality value	$2,000/ton	Personal communication, Sam Sadler, Oregon Energy Office, based on ORA 345001-0010, paragraph 33, April 23, 2000
Cost of electric recharging station	$2,225 material; assume labor costs the same for a total of $4,450	Personal communication, Steve Cox, Portland General Electric, April 4, 2000 (material costs)
Cost of natural gas refueling station	$6,500; a state rebate is available that utility will purchase for 28.9% of installation cost; use $6,500*(1-.289)=$4,622 as first cost	Personal communication, Doug Dunford, Northwest Natural Gas, April 4, 2000
Vegetated (green) roof costs and benefits	$3.50/sq.ft. incremental first cost; structural costs vary depending on building; 35-year lifetime (at a minimum); $0.10/sq.ft. maintenance in year 15; assume 40% decrease in water runoff and assume a 40% decrease in stormwater charges	Personal communication, Dave Genschel, W.P. Hickman Systems; www.greenroofs.com; email message from Sigi Koko, May 1, 2000; personal communication, Charlie Miller, Roofscape, April 5, 2000; Konopaci, Gartland, Akbari, and Rainer. 1998.
Reflective roof coating cost	$2.50/sq.ft. for reflective material; no cost for reflective paint on metal roof	Vendors
Inflation rate	2.80%	Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - April 2000, Annual Supplement to NIST Handbook 135 and NBS Special Publication 709
Discount rate	3% real	Typical rate based on multiple sources; equivalent to a nominal bond yield of 5.8%

3 City Office Building Analysis

This section presents our analysis of how the LEED™ system could have been applied to a Portland City office building. It describes the building first. Next, it presents information about how the existing building would be rated if the LEED™ rating system, Version 2, were applied to it as built. The following subsection discusses the options that could have been considered for inclusion in the building to achieve LEED™ certification. Next, it discusses what options we would have proposed for the building to meet the LEED™ requirements based on two different cost criteria. Finally, the results of the analysis are summarized and several conclusions are presented.

As with all the buildings that we examined in this study, we have taken the building as it was designed and built and conducted a "what if" analysis to explore what changes might have been made to meet the LEED™ requirements. This analysis does not consider how the building could now be retrofit. The authors also note that the rating system did not exist at the time this building was being designed and built, so the results should not be interpreted as a critique or assessment of the decisions that were made originally. We note furthermore that some of the recommended equipment, materials, or measures might not have been available during the planning phase, although most are available now or should be feasible in the near future. Thus, our analysis treats the building as if it were being designed and built today to meet LEED™ given all currently available options that would earn credits under LEED™ (except where noted).

3.1 Building Description

The Portland Development Center at 1900 SW 4th is a seven-story building completed in 1999 at a total cost of $19.4M, with 143,152 square feet of office space built over an existing two-story, underground parking garage. The garage is owned by Portland State University and was excluded from this analysis. The building is occupied by approximately 550 City staff who work during regular working hours from Monday through Friday. The building is commonly referred to as the "1900 Building."

The building design and location were determined through a competitive "shotgun" bid process during which the functional requirements were specified, but bidders were open to propose a wide range of options including providing an existing building through a lease, constructing a new building on a new or existing site, a remodel, or other options. The winning bid was an innovative proposal to build atop an existing structure and incorporate a raised access floor system. This latter feature has been used rarely in Pacific Northwest buildings and is highly energy efficient, adaptable to changes in office design, and allows individuals to control the temperature of their own workspace. Modular floor plates and the use of carpet tiles are essential components of the underfloor system, allowing easy movement, addition, or removal of diffusers throughout the space. The modular carpeting also allows selective replacement of tiles in heavy traffic areas, saving considerable expense and reducing waste.

The building exterior is clad in aluminum panels and glass walls with black EPDM covering the roof. The typical floor plate contains a deep bay of open office space on the south, east, and north side wrapping a core of vertical circulation, restrooms, and support spaces. The interior finishes include carpet tile[1] over the raised access floor, suspended acoustical ceiling tile, and painted gypsum board walls with wood paneled accent walls in public lobbies.

Cooling for the first two floors is supplied with existing chiller capacity located in the adjacent building. The top five floors are served by a single 105 ton McQuay chiller having a full-load efficiency of 0.86 kW/ton. Water is circulated in the chilled water loop at 45°F and 342 gallons per minute (gpm). The thermal loading of the building is dominated by internal gains from people, lights, computer equipment, copy machines, and kitchen equipment.

Three 50 hp supply fans deliver approximately 120,000 cubic feet per minute (cfm) of air through the 12” raised floor system at a low 0.07 inches (of water) of pressure. A single supply fan and one of the three 25 hp return fans have VSDs. The building is exhausted through vents in the bathrooms, elevator equipment rooms, and the blueprint storage area. No odors were detected during our site visit, and the diffuse floor air supply appears to provide good mixing.

Windows are argon-filled insulating glass units with thermally-broken aluminum frames. The glass plus frame U-value is 0.41. Glazing is lightly tinted and has no reflective or spectrally selective coatings or films. The shading coefficient is 0.43. There are good views of the mountains and surrounding city from most of the perimeter areas above the third floor. Sunlight enters the workspace from vision windows alone. No skylights, light shelves, clerestories, or other daylighting techniques are employed in the existing building.

Lighting is provided by recessed 2’×4’ parabolic troffers in all office areas. The fixtures have either two or three T-8 lamps each and all use electronic ballasts. Lighting power density is 0.75 W/ft^2 throughout the open office areas, with 2-lamp fixtures 8'×10' on center and 3-lamp fixtures 10'×12' on center. Building-wide lighting levels average about 0.83 W/ft^2. Lighting circuits are in large rectangular blocks in the open areas with single level switching throughout. No bi-level switching was found during the site survey. The perimeter zones are not on separate circuits. Occupancy sensors are used in a few locations in the existing building and a sweep system is used to turn lights off after-hours.

[1] In addition to offering benefits of reduced carpet replacement costs as noted earlier, they also open up possibilities of recycling through recently developed programs by major carpet providers.

Table 3-1 presents a summary of the 1900 Building shell and systems.

Table 3-1
1900 SW 4th Summary Building Energy Characteristics

Shell	
Walls	Aluminum panel with R-19 insulation.
Ceiling	Light-colored membrane with R-23 insulation.
Glazing	2-pane, gas-filled I.G. units with thermally-broken aluminum frames and average system U-value of 0.41. Shading coefficient is 0.43.
Floors	R-19 metal deck over unheated garage.
HVAC	
Ventilation	120,000 cfm through 12” raised floor system at 0.07” w.g. Exhausted through bathrooms and elevator equipment rooms.
Cooling	Chilled water distribution at 45°F from existing chillers in neighboring building.
Heating	Electric reheat system.
Lighting	
Fixtures	2 -lamp and 3-lamp 2x4 parabolic troffers with T8 lamps and electronic ballasts. CFLs in halls, bathrooms. LPD = 0.75 W/ft^2 in open offices, average is about 0.83 W/ft^2 for whole building.
Controls	Lighting is on a timer and there are few occupancy sensors and no photocells.

3.2 RATING AS BUILT

The existing 1900 Building was analyzed using the LEED™ rating system and determined to score 20 out of a possible 64 core points. A minimum of 32 points is needed for certification. This section provides a description of how the existing building scored on each measure along with a discussion of the factors that we used to make the rating decisions.

3.2.1 Data

Data were obtained for the LEED rating analysis through site visits, interviews with project staff, and construction documents. In a few cases, information on the drawings could not be verified or information was simply not available. These cases are described here, along with the assumptions that we made:

- We used the DOE-2 building energy simulation model to estimate that the building would have used 2,492,000 kWh annually *if built to just meet ASHRAE Standard 90.1-1999.* We were unable to calibrate the DOE-2 model because metered data were not available at the time we did our study, so this estimate should be considered to be a reasonable first approximation.
- We assumed that wall, ceiling, and floor insulation levels are as indicated on the construction drawings.
- Pressure in the underfloor air delivery system was assumed to be the levels indicated in the mechanical specifications.
- Construction cost data did not separate labor from materials so assumptions were made based on interviews with the general contractor.
- The results of the construction waste management plan were not available. Data were synthesized from interviews with the general contractor, demolition subcontractor, and waste hauler.

3.2.2 Rating

The following tables present, by LEED™ category, the points possible for each LEED™ measure and the points earned for the existing building. Note that several prerequisites are required under LEED™, but earn no points. The six LEED™ categories are as follows:[2]

- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation Credits

[2] Note that the sixth category, Innovation Credits, is not part of the core points under the LEED™ system, but permits a building to earn extra credit for innovative measures, practices, or use of a LEED™-certified rater.

Sustainable Sites

Table 3-2 presents the points possible for the options included in the Sustainable Sites category. It also shows the points the building earned based on our assessment.

Table 3-2
1900 Building As-built LEED™ Rating
Sustainable Sites

Sustainable Sites	Points Possible	Points Earned
P1: Erosion and Sedimentation	0	meets
C1: Site Selection	1	1
C2: Urban Redevelopment	1	1
C3: Brownfield Development	1	0
C4: Alternative Transportation	4	3
C5: Reduced Site Disturbance	2	0
C6: Stormwater Management	2	0
C7: Landscape and Exterior Design	2	1
C8: Light Pollution Reduction	1	1
Sustainable Sites Subtotal	*14*	*7*

Detailed information on each of the options is presented below:

Site Prerequisite 1: Erosion and Sedimentation — The existing building meets this prerequisite.

Site Credit 1: Site Selection — The selection of a previously developed, urban site was very appropriate for this building both because of its location to serve constituents and to minimize the impacts of a new building.

Site Credit 2: Urban Redevelopment — See comments on Site Credit 1 above.

Site Credit 3: Brownfield Redevelopment — The building was not built on a brownfield site.

Site Credit 4: Alternative Transportation — Public transit: The building is between 1 and 2 blocks from numerous bus lines.
Bike facilities: Long-term bike spaces provide parking for 3% of the occupants; outside space brings it to 8%. Ideally, the full 5% required for a credit would be long-term spaces. Shower facilities meet LEED™ requirements, but would be inadequate (only one for each gender) if 5% of the occupants actually rode bikes.
Parking: The building uses existing parking spaces for fleet vehicles. No parking was added for employees and no net parking was added to the City's inventory.

Site Credit 5: Reduced Site Disturbance — The site was a previously developed site and open area was not restored. No open space is required in the City's CX zone, which applies to this building location. This credit is primarily intended for buildings on more suburban sites and would be difficult to achieve while also meeting Site Credit 2 - Urban Redevelopment.

Site Credit 6: Stormwater Management — The impervious surface area of the site increased with the new development and no on-site stormwater detention was practical due to the existing below-grade parking. An oil separator was added to address water quality, but it does not meet the strict requirements of LEED™. Due to the location of the site and the lack of pollutant sources, stormwater detention and treatment do not appear to be critical issues on this site.

Site Credit 7: Landscape & Exterior Design to Reduce Heat Islands — All of the site's non-roof impervious surface area is concrete with a reflectance of approximately 0.4, which meets the LEED™ requirement and earns a credit. The roof surface is black and, therefore, is not ENERGY STAR compliant.

Site Credit 8: Light Pollution Reduction — Exterior lighting was minimized and does not appear to areas outside of the site.

Water Efficiency

Table 3-3 presents the points possible for the options included in the Water Efficiency category and the points the building earned based on our assessment.

Table 3-3
1900 Building As-built LEED™ Rating
Water Efficiency

Water Efficiency	Points Possible	Points Earned
C1: Water Efficient Landscaping	2	0
C2: Innovative Wastewater Tech	1	0
C3: Water Use Reduction	2	1
Water Efficiency Subtotal	*5*	*1*

The following discussion presents more details on our assessment:

Water Credit 1: Water Efficient Landscaping — A spray type sprinkler was installed rather than a drip style (which would have earned a single point).

Water Credit 2: Innovative Wastewater Technologies — No on-site wastewater treatment is performed.

Water Credit 3: Water Use Reduction — The existing building has 2.8 gallon per flush (gpf) commercial toilets and low-flow faucets. Showers, urinals, and HVAC equipment are all standard water usage for commercial buildings in the area.

Energy and Atmosphere

Table 3-4 presents the points possible for options in the Energy and Atmosphere category along with our ratings for the existing building.

Table 3-4
1900 SW 4th As-built LEED™ Rating
Energy and Atmosphere

Energy and Atmosphere	Points Possible	Points Earned
P1: Fundamental Commissioning	0	does not meet
P2: Minimum Energy Performance	0	meets
P3: CFC Reduction in HVAC&R Equip	0	meets
C1: Optimize Energy Performance	10	2
C2: Renewable Energy	3	0
C3: Best Practice Commissioning	1	0
C4: Elimination of HCFCs and Halons	1	0
C5: Measurement and Verification	1	0
C6: Green Power	1	0
Energy and Atmosphere Subtotal	*17*	*2*

Energy Prerequisite 1: Fundamental Building Systems Commissioning.

No formal commissioning plan was written or executed for this building. Largely because of this, the estimate of energy saved for the underfloor air delivery system could be generous since the assumption was made that it functions at the pressure specified in the construction documents. Because of the lack of occupancy sensors, timers, photocells, or other advanced lighting controls, the impact of not commissioning the lighting system is not as great for the existing building as it would be for upgraded systems.

Energy Prerequisite 2: Minimum Energy Performance

The building meets the existing Oregon Energy Code as evidenced by its filing.

Energy Prerequisite 3: CFC Reduction in HVAC&R Equipment

The building meets this prerequisite. According to Section 15.440 of the Specification Guide, drinking fountains and refrigerators use HFC-134A. HVAC equipment uses the R22 (non-CFC-based) refrigerant.

Energy Credit 1: Optimize Energy Performance.

The building is rated with the "New Building" criteria. A DOE-2 simulation built up from the construction documents and observations made during a site visit indicate the existing building uses approximately 24% less electricity than a building in minimal compliance with ASHRAE Standard 90.1-1999. Most of the difference is a result of the air handling and lighting systems.

Energy Credit 2: Renewable Energy

No renewable generation capacity is installed.

Energy Credit 3: Best Practice Commissioning

As noted above, no formal commissioning was performed.

Energy Credit 4: Elimination of HCFCs and Halons

The standard chiller uses an HCFC refrigerant.

Energy Credit 5: Measurement and Verification

No comprehensive measurement and verification (M&V) was conducted.

Energy Credit 6: Green Power — No green power was purchased for the building.[3]

Materials and Resources

Table 3-5 presents the Materials and Resources points possible under LEED™ and our assessment of the points that the as-built building would have scored.

Table 3-5
1900 Building As-built LEED™ Rating
Materials and Resources

Materials and Resources	Points Possible	Points Earned
P1: Storage & Collection of Recyclables	0	meets
C1: Building Reuse	3	0
C2: Construction Waste Management	2	2
C3: Resource Reuse	2	0
C4: Recycled Content	2	1
C5: Local/Regional Materials	2	0
C6: Rapidly Renewable Materials	1	0
C7: Certified Wood	1	0
Materials and Resources Subtotal	*13*	*3*

The following discussion presents more details on each of the options:

Material Prerequisite: Storage and Collection of Recyclables — A dedicated area was provided at the loading dock for paper and cardboard recycling. Collection of refundable cans and bottles was handled throughout the building. Provisions for recycling of non-refundable glass and plastics were not observed, but we assumed that the prerequisite was met (see Section 6).

Material Credit 1: Building Reuse — This building was not a reuse of an existing building; however, it was built upon an existing structure and site, so it deserves recognition although it did not meet the specific LEED™ requirement.

Material Credit 2: Construction Waste Management — Based on interviews with the general contractor and demolition subcontractor, it appears that over 86% of demolition and construction waste was recycled. Ideally, the City would require measurement and verification to ensure the efficacy of the construction waste management programs. This would be required for an actual LEED™ certification.

Material Credit 3: Resource Reuse — Based on the construction documents, no salvaged or refurbished materials were installed in the building.

Material Credit 4: Recycled Content — Based on information from the Steel Recyclers Association, all steel used in construction contains at least 20% post-consumer content. This, combined with the acoustical ceiling tile used, accounted for over 25% of the building materials. The carpet contained recycled content, but not enough to meet 20% post-consumer standard.

Material Credit 5: Local/Regional Materials — Based on the construction documents and the contractor's submittals, it appears that approximately 6% of the building materials were manufactured locally, which did not meet the 20% LEED™ requirement.

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[3] Note that during preparation of this report the City of Portland made a commitment to purchase green power, but it is not targeted specifically to this building.

Material Credit 6: Rapidly Renewable Materials

No rapidly renewable materials were specified.

Material Credit 7: Certified Wood

No certified wood was specified.

Indoor Environmental Quality

Table 3-6 summarizes our rating in the Indoor Environmental Quality category and shows the number of points possible for each option.

Table 3-6
1900 Building As-built LEED™ Rating
Indoor Environmental Quality

Indoor Environmental Quality	Points Possible	Points Earned
P1: Minimum IAQ Performance	0	meets
P2: Environmental Tobacco Smoke	0	meets
C1: Carbon Dioxide Monitoring	1	0
C2: Increase Ventilation Effectiveness	1	1
C3: Construction IAQ Mgmt Plan	2	2
C4: Low-Emitting Materials	4	1
C5: Indoor Pollutant Source Control	1	0
C6: Controllability of Systems	2	1
C7: Thermal Comfort	2	1
C8: Daylight and Views	2	0
Indoor Environmental Quality Subtotal	*15*	*6*

Details for each of the options are presented below:

IEQ Prerequisite 1: Minimum IAQ Performance

The existing building meets ASHRAE Standard 62 recommended practice and this prerequisite. The HVAC air intake is located on the opposite side of the building from roads, garbage, the loading dock, and the parking garage. Drip pans in HVAC system are properly plumbed with drains, and relative humidity is maintained below 65%.

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

Smoking is forbidden in all areas of the building.

IEQ Credit 1: Carbon Dioxide (CO_2) Monitoring

No sensor was installed. The existing building provides a high percentage and flow of outside air (over 25%) so there is no design need to install a CO_2 sensor, as respiration will not produce nearly enough CO_2 to saturate to 530 ppm with the existing occupancy level.

IEQ Credit 2: Increase Ventilation Effectiveness

Diffusion patterns appeared to be excellent during the site visit. It should be noted that each time a major remodeling takes place building maintenance staff should check to make sure that the new distribution of diffusers provides good mixing.

IEQ Credit 3: Construction IAQ Management Plan — In accordance with the SMACNA guideline, the air conditioning system was operated continuously during construction with 100% outside air and filters were changed before occupancy.[4]

IEQ Credit 4: Low-Emitting Materials — The installed carpet tiles meet the Carpet and Rug Institute's Green Label Indoor Air Quality Test criteria, but the paints and adhesives do not meet their respective IEQ criteria for LEED™ credits. The bulk of the composite wood products used in casework were specified to be formaldehyde free, but the remaining specified composite wood products are not available without formaldehyde.

IEQ Credit 5: Indoor Chemical and Pollutant Source Control — The front entry has a low pressure differential with the outside, minimizing air exchange. To get the credit, however, the building must also have separate drains for dumping of cleaning chemicals.

IEQ Credit 6: Controllability of Systems — Individual airflow, temperature, and lighting controls are accessible for nearly every worker in the open and private office areas. The perimeter areas point is not awarded since the windows are not operable.

IEQ Credit 7: Thermal Comfort — Humidity control is unnecessary in this building because of the climate. The building already complies with ASHRAE Standard 55 simply by being air conditioned in Portland. Despite this, the building cannot earn the second LEED credit in this category without installing a permanent humidity monitoring system.

IEQ Credit 8: Daylight and Views — Diffused sunlight reaches the perimeter areas of the building, but does not penetrate at a useful level beyond about 20 feet from the windows. Ninety percent of the workspaces have a direct line of sight to a vision window when standing (i.e., cubicle walls block view when seated); however, LEED requires that views be available while seated.

Innovation Credits and Design/Build Process

Table 3-7 summarizes our findings regarding the Innovation and Design/Build Process category. It also presents the number of points possible. Note that these possible points are not part of the core credits under LEED™.

Table 3-7
1900 Building As-built LEED™ Rating
Innovation Credits and D/B Process

Innovation Credits and D/B Process	Points Possible	Points Earned
C1: Innovation Credits	4	0
C2: Accredited Professional	1	0
Innovation Credits Subtotal	*5*	*0*

[4] Note that it was discovered after occupancy that some filters were inadvertently left in place after construction was completed.

The following discussion presents more details on our ratings:

I & D/B Credit 1 Innovation credits were not awarded for this building. We note, however, that the City and contractors implemented several innovations in this building, including the raised floor system, that have the potential to reduce operating costs significantly over the life of the building. Our energy analysis explicitly takes the potential energy savings into account and the building receives the other credits clearly attributable to this system for improved occupant comfort and controls.

I & D/B Credit 2 A LEED™-trained professional was not involved in the project team for this building. However, we note that the training and certification process had not been established at the time this building was designed and constructed, so this was not a feasible option.

Overall Rating

Table 3-8 summarizes the LEED™ points possible and the points earned by category. Note that the most points and the highest percentage of points earned were for Sustainable Sites and Indoor Environmental Quality. The fewest points and the lowest percentage of points earned for the core categories were under the Energy and Atmosphere and Water Efficiency categories.

Table 3-8
1900 Building As-built LEED™ Rating
Grand Total

LEED Totals	Points Possible	Points Earned	% of Points Earned
Sustainable Sites	*14*	*7*	*50%*
Water Efficiency	*5*	*1*	*20%*
Energy and Atmosphere	*17*	*2*	*12%*
Materials and Resources	*13*	*3*	*23%*
Indoor Environmental Quality	*15*	*7*	*47%*
Total Core LEED Points	**64**	**20**	**31%**
Innovation Credits	*5*	*0*	*0%*
Total Score	**69**	**20**	**29%**

A total of 64 points is included in the LEED™ core categories, although some are mutually exclusive and, therefore, not achievable on a single building project. The 1900 Building earned 20 points based on our rating and the total necessary for certification is 32. Thus, 12 additional points would be needed for certification.

3.3 CANDIDATE LEED™ MEASURES

In this subsection, we present the measures that we considered as potential options for inclusion in a building identical to the 1900 Building if it were being designed now to meet the basic LEED™-certified requirements. These potential options were those that passed a preliminary screening. Measures were screened based on an initial assessment of the technical and economic feasibility of applying them to the site. The screening process utilized discussions with City of Portland staff, past experience with cost-effective measures in other projects, and recommendations within the LEED guidelines. As described in Section 2, our initial screening took into account the following criteria:

- excessive first costs or potentially large life cycle costs compared to potential benefits and the respective costs of other measures;
- inapplicability or lack of feasibility for the site (e.g., limitation of disturbance to a greenfield site, since this site was already developed);
- requirements for major redesign or siting changes (e.g., major construction changes to accommodate daylighting or relocation to a Brownfield site); and
- unresolved ecological benefits for the site (e.g., elimination of HCFCs and Halons[5]).

We next evaluated the remaining set of options, or the candidate measures, in terms of their costs and benefits. Sixteen (16) measures survived the screening, allowing a possible 22 incremental points. As noted earlier, 12 incremental points would be required for certification of this building.

The candidate measures are discussed in the following subsections by LEED™ category. Tables similar to those presented earlier summarize the information for the candidate measures. Note that each specific measure is assigned a number in the tables that is used for future reference in this section. The tables show the number of points possible under LEED™ for the measure, the rating we gave to the existing building, and the incremental points that we considered to be achievable for the measure.

3.3.1 Candidate Measures—Sustainable Sites

Table 3-9 presents the candidate measures in the Sustainable Sites category.

Table 3-9
1900 Building Candidate LEED™ Measures
Sustainable Sites

Candidate Measure #	Sustainable Sites	Points Possible	Existing Building	Incremental Points Considered
1	C4: Alternative Transportation	4	3	1
2	C6: Stormwater Management	2	0	1
3a	C7a: Landscape and Exterior Design	1	1	1
3b	C7b: Landscape and Exterior Design	1	1	1
	Sustainable Sites Subtotal	*14*	*7*	*2 or 3*

Note: Shaded cells indicate measures that are alternative ways of achieving the credits so their incremental points are not additive.

[5] This measure is controversial because of the confusing message it conveys: switching to the use of HCFC refrigerants is ecologically beneficial. In our opinion, the most ecological way to meet this requirement is to eliminate mechanical cooling entirely, and that option was not considered because of the necessity to significantly alter the shell and floor plate design to achieve a comfortable climate in a building of this size.

The following discussion presents more detailed information on each measure selected for further consideration, as well as those that were eliminated because they failed to meet our screening criteria:

Site Credit 3: Brownfield Redevelopment — Assessment of the brownfield option was beyond the scope of our study, but we believe that it should be considered by the City for future facilities.

Site Credit 4: Alternative Transportation — We assessed the option of providing alternative fueling station(s) for vehicles parked in the garage used by the building. Both an electric recharging station and natural gas refueling unit were considered; the electric station was assumed because of slightly lower first costs. To meet the LEED™ requirement, a process would have to be implemented to ensure that an adequate number of vehicles were recharged during a 24-hour period. Switching vehicles to alternative fuels supports the City's goals of cleaner air and reduced greenhouse gas emissions.

Site Credit 5: Reduced Site Disturbance — As noted earlier, this credit is primarily intended for buildings on more suburban sites and would be difficult to achieve while also meeting Site Credit 2 - Urban Redevelopment.

Site Credit 6: Stormwater Management — A vegetated roof, although increasing first cost for the roofing installation and added structure, provides many benefits including reduced stormwater runoff, reduced roof maintenance, reduced heat islands (Site Credit 7), and improved energy efficiency.

Site Credit 7: Landscape & Exterior Design to Reduce Heat Islands — See comments in Credit 6 above. In place of a vegetated roof, a white coating could be applied to the specified roof to earn a point under this credit and reduce roof maintenance; the white coating, however, would not earn a point under Credit 6 as the vegetated roof would.

3.3.2 Candidate Measures—Water Efficiency

Table 3-10 summarizes the candidate measures in the Water Efficiency category.

Table 3-10
1900 Building Candidate LEED™ Measures
Water Efficiency

Candidate Measure #	Water Efficiency	Points Possible	Existing Building	Incremental Points Considered
4	C1: Water Efficient Landscaping	2	0	2
5	C2: Innovative Wastewater Tech	1	0	1
6	C3: Water Use Reduction	2	1	1
	Water Efficiency Subtotal	*5*	*1*	*4*

Each of the measures is discussed in more detail below:

Water Credit 1: Water Efficient Landscaping — It is possible to get a single credit for installing a drip style irrigation system. However, this adds to the project cost, whereas eliminating the irrigation system entirely reduces the cost of landscaping and earns a second credit. Because of the increasing interest in native landscaping, the financial savings available, and the water savings that earn the LEED credit, the option to eliminate the entire irrigation system was chosen.

Water Credit 2: Innovative Wastewater Technologies

This measure would use recovered faucet water to flush toilets. Note that commercial building toilet flushing with greywater from sinks is not allowed under current code, but codes are likely to be changed to allow this option. We have analyzed this option given that it might be legal in the future, but we have not included it in those measures recommended to meet the LEED™ requirement. We have assumed based on available data that toilet flushing requires more water than the amount available from faucet drain water.

Water Credit 3: Water Use Reduction

To get an additional credit, this measure would decrease water usage in the building to meet a standard 30% more stringent than the EPAct92 requirements. The measures include the following specifications: showerheads = 1.75 gpm, faucets ≤ 1.75 gpm, urinals = 0.7 gpf, commercial 2-piece gravity-type toilets ≤ 2.4 gpf. Savings reported for this measure are in addition to water efficient landscaping measure savings.

3.3.3 Candidate Measures—Energy and Atmosphere

Table 3-11 presents the candidate measures in the Energy and Atmosphere category.

Table 3-11
1900 Building Candidate LEED™ Measures
Energy and Atmosphere

Candidate Measure #	**Energy and Atmosphere**	Points Possible	Existing Building	Incremental Points Considered
	P1: Fundamental Commissioning		does not meet	meets
7a	C1a: Optimize Energy Performance	10	2	2
7b	C1b: Optimize Energy Performance	10	2	4
8	C2: Renewable Energy	3	0	1
9	C3: Best Practice Commissioning	1	0	1
10	C5: Measurement and Verification	1	0	1
11	C6: Green Power	1	0	1
	Energy and Atmosphere Subtotal	*17*	*2*	*6-8*

Note: Shaded cells indicate measures that are alternative ways of achieving the credits so their incremental points are not additive.

Detailed information on the prerequisite that the building did not meet and the energy performance measure is presented below:

Prerequisite 1: Fundamental Building Systems Commissioning.

We include in the prerequisite meeting the fundamental requirements plus 1) the Energy and Atmosphere Credit 3: Best Practice Commissioning (the more stringent commissioning credit) and 2) the Energy and Atmosphere Credit 5: Measurement and Verification.

Energy Credit 1: Optimize Energy Performance

The existing building uses an estimated 1,893,900 kWh annually. DOE-2 models of the building indicate that with systems minimally compliant with ASHRAE 90.1-1999, the building would consume approximately 2,492,000 kWh; thus, the as-built building uses 24% less energy than the baseline level. Two measures are considered here. Measure 7a is to reduce usage by 149,500 kWh to achieve a level of efficiency 30% better than required by the ASHRAE Standard; Measure 7b is to reduce usage by 398,700 kWh to achieve a level of efficiency 40% better than required by the ASHRAE Standard.

The 149,500 kWh of annual savings needed for Measure 7a can be obtained by changing the chiller to a unit with an efficiency of 0.50 kW/ton or better. The existing 105 ton unit uses 0.86 kW/ton at peak.

The 398,700 kWh of savings needed to achieve Measure 7b requires additional lighting, HVAC, and thermal gain reduction measures. About a quarter of the private offices were in use during the daytime site visit, but more than half the private offices had their lights on. While the sweep system lighting timer is effective for after-hours lighting control, occupancy sensors in private offices and bathrooms and conference rooms are recommended to cut daytime usage. Given the extensive task lighting, we recommended decreasing the ambient lighting in open offices from 0.75 to 0.63 W/ft^2 in perimeter areas by increasing fixture spacing to a 10’x12’ grid—this would save both energy and money because of the reduced number of fixtures. This measure also includes adding perimeter daylighting controls for floors 3 through 7 and adding VSDs on the #2 supply and return motors (50 and 25hp, respectively). The measure also includes building enclosures for copiers, printers, and computer servers and venting these spaces to reduce heat gain from the equipment as well as to get a credit in the Indoor Air Quality section for ozone reduction.

Table 3-12 presents descriptive information on the energy submeasures for the first energy credit.

Table 3-12
Optimize Energy Submeasures, Measure C1

Submeasure	Description	Cost
Lighting	*Lighting equipment density reduction* Change 8’×10’ open plan grid to 8’×12’ 0.75W/ft^2 to 0.63W/ft^2 in perimeter areas	-$24,000
	Daylighting continuous dimming controls Perimeter daylighting controls	$28,320
HVAC	*VSDs on #2 50hp and 25hp AHU motors*	$18,075
	Efficient chiller 0.5 kW/ton or better ($50/ton additional)	$5,250
Thermal Gain	*Isolate and exhaust hot equipment* Additional walls and ventilation areas for copy machines, printers, computer servers	$30,000
	Total	**$57,645**

Details for the other candidate measures and those that we excluded are presented in the following discussion:

Energy Credit 2: Renewable Energy — The cost of building integrated photovoltaic modules is partially offset by the expensive aluminum panels they replace. Siting of the panels should be chosen based on maximum solar access, and pathways should be accessible to the public for viewing the panels.

Energy Credit 3: Best Practice Commissioning — This measures requires a third-party review of the commissioning plan and tying final payment to successful commissioning and implementation of a performance-based fees contract. We combine this measure with the prerequisite commissioning requirement and estimate commissioning costs based on including this measure.

Energy Credit 4: Elimination of HCFCs and Halons — As noted earlier, the most ecological way to meet this requirement would be to eliminate mechanical cooling entirely. We did not consider that option, however, because of the necessity to significantly alter the shell and floor plate design to achieve a comfortable climate in a building of this size.

Energy Credit 5: Measurement and Verification — This measure requires implementing a comprehensive measurement and verification plan and meeting the installed equipment requirements for continuous metering described in the IPMVP Option B. This is considered an essential part of any complete commissioning plan. The IPMVP recommends installing permanent measurement devices and reviewing on a regular basis the operation of HVAC equipment, lighting, and security systems. We combine this measure with the prerequisite commissioning requirement and estimate commissioning costs based on including this measure.

Energy Credit 6: Green Power — Engage in a 2-year contract to purchase power with a minimum of 30% generated from renewable sources that meet the CRS Green-E requirements. PGE serves many of the City buildings and the utility offers Green Power at a 0.5 cent/kWh premium.

Table 3-13 presents our estimates of the emissions reductions that would occur by switching to 30% green power.[6] The amount of green power purchased (448,560 kWh per year) was estimated based on the electricity consumption of the building *after* implementing Measure 7b.

Table 3-13
Impact of 30% Green Electricity Purchase on Emissions Reductions

Pollutant	Annual Reduction
CO_2	740,124 lbs/yr
NO_x	1,256 lbs/yr
SO_2	1,570 lbs/yr

[6] Emissions reductions are estimated as described in Section 2 by using the emission rates of fossil fueled-powerplants in PGE's generating mix.

3.3.4 Candidate Measures—Materials and Resources

Table 3-14 presents the candidate measures that we considered in the Materials and Resources category.

Table 3-14
1900 Building Candidate LEED™ Measures
Materials and Resources

Candidate Measure #	**Materials and Resources**	Points Possible	Existing Building	Incremental Points Considered
12	C3: Resource Reuse	2	0	1
13	C7: Certified Wood	1	0	1
	Materials and Resources Subtotal	*13*	*3*	*2*

Each of the measures is discussed in more detail below including those that we did not analyze because they failed to meet our screening criteria:

Material Credit 1: Building Reuse — It would have required a major change in the project to reuse an existing building and consideration of this change was beyond the scope of our study. However, as noted earlier, the building deserves recognition for taking advantage of an existing structure for its foundation. We believe that building reuse should be considered by the City in future developments as a prime way to revitalize the city and preserve embodied energy and resources.

Material Credit 3: Resource Reuse — We identified a source of used access flooring that would have achieved credit for this measure and provided significant first-cost savings. The quantity of flooring in the building is sufficient to exceed the 5% required by LEED™ for one point.

Material Credit 4: Recycled Content — Appropriate recycled content materials do not appear to be available to achieve a second point under this credit.

Material Credit 5: Local/Regional Materials — A sufficient quantity of potential substitutions of local/regional materials has not been identified.

Material Credit 6: Rapidly Renewable Materials — There were insufficient opportunities to use rapidly renewable materials to receive credit for this measure.

Material Credit 7: Certified Wood — FSC certified wood could be specified for a minimum of 50% or even 100% of wood based materials with a minimal premium in material cost.

3.3.5 Candidate Measures—Indoor Environmental Quality

Table 3-15 presents the candidate measures that we considered in the Indoor Environmental Quality category. The comments below provide more information on each of the candidate measures that we retained in our analysis and those that were eliminated from further analysis:

Table 3-15
1900 Building Candidate LEED™ Measures
Indoor Environmental Quality

Candidate Measure #	**Indoor Environmental Quality**	Points Possible	Existing Building	Incremental Points Considered
14	C1: Carbon Dioxide Monitoring	1	0	1
15	C4: Low-Emitting Materials	4	1	2
16	C5: Indoor Pollutant Source Control	1	0	1
	Indoor Environmental Quality Subtotal	*15*	*7*	*4*

IEQ Credit 1: Carbon Dioxide (CO_2) Monitoring — Despite our impression that a permanent CO_2 monitor is not needed for this system, this study looks at the economics of installing one anyway to comply with LEED requirements. If this were an actual application for LEED certification, the underfloor air delivery system and its related high flow rates and good mixing—the reasons that a CO_2 sensor is not needed—might be submitted as an innovation credit, instead of actually installing a CO_2 sensor.

IEQ Credit 4: Low-Emitting Materials — In addition to the low-emitting carpet, use low or very-low volatile organic compound emission paints and adhesives.

IEQ Credit 5: Indoor Chemical and Pollutant Source Control — To complete the measure, install separate drains in cleaning closets for the disposal of cleaning agents.

IEQ Credit 6: Controllability of Systems — No changes were considered because operable windows would eliminate the ability to use the existing HVAC system. This is the kind of measure that is best to include in the early stages of design, before the shape of a building is determined.

IEQ Credit 7: Thermal Comfort — Humidity control is unnecessary in this building because of the climate. The building already complies with ASHRAE Standard 55 simply by being air conditioned in Portland. Despite this, the building cannot earn the second LEED credit in this category without installing a permanent humidity monitoring system and we eliminated this option from consideration because it would be inappropriate.

IEQ Credit 8: Daylight and Views — No changes were considered, since the access to daylight requirement for the first point would require a significant change in the building shell and plan. The second credit—requirement for direct line of sight while seated—could be achieved with lower partitions, but with a potentially detrimental loss of acoustical privacy for staff.

3.3.6 Candidate Measures—Innovation Credits and Design/Build Process

Table 3-16 summarizes our assessment of credits that could have been obtained through either building or siting decisions or through the use of a LEED™-trained professional. The details of our consideration of the measures are discussed below the table.

Table 3-16
1900 Building Candidate LEED™ Measures
Innovation Credits and Design/Build Process

Candidate Measure #	**Innovation and Design/Build Process**	Points Possible	Existing Building	Incremental Points Considered
17	C2: Accredited Professional	1	0	1
	Innovation and Design/Build Process Subtotal	*5*	*0*	*1*

I & D/B Credit 1 We considered a range of possible innovations that could have received credit for this building, but did not propose any for further assessment. Without more direct involvement in the design and planning process, we found it impractical to propose innovations now without knowing whether they would have been limited by project constraints. Nevertheless, we believe that several characteristics of this building were innovative, although it might be hard to receive credit for them under LEED™. We believe that it is important for designers and planners to consider possible innovations that would receive LEED™ credit, however.

I & D/B Credit 2 We believe that it would be useful to include a LEED™-trained professional in the project team for projects like this in the future. We do not rely on this option as one of the credits that we analyze for this building, however, because it is useful to determine first whether the building could meet the LEED™ requirement with specific building measures alone.

3.3.7 Candidate Measures—Summary Information

Table 3-17 summarizes the measures that we retained to consider further as means to meet the basic LEED™ certification level. Generally, the most incremental points that we considered were in the categories where the gap was the largest between the building rating and the points possible. In particular, this was the case for the Energy and Atmosphere category. However, it appeared that several options should be considered also in the Sustainable Sites and Indoor Environmental Quality categories; the 1900 Building as built received almost half the points available in each of these categories. In the Water Efficiency category, we determined that the options that would achieve all the available points should be carried forward for further analysis.

3.4 MEASURES TO MEET THE LEED™ CERTIFICATION REQUIREMENT

This subsection presents the results of two cost-benefit analyses that we used to select measures to meet the basic LEED™ certification requirement. The first set of results discussed is based on meeting LEED™ by selecting measures that would do so at minimum first cost. The second set

Table 3-17
1900 Building Candidate LEED™ Measures
Grand Total

LEED Categories	Points Possible	Existing Building	Incremental Points Considered
Sustainable Sites Subtotal	*14*	*7*	*4*
Water Efficiency Subtotal	*5*	*1*	*4*
Energy and Atmosphere Subtotal	*17*	*2*	*6-8*
Materials and Resources Subtotal	*13*	*3*	*2*
Indoor Environmental Quality Subtotal	*15*	*7*	*4*
Total Core LEED Points	**64**	**20**	**20-22**
Innovation Credits Subtotal	5	0	0
Total Score	**69**	**20**	**20-22**

of results is based on meeting the requirement by selecting measures that would minimize the life cycle costs. Life cycle costs are defined as the net present value of first costs and future costs and benefits[7]. In both cases, the analysis is based on the perspective of the building owner/operator.

Impacts on other key groups are discussed, but the analysis is based on an optimization from the perspective of the owner/operator.

3.4.1 Measure Selection Based on Lowest First Costs

This subsection presents the candidate measures described above ranked by least first cost for the number of LEED™ points earned by the measure. The incremental first cost per point ($FC/Pt.) is shown for each measure and the measures are ranked from lowest (most negative) to highest incremental $FC/Pt.[8]

[7] As noted in Section 2, the real discount rate used is 3%, and the life-cycle period assumed is 25 years. See Section 2 for a more detailed discussion of life cycle cost assumptions.

[8] We note that measures that reduce first cost are important in the interest of minimizing building first cost, even without the objective of meeting the LEED™ requirements

Measures Required for LEED™ Certification

Table 3-18 presents the results of applying the least first cost criterion to the candidate measures. Because of the importance of the life cycle perspective and for comparison purposes, the table also provides life cycle cost estimates, even though they were not used to select this set of measures. The measures required to just meet LEED™ certification are shown in the top half of Table 3-18.

The first column shows the tracking number assigned earlier to each measure. The second column identifies the measure. The third column indicates the number of LEED™ points that apply to that measure. The fourth column shows the cumulative points earned by the measures. The fifth column indicates the incremental first cost per point earned by the measure. The sixth column shows the incremental Direct and Regional System first cost for the measure. The seventh column presents the incremental Direct and Regional System life cycle cost for the measure. As noted earlier, the Direct and Regional System costs would differ if the marginal costs of supplying energy or water or treating waste differed from the average costs as reflected in customer rates. In our study, however, we were unable to obtain reliable estimates of these marginal costs over the 25-year time horizon examined. Therefore, we used marginal costs equal to the average costs projected throughout the period and, consequently, the Direct and Regional System costs and benefits were assumed to be equivalent.

The eighth column shows the Societal incremental life cycle costs. These values take into account societal impacts that we were able to monetize. The ninth column identifies some of the benefits that were not estimated in our analysis.

Table 3-18
1900 Building Candidate Measures Sorted By First Cost, Incremental Impacts

Candidate Measure Number (1)	Measure (2)	Pts. (3)	Cumulative Pts. (4)	$FC/Pt. (5)	Direct/Regional System First cost (6)	Direct/Regional System LCC (7)	Societal LCC (8)	Non-quantified Benefits (9)
	Fundamental Building Systems Commissioning*	0	0	n/a	$194,000	-$2,680,000	-$2,680,000	
12	Resource Reuse	1	1	-$125,400	-$125,400	-$125,400	-$125,400	Reduced pollution associated with producing new materials
4	Water Efficient Landscaping	2	3	-$7,500	-$15,000	-$36,617	-$36,617	
6	Water Use Reduction	1	4	$0	$0	-$14,360	-$14,360	
9	Best Practice Commissioning	1	5	$0	$0	$0	$0	
10	Measurement and Verification	1	6	$0	$0	$0	$0	
11	Green Power	1	7	$0	$0	$39,028	-$47,224	Fish/wildlife habitat
14	Carbon Dioxide (CO2) Monitoring	1	8	$2,289	$2,289	$2,289	$2,289	
7a	Optimize Energy Performance - 30%	2	10	$2,625	$5,250	-$86,576	-$119,372	
15a	Low-Emitting Materials**	1	11	$2,500	$2,500	$2,500	$2,500	Worker health benefits
16	Indoor Chemical and Pollutant Source Control	1	12	$2,660	$2,660	$9,620	$9,620	Worker health benefits
	Total needed		***12***		*$66,300*	*-$2,890,000*	*-$3,010,000*	
	Simple payback = 5 months							
	Measures Not Needed							
15b	Low-Emitting Materials**	1		$3,000	$3,000	$3,000	$3,000	Worker health benefits
1	Alternative Transportation	1		$4,622	$4622	$4622	$4622	Air pollution benefits from reduced use of gasoline-fueled vehicles
13	Certified Wood	1		$9,500	$9,500	$9,500	$9,500	Forest ecosystem benefits
7b	Optimize Energy Performance - 40%	4		$14,411	$57,645	-$187,257	-$274,724	
3a	Landscape and Exterior Design to Reduce Heat Islands (reflective roof)	1		$44,000	$44,000	$27,975	$23,760	Heat island benefits to surrounding buildings
5	Innovative Wastewater Technologies	1		$45,000	$45,000	$52,374	$52,374	
2	Stormwater Management (green roof)	1		$74,500	$74,500	-$3,023	-$7,286	Reduced impacts on fish habitat; improved aesthetics
8	Renewable Energy	1		$178,000	$178,000	$166,881	$150,481	

*The Fundamental Building Systems Prerequisite is required, regardless of cost. This measure includes Best Practice Commissioning and Measurement and Verification and their costs and benefits.
**Low-Emitting Materials is broken into adhesives (15a) and paints (15b).
Note: Direct and Regional System values are assumed to be the same in this analysis because no marginal cost data were available. They would be different if estimated marginal costs were higher than average costs.

Most of the 11 options selected were described in Section 3.3, but a brief description and additional information are provided here.

The first measure listed in Table 3-18, Fundamental Building Systems Commissioning is the one prerequisite that was not met by the existing building. Despite its high first cost, it must be met for the building to qualify under the LEED™ system, so it is included. We assumed that this measure included both the Best Practice Commissioning and Measurement and Verification options so its first cost and its benefits encompass all three options. The estimated costs for this complete activity were estimated at 1% of the building cost, which is a mid-range estimate for the costs based on available data in the literature.

We did not attribute any energy savings to this combined measure because the energy performance measure (Measure 7) received full credit for the energy savings that we estimated with our building simulation model. We constructed our analysis so that complete commissioning and measurement/verification would be included with energy-efficiency improvements as a way to ensure that the estimated energy savings were achieved. The substantial benefits shown in the table that were estimated for the combined Building Systems Commissioning measure were a result of an estimated increase in employee productivity. We assumed an average annual salary of $30,000 for the 550 employees. We then assumed a minimal productivity increase of 1%, leading to annual productivity economic savings estimated to be $165,000.[9]

The first-cost savings for Measure 12 were based on using salvaged floor components. Measure 4 would reduce first cost by eliminating the irrigation system in conjunction with planting vegetation that would require no irrigation. Measure 6 could have been implemented by specifying more water-efficient fixtures, for no incremental cost, but with life cycle water savings.

A green power purchase (Measure 11) would not have increased first cost, but it would have increased electricity costs. Over the 25-year life cycle, however, this measure would have reduced emissions sufficiently to provide societal benefits valued at over twice the added cost of the electricity.

The energy savings associated with Measure 7a could have been achieved at an incremental cost of only about $5,000, primarily because the 1900 Building was so close to meeting this requirement. This improvement in energy efficiency would have produced life cycle utility bill savings of nearly $92,000, or about 18 times the incremental first cost. From the societal perspective, these energy savings would have produced emissions reductions valued at an additional $32,000. These reductions include over 100 tons annually of CO_2 that would not be produced, which would be equivalent to removing about 25 cars from the streets.

Measure 16 (installation of separate drains for disposal of cleaning agents) could have been implemented for a cost of slightly less than $3,000, but would have increased life cycle costs because of anticipated higher maintenance costs.

[9] Since indirect employee costs and benefits were not included, this is a very conservative estimate of the economic impacts. Productivity increases associated with green buildings have been estimated to range from a few percent to 20% or more. Values attributable to improved air quality alone are typically about 3%. Because the air quality in the 1900 Building was deemed to be relatively good as built, we made a conservative assumption that only a 1% improvement would be achieved.

In summary, if the objective had been to meet the LEED™ requirements by selecting those measures that had the lowest first cost, a net investment of $66,300 would have been required. This was equivalent to about 0.3% of the total construction cost of the building. Based on the stream of future benefits associated with this investment, these measures would have had a simple payback of about 5 months, and produced a net reduction of about $2.9M, including productivity benefits, in the life cycle cost of constructing and operating the building.

Additional Measures Not Required for LEED™ Certification

The measures shown in Table 3-18 that would not have been required for LEED™ certification are discussed below. These measures are listed in the lower part of the table.

Energy efficiency could have been increased to a 40% improvement (Measure 7b) over the base level required by LEED™ for an incremental first cost of a little less than $60,000. Resulting energy savings would have reduced electricity costs by about $250,000 over the 25-year life cycle. Air pollution benefits were estimated to be almost $90,000. This figure includes over 300 tons of CO_2 that would not be produced each year, which is equivalent to removing about 70 automobiles from the streets.

Use of a high albedo roof (Measure 3a) would increase the first cost of the roof, but would reduce the required frequency of roof replacements and would save cooling energy. There would be small societal benefits associated with the reduced electricity consumption.

The Innovative Wastewater Technologies option (Measure 5) was based on installing a system to use greywater for toilet flushing. Although this measure would reduce potable water usage and costs, our analysis suggested that increased maintenance costs would be slightly higher than the value of water savings. As noted earlier, current codes would not allow use of this type of system anyway, but we conducted a preliminary assessment of it.

The Stormwater Management option (Measure 2) was based on installing a vegetated roof. If installed, this option would receive credit under Measure 3b in place of the high albedo roof and there would be no costs associated with it there. This system would increase the roof first cost, but would reduce energy use, roof maintenance costs, and stormwater runoff.

Air emission and energy bill savings for the Renewable Energy option (Measure 8) were based on producing 5% of the electricity used by the building after implementing Measure 7b.

Non-Quantified Benefits

Table 3-18 also shows some of the potential benefits that we were unable to analyze. For example, use of salvaged floor components would have eliminated the energy and air pollution impacts associated with producing new materials. We did not attempt to estimate these impacts, although it would be possible to do so.

The use of low-emitting materials and indoor chemical and pollutant source control would have positive effects on workers' health. We did not estimate these impacts, but they could be included implicitly in the productivity enhancements attributed to building commissioning.

The most difficult to quantify benefits would probably be those associated with reducing impacts on ecosystems and fish and wildlife habitat. These benefits could be significant and very important in the City's efforts to address Endangered Species Act requirements, particularly if spread over a large number of buildings. We note here the importance of considering these impacts and the need for ways to analyze them.

3.4.2 Measure Selection Based on Lowest Life Cycle costs

This subsection presents the candidate measures ranked according to their impacts on life cycle cost. Because one objective of this study was to determine the life cycle cost impacts on the City of constructing and operating green buildings, our ranking was based on costs and benefits that would affect the building owner/operator or occupants. It should be noted, however, that it would be possible to take the perspective of various other market actors, such as the regional community or the world community as a whole, in the analysis of life cycle costs, and the rankings might be different. As before, we dealt partially with different perspectives by presenting those Societal impacts that we could quantify and identifying non-quantified benefits.

This subsection focuses on the differences from the results presented earlier for the lowest first cost ranking. All the options presented here were already discussed at some length in the preceding subsection.

Table 3-19 presents the results of ranking the candidate measures using the least life cycle cost criterion. Nine of the candidate measures were required to meet the LEED™ certified level. The table presents the information in the same columns as Table 3-18, except for column 5, which shows the life cycle cost per LEED™ point ($LCC/Pt.).

Compared to the measures selected based on lowest first cost, the following measures were dropped from the list required to meet LEED™ using the lowest life cycle cost criterion:

- the Green Power purchase (Measure 11),
- the Optimize Energy Performance - 30% option (Measure 7a), and
- the Indoor Chemical and Pollutant Source Control option (Measure 16).

Measure 11 was not included because it would increase the life cycle cost of energy purchased. It is important to note that by dropping this measure, however, the societal benefits of the emissions reductions would not be attained. Their economic value was estimated to be more than twice as large as the direct economic premium paid for the green power.

Table 3-19
1900 Building Candidate Measures Sorted By Life Cycle Cost, Incremental Impacts

Candidate Measure Number	Measure	Pts.	Cumulative Pts.	$LCC/Pt.	Direct/Regional System First cost	Direct/Regional System LCC	Societal LCC	Non-quantified Benefits
	Fundamental Building Systems Commissioning*	0	0	n/a	$194,000	-$2,680,000	-$2,680,000	
12	Resource Reuse	1	1	-$125,400	-$125,400	-$125,400	-$125,400	Reduced impacts of using new materials
7b	Optimize Energy Performance - 40%	4	5	-$46,814	$57,645	-$187,257	-$274,724	
4	Water Efficient Landscaping	2	7	-$18,309	-$15,000	-$36,617	-$36,617	
6	Water Use Reduction	1	8	-$14,360	$0	-$14,360	-$14,360	
2	Stormwater Management (green roof)	1	9	-$3,023	$74,500	-$3,023	-$7,286	Reduced impacts on fish habitat; improved aesthetics
3b	Landscape and Exterior Design to Reduce Heat Islands (green roof)	1	10	$0	$0	$0	$0	Heat island benefits to surrounding buildings; improved aesthetics
9	Best Practice Commissioning	1	11	$0	$0	$0	$0	
10	Measurement and Verification	1	12	$0	$0	$0	$0	
	Total needed		***12***		*$185,750*	*-$3,047,000*	*-$3,138,000*	
	Simple payback = 1 year							
	Measures Not Needed							
7a	Optimize Energy Performance - 30%***	2		-$43,288	$5,250	-$86,576	-$119,372	
14	Carbon Dioxide (CO2) Monitoring	1	11	$2,289	$2,289	$2,289	$2,289	
15a	Low-Emitting Materials**	1	12	$2,500	$2,500	$2,500	$2,500	Worker health benefits
15b	Low-Emitting Materials**	1		$3,000	$3,000	$3,000	$3,000	Worker health benefits
1	Alternative Transportation	1	12	$4,622	$4,622	$4,622	$4,622	Air pollution benefits from reduced use of gasoline-fueled vehicles
13	Certified Wood	1		$9,500	$9,500	$9,500	$9,500	Forest ecosystem benefits
16	Indoor Chemical and Pollutant Source Control	1		$9,620	$2,660	$9,620	$9,620	Worker health benefits
11	Green Power	1		$39,028	$0	$39,028	-$47,224	Fish/wildlife habitat
5	Innovative Wastewater Technologies	1		$52,374	$45,000	$52,374	$52,374	
8	Renewable Energy	1		$166,881	$178,000	$166,881	$150,481	

*The Fundamental Building Systems Prerequisite is required, regardless of cost. This measure includes Best Practice Commissioning and Measurement and Verification and their costs and benefits.
** Low-Emitting Materials is broken into adhesives (15a) and paints (15b).
*** The 30% Optimize Energy Performance measure is mutually exclusive of the 40% measure which was selected.
Note: Direct and Regional System values are assumed to be the same in this analysis because no marginal cost data were available. They would be different if estimated marginal costs were higher than average costs.

Measure 7a was eliminated because it would be replaced by the Optimize Energy Performance - 40% option (Measure 7b). Measure 7b would have a higher first cost, but would reduce life cycle energy costs significantly more than the original option and provide additional societal benefits as well. The energy savings associated with Measure 7b could have been achieved at an incremental cost of about $60,000, but would have reduced the present value of future electricity bills by four times that amount. From the societal perspective, these energy savings would have produced emissions reductions valued at about $90,000. These reductions include over 300 tons of CO_2 that would not be produced each year, which would be equivalent to removing about 70 cars from the streets.

Measure 16 was eliminated because its estimated life cycle costs were higher than other measures, even though its first cost was relatively small. Based on the life cycle cost minimization approach, low-emitting paints (Measure 15b), an electric recharging station (Measure 1), or the use of certified wood (Measure 13) would be selected before Measure 16.

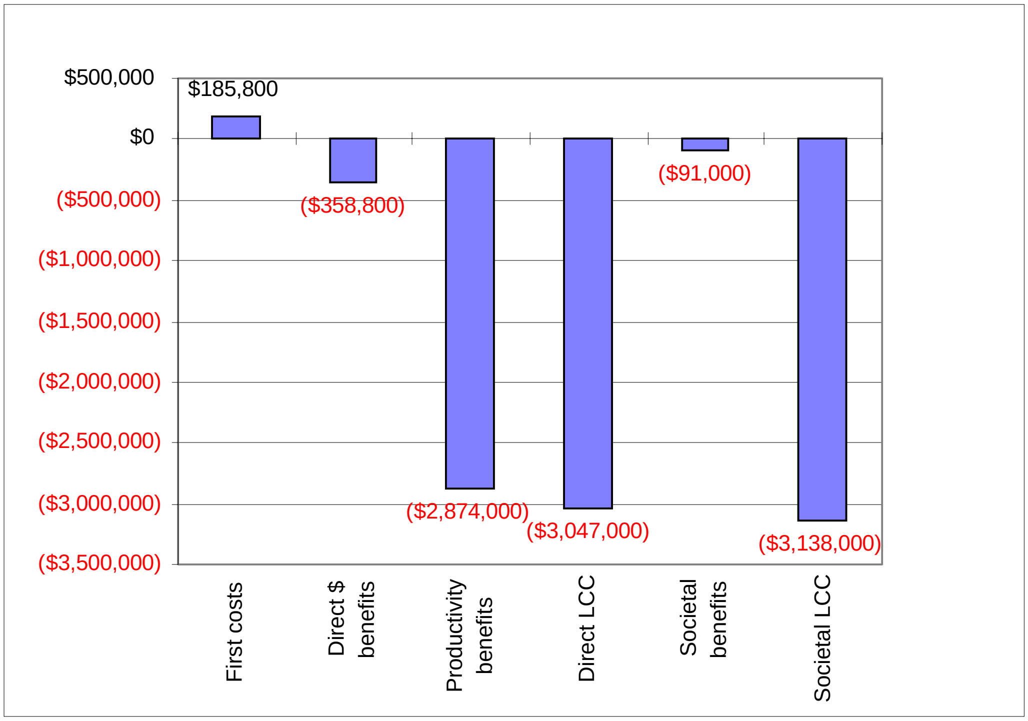
Probably the biggest change from the least first-cost set of measures was the inclusion of a green roof (Measures 2 and 3b).[10] This measure would get one LEED™ credit for reducing stormwater and one credit for reducing the heat island effect. It would add a relatively large amount to the first cost, $74,500, but would reduce the direct life cycle cost of the building by a little over $3,000 from reduced roof replacements, stormwater, and energy costs. To estimate stormwater cost savings, we assumed that the building would be charged a reduced amount proportional to the decrease in runoff attributable to the roof, rather than treating the green roof as a fully pervious surface.[11]

Figure 3-1 summarizes the costs and benefits associated with selecting measures to meet LEED™ requirements by selecting those measures that had the lowest life cycle cost. A net investment of about $186,000 would have been required, or roughly 1% of the total construction cost. This investment would have reduced the total life cycle costs incurred by the City by over $3M, or a reduction of about $150,000 more than the savings from selecting measures based on lowest first cost. The bulk of the savings would be attributable to the increased productivity of workers in the building. Based on the stream of future benefits associated with this investment, these measures would have had a simple payback of about one year.

[10] All the costs and benefits are shown under Measure 2.

[11] We are not aware of a specific stormwater rate policy that the City has developed for green roofs. Even without the reduced charges that we assume, however, the green roof would still be included.

Figure 3-1
Summary of 1900 Building Costs and Benefits



3.5 Overall Findings and Discussion

This subsection presents key overall observations about the findings from analyzing the 1900 Building.

3.5.1 Advantages of Using an Integrative System

The 1900 Building case study shows that a system, such as LEED™, which was developed to broaden the objectives used in the design/build process, can result in different decisions and benefits than the conventional process. In particular, evaluating measures based on their life cycle costs can produce significant long-term benefits for the building owner and occupants. Rewarding the use of salvaged materials can not only have positive societal benefits, but can create opportunities to reduce first costs as well. Explicitly recognizing societal impacts can lead to decisions that have significant payoffs beyond the building owners. In addition, an integrating framework such as LEED™ can promote the use of measures that have multiple benefits, such as green roofs, which can save energy, reduce runoff, extend roof life, and improve aesthetics.

> *Using a green building rating system to guide design and siting decisions can cause all members of the building community to look at the process from a broader, systems-oriented perspective. The lack of a systems perspective often results in design decisions that focus on optimizing individual components, at the expense of better performance for the building as whole. Consequently, one benefit of applying a tool such as LEED™ is that the interactions among building*

components and subsystems are more likely to be considered and this could result in an overall increase in the benefits produced by the building.

3.5.2 Criteria for Selecting Measures under LEED™

This building case study illustrates the need to develop criteria to guide the selection of measures to comply with the requirements of LEED™. The minimum first cost criterion was applied successfully to a wide range of feasible options to select those that could have been packaged together to achieve LEED™ certification at lowest first cost. The minimum life cycle cost criterion also was applied successfully, leading to a slightly different combination of measures that would minimize the life cycle cost of meeting the LEED™ requirement.

Because LEED™ certification could have been achieved with the 1900 Building in several different ways, it was essential to have criteria for selecting among possible measures. Both the minimum first cost and minimum life cycle cost criteria appeared to be feasible for selecting measures for this building. In keeping with the intent of the City's Green Building Initiative and the fundamental principles underlying the concept of green buildings, we believe that using the life cycle cost criterion is the preferred approach.

3.5.3 Costs and Benefits to the City of Greening the 1900 Building

Our analysis indicates that a building like the 1900 Building, if built today and designed to qualify as LEED™ certified, could have met the requirements at a first cost increase of less than 1%.

Significant direct economic benefits would accrue to the City over the first 25 years of the building's lifetime. The major savings that we estimated were due to worker productivity improvements, which are difficult to quantify (these are discussed in Section 3.5.5). The areas in which savings would occur that can be estimated with the most certainty would be associated with measures used to reduce water and energy consumption.

Assuming that the minimal productivity enhancements that we estimated would, in fact, occur, the up-front investment in green measures would return life cycle savings equivalent to more than 16 times the initial incremental investment.

3.5.4 Key Findings about Selected Measures

This analysis provided insights about the measures that could have been selected to LEED™-certify this building if it were being designed today.

Although this situation was probably relatively unique, rewarding the use of salvaged materials could have reduced construction costs significantly while earning a LEED™ credit. Measures to reduce water and energy use could have produced significant life cycle cost savings. Emphasizing the life cycle benefits *over first cost impacts would have resulted in investments leading to significantly larger energy savings. Incorporating a green roof would have increased first costs about 0.4%, but would have reduced life cycle costs.*

3.5.5 Significance of Productivity Improvements

As noted above, the estimated benefits due to improved worker productivity dominated the life cycle cost impacts that we estimated for constructing the 1900 Building to meet the LEED™ requirements. For example, almost 95% of the savings attributed to the measures selected by minimizing the life cycle cost was due to the assumed productivity enhancement. These results are consistent with the limited research available and conventional wisdom about the benefits of greening buildings.

Consistent with other studies, our results demonstrated that, because the largest costs associated with operating a building are the labor costs, productivity improvements can overwhelm other potential green building benefits.

Although the actual effect on productivity that would be achieved is debatable, we believe that the 1% increase we assumed is a conservative estimate. As noted earlier, the limited number of studies that have documented productivity effects have produced estimates from a few percent to 20% or more. However, most of these estimates were based on improvements in lighting and daylighting that would not apply significantly to the measures we analyzed for the 1900 Building. Consequently, we assumed in our analysis only a very small effect that would be related to the thorough commissioning of the building's systems and modifications that would improve indoor air quality and comfort.

It is important to note that even if no productivity increases were included, both the lowest first cost and lowest life cycle cost scenarios would lead to life cycle cost savings to the City. In the lowest first cost case, the net life cycle savings would be about $30,000. In the lowest life cycle cost case, the net savings would be about $173,000.

3.5.6 Energy Efficiency

The as-built 1900 Building performed very well based on a simulation of its energy consumption. Its estimated consumption was 24% less than the level estimated for a building built to the ASHRAE 90.1 Standard. Nevertheless, our analysis showed that the energy efficiency could have been improved even more to provide energy savings cost-effectively over many years. For example, we estimated that a 40% improvement over the ASHRAE Standard level could have been achieved at an incremental first cost of a little under $60,000, or about 0.3% of the construction cost.

Our analysis of this building suggested that low cost ways to improve energy efficiency should be investigated, even for buildings that are designed to perform better than required by code. A life cycle cost analysis should be conducted to *select efficiency measures that achieve savings that optimize life cycle cost given reasonable limits on the incremental first cost.*

3.5.7 Building Commissioning

The effects of all the measures that we analyzed were predicated on their being installed correctly, meeting performance expectations, and being operated correctly. LEED™ establishes fundamental commissioning as a prerequisite for buildings that are rated using the LEED™ system. We carried this a step further in our analysis by assuming that Best Practice Commissioning and Measurement and Verification would be implemented as a way to ensure that the predicted impacts were achieved. We attempted to incorporate all three performance quality assurance steps in our analysis by factoring in commissioning costs of 1% of construction costs, which is in the mid-range of typical commissioning cost estimates. Although we believe that this estimate was conservative, without a rigorous analysis of this building and its systems, it is uncertain whether the actual commissioning costs, in fact, would have been more or less than our estimate.

We believe, based on the extensive studies that have been conducted, that commissioning can have large benefits in terms of the proper performance of buildings, particularly green buildings. To receive full credit for the estimated effects of green measures installed in buildings, we believe that thorough commissioning should occur and, especially in large or complex buildings, appropriate measurement and verification should be implemented as well.

3.5.8 Societal and Non-quantified Impacts

Although our analysis indicated that the direct economic impacts of building the 1900 Building to be LEED™-certified would have been economically beneficial to the City over its life cycle, benefits beyond those that were quantified for the City would have been provided. First, air pollution reductions would have occurred that would have avoided negative effects on public health and global warming. Using recent estimates of the economic value of these benefits, we estimated that associated savings valued at at least $90,000 would have accrued to society at large. Second, benefits on the health of building occupants due to reduced indoor air pollutants and the benefits on fish and wildlife habitats would have occurred, but we were unable to estimate them in this study.

This case study suggested that the societal benefits of designing and operating the 1900 Building as a green building could be significant and they should be estimated. As a public entity, the City has an obligation to address the public good, and assess and take into account impacts beyond the direct budgetary effects of its decisions. Although we did not conduct an analysis to select those green building measures that might have provided the most benefits to society as a whole, our analysis did suggest that an option such as purchasing green power could have substantial societal benefits that could outweigh the direct incremental budgetary costs incurred by the City. For those green building impacts that were *difficult or impossible to quantify, we have identified them so that the reader can take them into consideration.*

3.5.9 Regional System Impacts

Because current energy price projections suggest that the price of new energy resources will escalate no faster than general inflation, we did not attempt to include the marginal cost impacts of adding new energy sources. Similarly, we were unable to obtain projections of the marginal costs of potable water and water treatment that took into account major projects that might be required to meet increasing demand in the Portland region.

If we had projections of marginal costs for providing these utilities, we would have estimated the green building benefits of the reduced demand on the regional systems required to provide these utilities. Increased demand at the margin would raise the aggregate costs for all customers more than it would the costs paid by the occupant of a particular building. Consequently, the benefits of building green would be distributed across all customers in the Portland region and would be larger than the direct benefits to the green building occupant. Without reliable estimates of marginal cost trends, however, we were unable to estimate the regional system impacts at any value other than the direct impacts on the building owner/occupants.

We believe that analyses of green buildings should estimate the impacts on the customers of those regional systems that are required to provide the energy, potable water, and water treatment that the customers require. In those cases where projections of marginal costs are available that take into account anticipated system cost increases, these projections should be used. In cases where no such projections are available, the possibility and likely magnitude of such impacts should be addressed.

4 City Community Policing Facility

This section presents our analysis of how LEED™ could have been applied to a Portland community policing facility. It describes the building first. Next, it presents information about how the existing building would be rated if the LEED™ rating system, Version 2, were applied to it as built. The following subsection discusses the options that could have been considered for inclusion in the building to achieve LEED™ certification. Next, it discusses what options we would have proposed for the building to meet the LEED™ requirements based on two different cost criteria. Finally, the results of the analysis are summarized and several conclusions are presented.

As noted earlier, we have taken this building as designed and built and conducted a "what if" analysis to explore what changes might have been made to meet the LEED™ requirements. This analysis does not consider how the building could now be retrofit. The authors also note that the rating system did not exist at the time this building was being designed and built, so the results should not be interpreted as a critique or assessment of the decisions that were made originally. We note furthermore that some of the recommended equipment, materials, or measures might not have been available during the planning phase, although most are available now or should be feasible in the near future. Thus, our analysis treats the facility as if it were being designed and built today to meet LEED™ given all currently available options that would earn credits under LEED™ (except where noted).

4.1 Building Description

The East Portland Police Precinct (East Precinct) is a two-story, 23,000 ft^2 building completed in 1997 with offices, training rooms, public lobby, lockers, showers, and holding cells. Total construction cost was a little under $4.5M. A 66,000 $ft^{2,}$ three-tiered concrete parking garage holding 51 patrol cars and 99 staff parking spaces and a service facility sits to the south of the precinct building. Energy bills totaled 790,400 kWh and 2,187 therms for 1999. The station employs people working in overlapping shifts of 15 to 40 people each, but with only between 5 and 30 working in the building on regular shifts. For purposes of our analysis, we assumed that 30 people worked during the weekday daylight shift and 5 at all other times, which is equivalent to 46 employees working 40-hour weeks in the building.

The building shell is constructed of structural brick with fixed windows arranged along the facade. An interior steel frame supports a floor and roof structure of composite wood joists. The roof is covered with rigid insulation and black built-up roofing. The building specification required a very compartmentalized plan with discrete offices, work areas, conference rooms, lockers, and other spaces distributed throughout the building. A small, landscaped courtyard brings light to several interior spaces. The interior finishes are comprised primarily of suspended acoustical tile ceilings, painted gypsum board walls and floors of carpet, vinyl composition tile, and ceramic tile. A secure bike storage room in the garage holds approximately 4 bicycles for staff and an exterior bike rack holds an additional six bicycles for visitors.

Cooling is supplied by two rooftop mounted package VAV systems. One is 36 tons with an efficiency of 8.5 EER. The other is a smaller 3.5 ton unit with an SEER of 10.0. Thermal loading of the building is fairly equal between internal gains and solar insolation and infiltration. A total of 58 kBtuh of heating is provided from electric ceiling-mounted heaters and another 90 kBtuh of heating is supplied from the rooftop unit.

The building is exhausted through vents in the bathrooms and lockers. No air quality issue were detected during the walkthrough, but we did observe uneven air flows in several spaces.

Windows are a mix of single-pane, bullet-proof and dual-pane insulating units, all with aluminum frames. Glazing is clear and has no reflective or spectrally selective coatings or films. The building is generally internally focused, but a few spaces have views out to the street and a public plaza and into the light court. No skylights, light shelves, clerestories, or other daylighting techniques are employed in the existing building with the exception of the interior light court.

Lighting is provided in most spaces with 3-lamp T-8 recessed troffers with electronic ballasts. A mix of lens troffers, parabolics and indirect pendants are used. Small rooms have bi-level switching. Exit signs are LEDs.

Table 4-1 presents a summary of the East Precinct shell and systems.

Table 4-1
East Precinct Summary Building Energy Characteristics

Shell	
Walls	2½" metal stud block walls with R-11 batt 1-story walls at courtyard are 3½" metal stud, R-13 batt
Roof	R-15 rigid insulation
Glazing	Fixed aluminum frame windows—some monolithic ballistic glass, most 1” commercial insulating glass
Floor	Slab on grade (no floors over unconditioned spaces)
HVAC	
Ventilation	14,600 cfm from the rooftop VAV unit and package A/C. About 5,000 cfm of exhaust relief through centrifugal ceiling fans
Cooling	36 tons rooftop VAV at 8.5 EER 3.5 tons rooftop package A/C at 10.0 SEER
Heating	148 kBtuh of heating from electric ceiling units and the rooftop unit
Lighting	
Fixtures	Primarily three lamp T-8 recessed troffers with electronic ballasts
Controls	Occupancy sensors are located in most spaces

4.2 RATING AS BUILT

The existing East Precinct building was analyzed and determined to score 12 out of a possible 64 core points on the LEED™system as built. A minimum of 32 points is needed for the basic level of certification. This section provides a description of how the existing building scored on each measure along with a discussion of the factors that went into making the rating decisions.

4.2.1 Data

Data were obtained for the LEED™rating analysis through site visits, interviews with project staff, and construction documents. In a few cases, information on the drawings could not be verified or information was simply not available. These cases are described here, along with the assumption made:

- Wall, ceiling, and floor insulation levels are as indicated on the construction drawings.
- Construction cost data did not separate labor from materials so assumptions were made based on industry standards.
- The results of the construction waste management plan were not available. Data were derived from an interview with the general contractor.

- Information on the specific materials used in the building were not always available so assumptions were made based upon the drawings, specifications, operation and maintenance manual and field observations.

4.2.2 Rating

The following tables present, by LEED™ category, the points possible for each LEED™ measure and the points earned for the existing building. The six LEED™ categories are the following:[1]

- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation Credits

Sustainable Sites

Table 4-2 shows the points possible for the Sustainable Sites options. It also displays the number of points that the building earned for each category based on our assessment.

Table 4-2
East Precinct As-built LEED™ Rating
Sustainable Sites

Sustainable Sites	Points Possible	Points Earned
P1: Erosion and Sedimentation	0	meets
C1: Site Selection	1	1
C2: Urban Redevelopment	1	0
C3: Brownfield Development	1	0
C4: Alternative Transportation	4	2
C5: Reduced Site Disturbance	2	1
C6: Stormwater Management*	2	2
C7: Landscape and Exterior Design	2	1
C8: Light Pollution Reduction	1	0
Sustainable Sites Subtotal	*14*	*7*
*Note that C6 gives credit for a stormwater measure that would be required under current requirements, even though it is not actually present.		

Detailed information on each of the options is presented below:

[1] Note that the sixth category, Innovation Credits, is not part of the core points under the LEED™ system, but permits a building to earn extra credit for innovative measures, practices, or use of a LEED™-certified rater.

Site Prerequisite 1: Erosion and Sedimentation	The existing building meets this prerequisite.
Site Credit 1: Site Selection	The building is located on an environmentally appropriate site.
Site Credit 2: Urban Redevelopment	The building is sited in a medium density area. The siting criteria for a precinct policing facility may conflict with the ability to locate the building in a more urban setting. Future development in the lightrail corridor may increase density.
Site Credit 3: Brownfield Redevelopment	The building was not constructed on a brownfield site.
Site Credit 4: Alternative Transportation	The site is less than 1/4 mile from 2 bus lines and approximately 1/2 mile from lightrail. Secure bicycle parking and showers are provided for more than 5% of employees on a typical peak shift. Employee parking was provided per union requirements, but none was required by zoning.
Site Credit 5: Reduced Site Disturbance	The site was previously undisturbed and the development impacted the entire site. 15.5% of the site was developed as a public plaza open space. No open space is required by zoning, but other commercial zones require 15% open space. We interpreted this situation to be appropriate for awarding a point in LEED™.
Site Credit 6: Stormwater Management	Although site impervious surface was increased significantly, all stormwater is taken into drywells to recharge groundwater on site. Oil separators were installed, but no other water quality treatment was provided. If built today, however, the Bureau of Environmental Services (BES) would require a Stormceptor or swale. As designed, the site does not provide space for a water quality swale so we assumed that a Stormceptor would have been installed. Based on current requirements, we give the building credit for having such a system, even though it didn't when built, because this measure would have to be provided. Because this is not related to LEED™, we attributed no costs to the measure.
Site Credit 7: Landscape & Exterior Design to Reduce Heat Islands	The parking garage covers more than 30% of the site and has an exposed concrete top tier with a reflectance of at least 0.3 that earns one point. The building has a black roof that is not Energy Star compliant.
Site Credit 8: Light Pollution Reduction	Exterior light fixtures do not have shielding to prevent light trespass and glare.

Water Efficiency

Table 4-3 presents the possible points and the number of points earned for each option in the Water Efficiency category.

Table 4-3
East Precinct As-built LEED™ Rating
Water Efficiency

Water Efficiency	Points Possible	Points Earned
C1: Water Efficient Landscaping	2	0
C2: Innovative Wastewater Tech	1	0
C3: Water Use Reduction	2	0
Water Efficiency Subtotal	*5*	*0*

Details on each option are presented below:

Water Credit 1: Water Efficient Landscaping — A spray type sprinkler was installed rather than a drip style and earned no points.

Water Credit 2: Innovative Wastewater Technologies — No on-site wastewater treatment is performed.

Water Credit 3: Water Use Reduction — The existing building has 3.5 gpf commercial toilets and standard low-flow faucets. Showers and urinals are all standard water usage for commercial buildings in the area.

Energy and Atmosphere

Table 4-4 presents the number of points possible for the Energy and Atmosphere options and our ratings for each. Note that no options were awarded points in this category.

Table 4-4
East Precinct As-built LEED™ Rating
Energy and Atmosphere

Energy and Atmosphere	Points Possible	Points Earned
P1: Fundamental Commissioning	0	doesn't meet
P2: Minimum Energy Performance	0	meets
P3: CFC Reduction in HVAC&R Equip	0	meets
C1: Optimize Energy Performance	10	0
C2: Renewable Energy	3	0
C3: Best Practice Commissioning	1	0
C4: Elimination of HCFCs and Halons	1	0
C5: Measurement and Verification	1	0
C6: Green Power	1	0
Energy and Atmosphere Subtotal	*17*	*0*

Details of each rating are presented below:

Energy Prerequisite 1: Fundamental Building Systems Commissioning. — No commissioning plan was written or executed for this building.

Energy Prerequisite 2: Minimum Energy Performance	The building meets existing Oregon Energy Code as evidenced by its filing with the state Energy Office.
Energy Prerequisite 3: CFC Reduction in HVAC&R Equipment	The building meets this prerequisite.
Energy Credit 1: Optimize Energy Performance.	The building is rated with the "New Building" criteria. A DOE-2 simulation built up from the construction documents and observations made during a site visit indicated the existing building uses approximately 16% less electricity than a building in minimal compliance with ASHRAE Standard 90.1-1999, which falls a little short of receiving points. Most of the difference is in the lighting and some in the air-conditioning system.[2]
Energy Credit 2: Renewable Energy	No renewable generation capacity is installed.
Energy Credit 3: Best Practice Commissioning	As noted above, no commissioning was done.
Energy Credit 4: Elimination of HCFCs and Halons	Standard compressors use an HCFC refrigerant.
Energy Credit 5: Measurement and Verification	This measure was not done.
Energy Credit 6: Green Power	Green power was not purchased for this building.

Materials and Resources

Table 4-5 presents our rating for each option in the Materials and Resources category and the number of points possible.

[2] Energy consumption was estimated by calibrating a DOE-2 simulation with the actual billing data and adjusting the estimate to standardized weather conditions.

Table 4-5
East Precinct As-built LEED™ Rating
Materials and Resources

Materials and Resources	Points Possible	Points Earned
P1: Storage & Collection of Recyclables	0	meets
C1: Building Reuse	3	0
C2: Construction Waste Management	2	0
C3: Resource Reuse	2	0
C4: Recycled Content	2	0
C5: Local/Regional Materials	2	2
C6: Rapidly Renewable Materials	1	0
C7: Certified Wood	1	0
Materials and Resources Subtotal	*13*	*2*

Details of each rating are presented below:

Material Prerequisite: Storage and Collection of Recyclables — Recyclable materials are collected in the sallyport storage area.

Material Credit 1: Building Reuse — The building is entirely new construction.

Material Credit 2: Construction Waste Management — The general contractor did not have an aggressive construction waste management plan.

Material Credit 3: Resource Reuse — Lockers were reused accounting for approximately 2% of building materials and providing a savings estimated to be $33,000. An additional 3% of materials would have to have been reused to qualify for a point under this credit.

Material Credit 4: Recycled Content — The building contains close to 20% recycled content materials, mostly in the form of steel building components. An additional 5% of materials would have to have been recycled content to qualify for a point under this credit.

Material Credit 5: Local/Regional Materials — More than 20% of building materials were determined likely to be regionally manufactured and more than half of these were assumed to be regionally extracted.

Material Credit 6: Rapidly Renewable Materials — No rapidly renewable materials were specified.

Material Credit 7: Certified Wood — No certified wood was specified.

Indoor Environmental Quality

Table 4-6 presents the points possible for each option in the Indoor Environmental Quality category and the points we awarded in our rating.

Table 4-6
East Precinct As-built LEED™ Rating
Indoor Environmental Quality

Indoor Environmental Quality	Points Possible	Points Earned
P1: Minimum IAQ Performance	0	meets
P2: Environmental Tobacco Smoke	0	meets
C1: Carbon Dioxide Monitoring	1	0
C2: Increase Ventilation Effectiveness	1	0
C3: Construction IAQ Mgmt Plan	2	1
C4: Low-Emitting Materials	4	1
C5: Indoor Pollutant Source Control	1	0
C6: Controllability of Systems	2	0
C7: Thermal Comfort	2	1
C8: Daylight and Views	2	0
Indoor Environmental Quality Subtotal	*15*	*3*

The ratings are discussed in more detail below:

IEQ Prerequisite 1: Minimum IAQ Performance — The existing building meets ASHRAE 62 recommended practice and this prerequisite.

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control — The building meets this prerequisite.

IEQ Credit 1: Carbon Dioxide (CO_2) Monitoring — The building does not use a continuous CO_2 monitor in the HVAC system.

IEQ Credit 2: Increase Ventilation Effectiveness — Diffusion patterns are patchy with the existing system. Some areas were identified with likely “dead” spots. The problem did not appear to be serious. To get the credit, however, less than 10% of the area can have these areas of poor circulation.

IEQ Credit 3: Construction IAQ Management Plan — Outside air and filters were changed before occupancy; however, the system was not operated continuously during construction.

IEQ Credit 4: Low-Emitting Materials — The installed carpet meets the Carpet and Rug Institute’s Green Label Indoor Air Quality Test criteria, but the paints and adhesives do not meet their respective IEQ criteria for LEED™ credits. The composite wood products used in the building contain added formaldehyde.

IEQ Credit 5: Indoor Chemical and Pollutant Source Control — The front entry has a low pressure differential with the outside, minimizing air exchange. The janitor’s closet was supplied with separate outside venting, but separately vented rooms were not provided for copy machines.

IEQ Credit 6: Controllability of Systems — The perimeter areas point is not awarded since the windows are not operable. Also, the controllability credit is not awarded because of the lack of separate thermal and lighting zones.

IEQ Credit 7:
Thermal Comfort

Humidity control is unnecessary in this building because of the climate. The building already complies with ASHRAE Standard 55 simply by being air conditioned in Portland. Despite this, the building cannot earn the second LEED™ credit in this category without installing a permanent humidity monitoring system.

IEQ Credit 8:
Daylight and Views

Diffuse sunlight reaches the perimeter areas of the building but does not penetrate effectively beyond about 10 feet from the windows. Approximately half of the regularly occupied spaces have direct access to daylight and views.

Innovation Credits and Design/Build Process

Table 4-7 summarizes the points possible in the Innovation and Design/Build Process category and our ratings.

Table 4-7
East Precinct As-built LEED™ Rating
Innovation Credits and D/B Process

Innovation Credits and D/B Process	Points Possible	Points Earned
C1: Innovation Credits	4	0
C2: Accredited Professional	1	0
Innovation Credits Subtotal	*5*	*0*

Each rating is discussed below:

I & D/B Credit 1 We did not identify any options in the building that would earn innovation credits.

I & D/B Credit 2 An accredited professional was not involved in this project.

Overall Rating

Table 4-8 summarizes the LEED™ points possible and points earned by category. Note that the most points and the highest percentage of points earned were for Sustainable Sites and Indoor Environmental Quality. The lowest points and the lowest percentage of points earned for the core categories were under the Energy and Atmosphere and Water Efficiency categories.

The total core points possible using the LEED™ criteria is 64 and we determined that the East Precinct earned 12 points as built. Because a total of 32 points is necessary for LEED™ certification, 20 additional points would be needed for certification.

Table 4-8
East Precinct As-built LEED™ Rating
Grand Total

LEED™ Totals	Points Possible	Points Earned	% of Points Earned
Sustainable Sites	*14*	*7*	*50%*
Water Efficiency	*5*	*0*	*0%*
Energy and Atmosphere	*17*	*0*	*0%*
Materials and Resources	*13*	*2*	*15%*
Indoor Environmental Quality	*15*	*3*	*20%*
Total Core LEED™ Points	**64**	**12**	**19%**
Innovation Credits	*5*	*0*	
Total Score	**69**	**12**	

4.3 CANDIDATE LEED™ MEASURES

In this section, we present the measures that we considered to be candidates for inclusion in a building identical to the East Precinct if it were being designed today to meet the basic LEED™ requirements. Candidate measures are those that passed an initial screening process and were then considered for further analysis. The screening process utilized discussions with City of Portland staff, past experience with cost-effective measures in other projects, and recommendations within the LEED™ guidelines.

Ideally, the initial screening provided a way to condense the potential measures to a reasonable set of options that could then be assessed. As described in Section 2, our initial screening for this building took into account the following criteria:

- excessive first costs or potentially large life cycle costs compared to potential benefits and the respective costs of other measures;
- inapplicability or lack of feasibility for the site;
- requirements for major redesign or siting changes (e.g., major construction changes to accommodate daylighting or relocation to a Brownfield site); and
- unresolved ecological benefits for the site (e.g., elimination of HCFCs and Halons[3]).

Nineteen measures survived the screening, allowing a possible 26 incremental points. Recall that 20 points were required for certification of this building. Because the number of points required

[3] This measure is controversial because of the confusing message it conveys: switching to the use of HCFC refrigerants is ecologically beneficial. In our opinion, the most ecological way to meet this requirement is to eliminate mechanical cooling entirely, and that option was not considered because of the necessity to significantly alter the shell and floor plate design to achieve a comfortable climate in a building of this size.

was close to the number of points available from the candidate measures, there was little flexibility possible in selecting measures for certification.[4]

The candidate measures are discussed in the following subsections by LEED™ category. Tables similar to those presented earlier summarize the information for the candidate measures. Note that each specific measure is assigned a number in the tables that is used for future reference in this section. The tables show the number of points possible under LEED™ for the measure, the rating we gave to the existing building, and the incremental points that we considered to be achievable for the option.

4.3.1 Candidate Measures—Sustainable Sites

Table 4-9 shows the candidate measures in the Sustainable Sites category.

Table 4-9
East Precinct Candidate LEED™ Measures
Sustainable Sites

Candidate Measure #	**Sustainable Sites**	Points Possible	Existing Building	Incremental Points Considered
1	C4: Alternative Transportation	4	2	1
2	C7: Landscape and Exterior Design	1	0	1
3	C8: Light Pollution Reduction	*1*	*0*	*1*
	Sustainable Sites Subtotal	*14*	*7*	*3*

More detailed information is presented below for each measure selected for further consideration, as well as those that were eliminated because they failed to meet our screening criteria:

Site Credit 3: Brownfield Redevelopment — Assessment of the brownfield option was beyond the scope of our study, but we believe that it should be considered by the City for future facilities.

Site Credit 4: Alternative Transportation — Provide natural gas alternative fueling station for 3% of the parking spaces. We assumed that 2 small refueling units could meet the need, and to meet the LEED™ requirement, a process would have to be implemented to ensure that an adequate number of vehicles were refueled during a 24-hour period. Switching vehicles to alternative fuels supports the City's goals of cleaner air and reduced greenhouse gas emissions.

Site Credit 5: Reduced Site Disturbance — Achieving additional credit would have required major design changes that were beyond the scope of our study to analyze.

Site Credit 6: Stormwater Management — As noted earlier, we have assumed that a Stormceptor would have been installed because of BES requirements if this building were built today. No additional options were considered.

[4] This was in contrast to the 1900 Building described in Section 3, where the difference between the rating as-built and the points required for certification was considerably less.

Site Credit 7: Landscape & Exterior Design to Reduce Heat Islands — Provide a vegetated roof or add a white coating on roof. A vegetated roof could reduce the number of drywells required and significantly extend the life of the roof, and possibly reduce stormwater treatment costs. A white coating would extend the roof life by ~40%. Both options would reduce building energy use.

Site Credit 8: Light Pollution Reduction — Upgrade lighting to provide shielded fixtures.

4.3.2 Candidate Measures—Water Efficiency

Table 4-10 summarizes the candidate measures that we considered in the Water Efficiency category.

Table 4-10
East Precinct Candidate LEED™ Measures
Water Efficiency

Candidate Measure #	**Water Efficiency**	Points Possible	Existing Building	Incremental Points Considered
4	C1: Water Efficient Landscaping	2	0	1
5	C2: Innovative Wastewater Tech	1	0	1
6	C3: Water Use Reduction	2	0	2
	Water Efficiency Subtotal	*5*	*0*	*4*

Details of the candidate options are presented below:

Water Credit 1: Water Efficient Landscaping — We recommend installing a drip style irrigation system. We did not recommend eliminating the irrigation entirely because of the importance of the rose garden.

Water Credit 2: Innovative Wastewater Technologies — Provide roof catchment of rainwater for toilet flushing.

Water Credit 3: Water Use Reduction — To get the 20% reduction credit, more efficient toilets, faucets, urinals, and showers would be specified. The second credit for a 30% reduction is obtained from installing the drip system specified in the Water Efficient Landscaping measure above.

4.3.3 Candidate Measures—Energy and Atmosphere

Table 4-11 presents the candidate measures in the Energy and Atmosphere category.

Table 4-11
East Precinct Candidate LEED™ Measures
Energy and Atmosphere

Candidate Measure #	Energy and Atmosphere	Points Possible	Existing Building	Incremental Points Considered
	P1: Fundamental Commissioning	0	doesn't meet	meets
7	C1: Optimize Energy Performance	10	0	4
8	C2: Renewable Energy	3	0	1
9	C3: Best Practice Commissioning	1	0	1
10	C4: Measurement and Verification	1	0	1
11	C6: Green Power	1	0	1
	Energy and Atmosphere Subtotal	*17*	*0*	*7*

Detailed information is presented below on each candidate measure as well as those that were screened out:

Prerequisite 1: Fundamental Building Systems Commissioning. We include in the prerequisite meeting the fundamental requirements plus 1) the Energy and Atmosphere Credit 3: Best Practice Commissioning (the more stringent commissioning credit) and 2) the Energy and Atmosphere Credit 5: Measurement and Verification.

Energy Credit 1: Optimize Energy Performance. We examined increasing the efficiency of the building an additional 14 % beyond current conditions to exceed the ASHRAE standard by a total of 30%. We recommend increasing the wall and ceiling insulation levels, adding a vegetated or light-colored roof, and specifying a 9.5 EER 36-ton packaged unit rather than the current 8.5 EER.

Table 4-12 presents the energy submeasures we proposed for satisfying the first energy credit.

Table 4-12
Optimize Energy Submeasures

Description	Incremental Cost
6,730 ft^2 of wall is changed from R-11 insulation to R-15 high-density batt at an incremental cost of \$0.22/sf or \$1,482.	\$1,482
4,908 ft^2 of wall is changed from R-13 to R-19 insulation at an incremental cost of \$0.04/ft^2 or \$196.	\$196
The 8.5 EER 36-ton package unit is replaced with a high-efficiency model having 9.5 EER at an incremental cost of \$41.67/ton or \$1,500.	\$1,500
The costs and energy savings of the alternate roof (light-colored or vegetated) are accounted for under other measures..	\$0
Total	**\$3,178**

The other options are discussed in more detail below:

Energy Credit 2: Renewable Energy. Install single-axis rooftop-mounted photovoltaic system with 35 kW of peak capacity to supply an annual 32,933 kWh on average. The cost of the system is assumed to be \$6.50 per watt (electric).

Energy Credit 3: Best Practice Commissioning — This measures requires a third-party review of the commissioning plan and tying final payment to successful commissioning and implementation of a performance-based fees contract. We combine this measure with the prerequisite commissioning requirement and estimate commissioning costs based on including this measure.

Energy Credit 4: Elimination of HCFCs and Halons — The most ecological way to meet this requirement would be to eliminate mechanical cooling entirely. We did not consider that option, however, because of the necessity to significantly alter the building design, which was beyond our analysis scope.

Energy Credit 5: Measurement and Verification — This measure requires implementing a comprehensive measurement and verification plan and meeting the installed equipment requirements for continuous metering described in the IPMVP Option B. This is considered an essential part of any complete commissioning plan. The IPMVP recommends installing permanent measurement devices and reviewing on a regular basis the operation of HVAC equipment, lighting, and security systems. We combine this measure with the prerequisite commissioning requirement and estimate commissioning costs based on including this measure.

Energy Credit 6: Green Power — Engage in a 2-year contract to purchase power with a minimum of 30% generated from renewable sources that meet the CRS Green-E requirements. This would amount to 197,000 kWh/yr for the LEED™ certified building at a 5 mil premium within PGE's territory.

Table 4-13 presents the emissions reductions that would occur by purchasing 30% green power, or 197,000 kWh per year.

Table 4-13
Impact of 30% Green Electricity Purchase on Emissions Reductions

Compound	Annual Reduction
CO_2	326,040 lbs/yr
NO_x	692 lbs/yr
SO_2	553 lbs/yr

4.3.4 Candidate Measures—Materials and Resources

Table 4-14 presents the candidate measures that we considered in the Materials and Resources category.

Table 4-14
East Precinct Candidate LEED™ Measures
Materials and Resources

Candidate Measure #	Materials and Resources	Points Possible	Existing Building	Incremental Points Considered
12	C2: Construction Waste Management	2	0	2
13	C4: Recycled Content	2	0	1
14	C7: Certified Wood	1	0	1
	Materials and Resources Subtotal	*13*	*2*	*4*

Details are presented below on each of the candidate measures and those that were eliminated from further consideration:

Material Credit 1: Building Reuse — It would have required a major change in the project to reuse an existing building and consideration of this change was beyond the scope of our study.

Material Credit 2: Construction Waste Management — With increased awareness and markets today, more than 75% of construction debris could be recycled. Case studies show that construction waste recycling pays for itself and sometimes saves money. There should be no increase in first cost.

Material Credit 3: Resource Reuse — We determined that it was unlikely that an adequate amount of additional salvaged materials could have been used to qualify for this credit.

Material Credit 4: Recycled Content — Specify recycled content flooring materials along with a few other minor building components to reach 25% of building materials.

Material Credit 6: Rapidly Renewable Materials — There were insufficient opportunities to use rapidly renewable materials to receive credit for this measure.

Material Credit 7: Certified Wood — Specify certified wood for at least 50% of wood products in the building. Truss joists make up ~48% of wood materials and are currently not available from certified sources.

4.3.5 Candidate Measures—Indoor Environmental Quality

Table 4-15 presents the candidate measures that we considered further in the Indoor Environmental Quality category.

Table 4-15
East Precinct Candidate LEED™ Measures
Indoor Environmental Quality

Candidate Measure #	**Indoor Environmental Quality**	Points Possible	Existing Building	Incremental Points Considered
15	C1: Carbon Dioxide Monitoring	1	0	1
16	C2: Increase Ventilation Effectiveness	1	0	1
17	C3: Construction IAQ Mgmt Plan	2	1	1
18	C4: Low-Emitting Materials	4	1	2
19	C5: Indoor Pollutant Source Control	1	0	1
20	C6: Controllability of Systems	2	0	1
21	C7: Thermal Comfort	2	1	1
	Indoor Environmental Quality Subtotal	*15*	*3*	*8*

Each of the candidate measures is described in more detail below:

IEQ Credit 1: Carbon Dioxide Monitoring — Add a continuous monitoring carbon dioxide sensor to the HVAC duct system to control percent outside air.

IEQ Credit 2: Increase ventilation Effectiveness

To achieve this credit, the building should be designed for good mixing in 90% of the occupied areas. An extra two person-days of design time was included for the cost of this measure. The actual cost is unknown, but may be zero or slightly higher.

IEQ Credit 3: Construction IAQ Management Plan

The fan units were protected during construction, but no ventilation was supplied. The recommendation is to provide continuous ventilation during the construction period.

IEQ Credit 4: Low-Emitting Materials

Specify low-VOC adhesives, paints, and coatings. Alternatives to composite wood structural elements may not be feasible. Even if it does not score a point, formaldehyde-free alternatives should be considered for casework and other interior finishes.

IEQ Credit 6: Controllability of Systems

For security reasons, we do not recommend switching to operable windows, so the first credit is not possible. The second credit is possible by adding approximately twenty lighting circuits and smaller HVAC zones. The existing packaged multi-zone system can serve more zones than it does currently, so the additional cost is incurred from the zone boxes and thermostats (we estimated a total of $620 incremental cost per additional HVAC zone).

IEQ Credit 7: Thermal Comfort

Install a full-time temperature and humidity monitor to achieve a credit.

4.3.6 Candidate Measures—Innovation Credits and Design/Build Process

Table 4-16 summarizes our assessment of credits that could have been obtained through either building or siting decisions or through the use of a LEED™-trained professional. The details of our consideration of the measures are discussed below the table.

Table 4-16
East Precinct Candidate LEED™ Measures
Innovation Credits and Design/Build Process

Candidate Measure #	**Innovation and Design/Build Process**	Points Possible	Existing Building	Incremental Points Considered
22	C2: Accredited Professional	1	0	1
	Innovation and Design/Build Process Subtotal	*5*	*0*	*1*

I & D/B Credit 1

We found it impractical to propose innovations at this point without knowing whether they would have been limited by project constraints. Nevertheless, we believe that it is important for designers and planners to consider possible innovations that would receive LEED™ credit.

I & D/B Credit 2

We believe that it would be useful to include a LEED™-trained professional in the project team for projects like this in the future. We do not rely on this option as one of the credits that we analyze for this building, however, because it is useful to determine first whether the building could meet the LEED™ requirement with specific building measures alone.

4.3.7 Candidate Measures—Summary Information

Table 4-17 summarizes the measures that we retained for further analysis to attain the basic LEED™ certification level. The most incremental points available for further consideration were in the Indoor Environmental Quality and Energy and Atmosphere categories. As noted earlier, the candidate measures yielded a total of 26 points that could be applied to certification.

Table 4-17
East Precinct Candidate LEED™ Measures
Grand Total

LEED™ Totals	Points Possible	Existing Building	Incremental Points Considered
Sustainable Sites Subtotal	*14*	*7*	*3*
Water Efficiency Subtotal	*5*	*0*	*4*
Energy and Atmosphere Subtotal	*17*	*0*	*7*
Materials and Resources Subtotal	*13*	*2*	*4*
Indoor Environmental Quality Subtotal	*15*	*3*	*8*
Total Core LEED™ Points	**64**	**12**	**26**
Innovation Credits Subtotal	5	0	0
Total Score	**69**	**12**	**26**

4.4 Measures to Meet the LEED™ Certification Requirement

This subsection presents the results of two cost-benefit analyses that we used to select measures to meet the basic LEED™ certification requirement. The first set of results discussed is based on meeting LEED™ by selecting measures that would do so at minimum first cost. The second set of results is based on meeting the requirement by selecting measures that would minimize the life cycle costs. Life cycle costs are defined as the net present value of first costs and future costs and benefits[5]. In both cases, the analysis is based on the perspective of the building owner/operator, but broader impacts are assessed.

4.4.1 Measure Selection Based on Lowest First Costs

This section presents the candidate measures described above ranked in order by first cost per LEED™ point earned ($FC/Pt.), starting with the lowest cost measures.

Measures Required for LEED™ Certification

Table 4-18 presents the results of applying the least first cost criterion to the candidate measures. The first column shows the tracking number assigned earlier to each measure. The second column identifies the measure. The third column indicates the number of LEED™ points that apply to that measure. The fourth column shows the cumulative points earned by the measures.

[5] As noted in Section 2, the real discount rate used is 3%, and the life-cycle period assumed is 25 years. See Section 2 for a more detailed discussion of life cycle cost assumptions.

The fifth column indicates the incremental first cost per point earned by the measure. The sixth column shows the incremental Direct and Regional System first cost for the measure. The seventh column presents the incremental Direct and Regional System life cycle cost for the measure. As noted earlier, the Direct and Regional System costs would differ if the marginal costs of supplying energy or water or treating waste differed from the average costs as reflected in customer rates. In our study, however, we were unable to obtain reliable estimates of these marginal costs over the 25-year time horizon examined. Therefore, we used marginal costs equal to the average costs projected throughout the period and, consequently, the Direct and Regional System costs and benefits were assumed to be equivalent.

The eighth column shows the Societal incremental life cycle costs. These values take into account societal impacts that we were able to monetize. The ninth column identifies some of the benefits that were not estimated in our analysis.

Fifteen measures (shown in the top part of the table) would be required to earn the 20 incremental points needed to meet the LEED™ certification criterion.

Most of the selected options were described earlier, but additional information is provided here.

The first option listed, Fundamental Building Systems Commissioning, is the one prerequisite that was not met. Because it must be met, it is included despite its relatively high cost. We assumed that this measure included both the Best Practice Commissioning and Measurement and Verification options so its first cost and its benefits encompass all three options. For all three of these activities, we estimated the costs at 1% of the building cost.

Table 4-18
East Precinct Candidate Measures Sorted By First Cost, Incremental Impacts

Candidate Measure Number (1)	Measure (2)	Pts. (3)	Cum-ulative Pts. (4)	$FC/Pt. (5)	Direct/Regional System First cost (6)	Direct/Regional System LCC (7)	Societal LCC (8)	Non-quantified Benefits (9)
	Fundamental Building Systems Commissioning*	0	0	n/a	*$45,000*	*-$435,000*	*-$435,000*	
6	Water Use Reduction	2	2	$0	$0	-$365	-$365	
9	Best Practice Commissioning	1	3	$0	$0	$0	$0	
10	Measurement and Verification	1	4	$0	$0	$0	$0	
12	Construction Waste Management	2	6	$0	$0	$0	$0	
17	Construction IAQ Mgmt Plan	1	7	$247	$247	$247	$247	Worker health
21	Thermal Comfort	1	8	$425	$425	$425	$425	
3	Light Pollution Reduction	1	9	$450	$450	$450	$450	Darker night sky; less glare
4	Water Efficient Landscaping	1	10	$600	$600	-$61	-$61	
7	Optimize Energy Performance	4	14	$795	$3,178	-$62,001	-$85,279	
11	Green Power	1	15	$988	$988	$988	-$796	Fish/wildlife habitat
16	Increase Ventilation Effectiveness	1	16	$1,000	$1,000	$1,000	$1,000	
18	Low-Emitting Materials	2	18	$1,500	$3,000	$3,000	$3,000	Worker health benefits
19	Indoor Pollutant Source Control	1	19	$1,500	$1,500	$1,500	$1,500	Worker health benefits
15	Carbon Dioxide Monitoring	1	20	$2,289	$2,289	$2,289	$2,289	
	Total needed		***20***		*$58,700*	*-$487,000*	*-$512,000*	
	Simple payback =22 months							
	Measures Not Needed							
13	Certified Wood	1		$4,400	$4,400	$4,400	$4,400	Forest ecosystem benefits
12	Recycled Content	1		$9,000	$9,000	$9,000	$9,000	Reduced pollution associated with producing new materials
1	Alternative Transportation	1		$9,240	$9,240	$9,240	$9,240	Air pollution benefits from reduced use of gasoline-fueled vehicles
20	Controllability of Systems	1		$16,400	$16,400	$16,400	$16,400	Worker comfort
5	Innovative Wastewater Technologies	1		$17,040	$17,040	$14,829	$14,829	
2	Landscape and Exterior Design (green roof)	1		$42,450	$42,450	-$26,497	-$32,385	Heat island benefits to surrounding buildings
8	Renewable Energy	1		$229,994	$229,994	$209,766	$202,541	

*The Fundamental Building Systems Prerequisite is required, regardless of cost. This measure includes Best Practice Commissioning and Measurement and Verification and their costs and benefits.

We did not attribute any energy savings to this combined measure because the energy performance measure (Measure 7) received full credit for the energy savings that we estimated with our building simulation model. We constructed our analysis so that complete commissioning and measurement/verification would be included with energy-efficiency improvements as a way to ensure that the estimated energy savings were achieved. The substantial benefits shown in the table that were estimated for the combined Building Systems

Commissioning measure were a result of an estimated increase in employee productivity. We assumed an average annual salary of $30,000 for the 46 employees. We then assumed a minimal productivity increase of 2%, leading to annual productivity economic savings estimated to be $27,000.[6]

The energy savings associated with Measure 7 could have been achieved at an incremental cost of only about $3,000. This improvement in energy efficiency would have produced life cycle utility bill discounted savings of about $65,000, or over 20 times the incremental first cost. From the societal perspective, these energy savings would have produced emissions reductions valued at an additional $23,000. These reductions include over 70 tons annually of CO_2 that would not be produced, which would be equivalent to removing about 15 cars from the streets.

A green power purchase (Measure 11) would not have increased first cost, but it would have increased electricity costs. Over the 25-year life cycle, however, this measure would have reduced emissions sufficiently to provide societal benefits valued at almost twice the added cost of the electricity.

In summary, if the objective had been to meet the LEED™ requirements by selecting those measures with the lowest first cost, a net investment of $59,000 would have been required. This was equivalent to about 1.3% of the total construction cost. These measures would have had a simple payback of about 22 months, and produced a net reduction of $487,000 in the life cycle cost of constructing and operating the building.

Non-Quantified Benefits

The comments in Section 3 on non-quantified benefits apply in this analysis as well. The most difficult to quantify benefits would probably be those associated with reducing impacts on ecosystems and fish and wildlife habitat. These benefits could be significant and very important in the City's efforts to address Endangered Species Act requirements, particularly if spread over a large number of buildings. We note here the importance of considering these impacts and the need for ways to analyze them.

4.4.2 Measure Selection Based on Lowest Life Cycle Costs

This subsection presents the candidate measures ranked according to their impacts on life cycle cost. Our ranking was based on costs and benefits that would affect the building owner/operator or occupants. As before, we dealt partially with different perspectives by presenting those Societal impacts that we could quantify and identifying non-quantified benefits.

This discussion focuses on the differences from the results presented earlier for the lowest first cost ranking. Table 4-19 presents the results of ranking the candidate measures using the least

[6] Productivity increases associated with green buildings have been estimated to range from a few percent to 20% or more. Values attributable to improved air quality alone are typically about 3%. Because the air distribution was not uniformly adequate in the East Precinct, we made a conservative assumption that only a 2% improvement would be achieved. Since we did not include indirect costs and benefits associated with employees, the economic impacts are underestimated.

life cycle cost criterion. Fifteen of the candidate measures were required to meet the LEED™ certified level. The table presents the information in the same columns as Table 4-18, except for column 5, which shows the life cycle cost per LEED™ point ($LCC/Pt.).

The only change from the results for the lowest first cost approach is that the green roof measure (Landscape and Exterior Design) has been included, replacing the carbon dioxide monitoring measure. This occurred because the green roof reduced life cycle costs when compared with the standard roof over the period analyzed. Although the initial incremental cost of the green roof was about $45,500, it was offset partially because we deducted the cost of one dry well that could have probably been eliminated. The major cost saving was because the conventional roof would not have to be replaced every 12 years. We assumed that the green roof would have to be replaced completely after 35 years; based on available data, this was a conservative assumption.

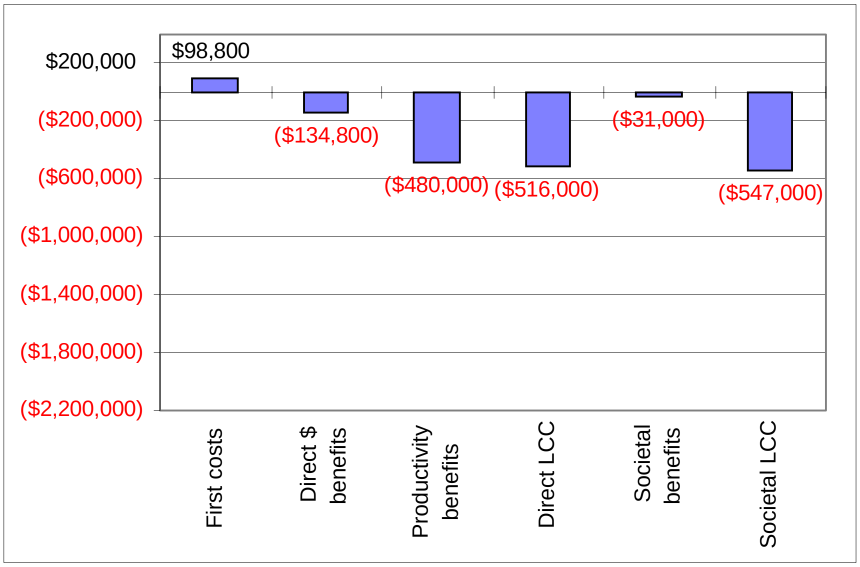
Figure 4-1 summarizes the costs and benefits if the objective had been to meet the LEED™ requirements by selecting those measures that had the lowest life cycle cost. A net investment of about $98,800 would have been required, or roughly 2.2% of the total construction cost. This investment would have reduced the total life cycle costs incurred by the City by about $516,000 or a reduction of about $30,000 more than the savings from selecting measures based on lowest first cost. The bulk of the savings would be attributable to the increased productivity of workers in the building. Based on the stream of future benefits associated with this investment, these measures would have had a simple payback of about 33 months.

Table 4-19
East Precinct Candidate Measures Sorted By Life Cycle Cost, Incremental Impacts

Candidate Measure Number (1)	Measure (2)	Pts. (3)	Cum-ulative Pts. (4)	$LCC/Pt. (5)	Direct/Regional System First cost (6)	Direct/Regional System LCC (7)	Societal LCC (8)	Non-quantified Benefits (9)
	Fundamental Building Systems Commissioning*	0	0	n/a	*$45,000*	*-$435,000*	*-$435,000*	
9	Best Practice Commissioning	1	1	$0	$0	$0	$0	
10	Measurement and Verification	1	2	$0	$0	$0	$0	
2	Landscape and Exterior Design (green roof)	1	3	-$26,497	$42,450	-$26,497	-$32,385	Heat island benefits to surrounding buildings
7	Optimize Energy Performance	4	7	-$15,500	$3,178	-$62,001	-$85,279	
6	Water Use Reduction	2	9	-$183	$0	-$365	-$365	
4	Water Efficient Landscaping	1	10	-$61	$600	-$61	-$61	
12	Construction Waste Management	2	12	$0	$0	$0	$0	
17	Construction IAQ Mgmt Plan	1	13	$247	$247	$247	$247	Worker health
21	Thermal Comfort	1	14	$425	$425	$425	$425	Worker comfort
3	Light Pollution Reduction	1	15	$450	$450	$450	$450	Darker night sky; less glare
11	Green Power	1	16	$988	$988	$988	-$796	Fish/wildlife habitat
16	Increase Ventilation Effectiveness	1	17	$1,000	$1,000	$1,000	$1,000	
19	Indoor Pollutant Source Control	1	18	$1,500	$1,500	$1,500	$1,500	
18	Low-Emitting Materials	2	20	$1,500	$3,000	$3,000	$3,000	
	Total needed		***20***		*$98,800*	*-$516,000*	*-$547,000*	
	Simple payback = 33 months							
	Measures Not Needed							
15	Carbon Dioxide Monitoring	1		$2,289	$2,289	$2,289	$2,289	
14	Certified Wood	1		$4,400	$4,400	$4,400	$4,400	
13	Recycled Content	1		$9,000	$9,000	$9,000	$9,000	
1	Alternative Transportation	1		$9,240	$9,240	$9,240	$9,240	Air pollution benefits from reduced use of gasoline-fueled vehicles
5	Innovative Wastewater Technologies	1		$17,040	$17,040	$14,829	$14,829	
20	Controllability of Systems	1		$16,400	$16,400	$16,400	$16,400	
8	Renewable Energy	1		$209,766	$229,994	$209,766	$202,541	

*The Fundamental Building Systems Prerequisite is required, regardless of cost. This measure includes Best Practice Commissioning and Measurement and Verification and their costs and benefits.
Note: Direct and Regional System values are assumed to be the same in this analysis because no marginal cost data were available. They would be different if estimated marginal costs were higher than average costs.

Figure 4-1
Summary of East Precinct Costs and Benefits



4.5 OVERALL FINDINGS AND DISCUSSION

This subsection presents key overall observations about the findings from analyzing the East Precinct building.

4.5.1 Costs and Benefits to the City of Greening the East Precinct

Our analysis indicates that a building like the East Precinct, if built today and designed to qualify as LEED™ certified, could have met the requirements at a first cost increase of a little more than 1% if the objective was to minimize the increase in first cost.

Significant direct economic benefits would accrue to the City over the first 25 years of the building's lifetime. The major savings that we estimated were due to worker productivity improvements, which are difficult to quantify (these are discussed later). The areas in which savings would occur that can be estimated with the most certainty would be associated with measures used to reduce water and energy consumption.

> *Assuming that the minimal productivity enhancements that we estimated would, in fact, occur, the up-front investment in green measures would return life cycle savings equivalent to more than 6 times the initial incremental investment.*

4.5.2 Key Findings about Selected Measures

This analysis provided insights about the measures that could have been selected to LEED™-certify this building if it were being designed today.

Most of the feasible measures would have been required to receive LEED™ certification. Most of these measures, however, would have been relatively inexpensive to implement. Relatively low-cost measures to reduce energy use could have been installed that would have reduced life cycle energy costs by more than 20 times their cost. Incorporating a green roof would have increased first costs about 1%, but would have reduced life cycle costs by about $30,000.

4.5.3 Significance of Productivity Improvements

As noted above, the estimated benefits due to improved worker productivity dominated the life cycle cost impacts that we estimated for constructing the East Precinct to meet the LEED™ requirements. These results are consistent with the limited research available and conventional wisdom about the benefits of greening buildings.

Consistent with other studies, our results demonstrated that, because the largest costs associated with operating a building are the labor costs, productivity improvements can overwhelm other potential green building benefits.

Although the actual effect on productivity that would be achieved is debatable, we believe that the 2% increase that we assumed is a conservative estimate. As noted earlier, the limited number of studies that have documented productivity effects have produced estimates from a few percent to 20% or more. We assumed in our analysis a small effect that would be related to the thorough commissioning of the building's systems and modifications that would improve indoor air quality and comfort.

It is important to note that even if no productivity increases were included, both the lowest first cost and lowest life cycle cost scenarios would have led to life cycle cost savings to the City. In the lowest first cost case, the life cycle savings would have been about $7,000. In the lowest life cycle cost case, the savings would have been about $36,000.

4.5.4 Energy Efficiency

The as-built East Precinct performed well based on a simulation of its energy consumption. Its estimated consumption was 16% less than the level estimated for a building built to the ASHRAE 90.1 Standard. Our analysis showed that the energy efficiency could have been improved even more to provide energy savings cost-effectively over many years. We estimated that a 30% improvement over the ASHRAE Standard level could have been achieved at an incremental first cost of a little over $3,000, or less than 0.1% of the construction cost.

Our analysis of this building suggested that low cost ways to improve energy efficiency should be investigated, even for buildings that are designed to perform better than required by code. A life cycle cost analysis should be conducted to select efficiency measures that achieve savings that optimize life cycle cost given reasonable limits on the incremental first cost.

4.5.5 Building Commissioning

The effects of all the measures that we analyzed were predicated on their being installed correctly, meeting performance expectations, and being operated correctly. LEED™ establishes fundamental commissioning as a prerequisite for buildings that are rated using the LEED™ system. We carried this a step further in our analysis by assuming that Best Practice Commissioning and Measurement and Verification would be implemented as a way to ensure that the predicted impacts were achieved. We attempted to incorporate all three performance quality assurance steps in our analysis by factoring in commissioning costs of 1% of construction costs, which are in the mid-range of typical commissioning cost estimates. Although we believe that this estimate was conservative, without a rigorous analysis of this building and its systems, it is uncertain whether the actual commissioning costs, in fact, would have been more or less than our estimate.

> *We believe, based on the extensive studies that have been conducted, that commissioning can have large benefits in terms of the proper performance of buildings, particularly green buildings. To receive full credit for the estimated effects of green measures installed in buildings, we believe that thorough commissioning should occur and, especially in large or complex buildings, appropriate measurement and verification should be implemented as well.*

4.5.6 Societal and Non-quantified Impacts

Although our analysis indicated that the direct economic impacts of building the East Precinct to be LEED™-certified would have been economically beneficial to the City over its life cycle, benefits beyond those that were quantified for the City would have been provided. First, air pollution reductions would have occurred that would have avoided negative effects on public health and global warming. Using recent estimates of the economic value of these benefits, we estimated that associated savings valued at about $30,000 would have accrued to society at large. Second, benefits on the health of building occupants due to reduced indoor air pollutants and the benefits on fish and wildlife habitats would have occurred, but we were unable to estimate them in this study.

> *This case study suggested that the societal benefits of designing and operating a building like the East Precinct as a green building could be significant and they should be estimated. As a public entity, the City has an obligation to address the public good, and assess and take into account impacts beyond the direct budgetary effects of its decisions. Although we did not conduct an analysis to select those green building measures that might have provided the most benefits to society as a whole, our analysis did suggest that an option such as purchasing green power could have substantial societal benefits that could outweigh the direct incremental budgetary costs incurred by the City. For those green building impacts that were difficult or impossible to quantify, we have identified them so that the reader can take them into consideration.*

4.5.7 Regional System Impacts

As noted, we did not attempt to include the marginal cost impacts of adding new energy sources. Similarly, we were unable to obtain projections of the marginal costs of potable water and water treatment that took into account major projects that might be required to meet increasing demand in the Portland region. If we had projections of marginal costs for providing these utilities, we would have estimated the green building benefits of the reduced demand on the regional systems required to provide these utilities. These benefits of building green would be distributed across all customers in the Portland region and would be larger than the direct benefits to the green building occupant. Without reliable estimates of marginal cost trends, however, we were unable to estimate the regional system impacts at any value other than the direct impacts on the building owner/occupants.

> *We believe that analyses of green buildings should estimate the impacts on the customers of those regional systems that are required to provide the energy, potable water, and water treatment that the customers require. In those cases where projections of marginal costs are available that take into account anticipated system cost increases, these projections should be used. In cases where no such projections are available, the possibility and likely magnitude of such impacts should be addressed.*

5 CITY FIRE STATION

This section presents our analysis of how LEED™ could have been applied to a small Portland fire station. It describes the building first. Next, it presents information about how the existing building would be rated if the LEED™ rating system, Version 2, were applied to it as built. The following subsection discusses the options that could have been considered for inclusion in the building to achieve LEED™ certification. Next, it discusses what options we would have proposed for the building to meet the LEED™ requirements based on two different cost criteria. Finally, the results of the analysis are summarized and several conclusions are presented.

As with all buildings we studied, we have taken this building as designed and built and conducted a "what if" analysis to explore what changes might have been made to meet the LEED™ requirements. This analysis does not consider how the building could now be retrofit. The authors also note that the rating system did not exist at the time this building was being designed and built, so the results should not be interpreted as a critique or assessment of the decisions that were made originally. We note furthermore that some of the recommended equipment, materials, or measures might not have been available during the planning phase, although most are available now or should be feasible in the near future. Thus, our analysis treats the facility as if it were being designed and built today to meet LEED™ given all currently available options that would earn credits under LEED™ (except where noted).

5.1 BUILDING DESCRIPTION

Hayden Island Fire Station 17 (Fire Station 17) is a two story, 4,932 ft^2 building completed in 1995 with living quarters, offices, and an apparatus bay. Total construction cost was $782,000. For the year from mid-November 1998 through mid-November 1999, the station was billed for 39,360 kWh and 3,057 therms. The station is usually staffed by four people around the clock seven days per week or an equivalent of 17 people throughout an average day (adjusted to a 5-day work week).

The building exterior is composed of split-face concrete masonry unit bearing walls on the lower level and painted wood siding clad wood frame walls on the upper level. The roof is covered with blue standing seam metal panels over a fabricated wood truss structure. The interior structure consists of a slab-on-grade floor and concrete masonry unit partitions on the lower level and a steel girder/composite wood joist floor system and wood frame, gypsum board walls on the upper level. Interior finishes include gypsum board and suspended acoustical tile ceilings, painted gypsum board walls, and floors of carpet, sheet vinyl, and vinyl composition tiles.

The fully conditioned area of the building is approximately 2,450 ft^2. Cooling is supplied with three residential split system units having a combined capacity of 7 tons (one 2-ton and two 2.5-ton units). The apparatus bay has forced-air heating, but no cooling. The thermal loading of the building is dominated by solar radiation, conduction, and, especially, infiltration. Internal gains from people and lights are a small fraction of the cooling load and contribute little to meeting the heating load. A total of 132 kBtuh of heating is provided from three gas-fired condensing furnaces in the same packages as the cooling evaporators.

The building is exhausted through vents in the bathrooms. Air quality during the walkthrough was a little musty, and smoking was observed inside the building.

Windows are dual-pane with aluminum clad wood frames. The glass plus frame U-value is assumed to be 0.47, a typical value for comparable windows. Glazing is clear and has no reflective or spectrally selective coatings or films. There are good views from the south windows and adequate daylight throughout the windows. No skylights, light shelves, clerestories, or other daylighting techniques are employed in the existing building.

Lighting is provided by 3-lamp T-8 fixtures with magnetic “energy efficient” ballasts in the main living areas, 2-lamp T-8 fixtures in the smaller rooms, and 2-lamp 8-foot T-8 fixtures in the truck bay. Exit signs are 7W CFLs. Four exterior HIDs (three 175W and one 400W) provide yard lighting. Occupancy sensors are in the restrooms, storage rooms, and truck bay.

Table 5-1 presents a summary of the Fire Station 17 shell and systems.

Table 5-1
Fire Station 17 Summary Building Energy Characteristics

Shell	
Walls	First floor is masonry with R-6 rigid insulation. Second floor is 2x6 16” o.c. with R-21 batt insulation
Ceiling	Pre-finished metal roof on 5/8” CDX with R-21 insulation
Glazing	Mix of fixed and operable wood clad insulating glass units
Floors	R-21 batt insulation over apparatus bay
Apparatus Bay	R-10 polyurethane foam roll-door with single glazed window taking up 29% of the door area
HVAC	
Ventilation	2600 cfm from three residential furnace
Cooling	7 tons of residential split system capacity from three separate units
Heating	132 kBtuh of heating from three horizontal gas-fired furnaces
Lighting	
Fixtures	Primarily two and three lamp T-8 with magnetic EE ballasts.
Controls	Occupancy sensors in bathrooms, storage, exercise room and apparatus bay.

5.2 Rating as Built

The existing Fire Station 17 was analyzed and determined to score 16 out of a possible 64 points on the LEED™ system. A minimum of 32 points is needed for certification. This section provides a description of how the existing building scored on each measure along with a discussion of the factors that went into making the rating decisions.

5.2.1 Data

Data were obtained for the LEED™ rating analysis through site visits, interviews with project staff, and construction documents. In a few cases, information on the drawings could not be verified or information was simply not available. These cases are described here, along with the assumption made:

- Wall, ceiling, and, floor insulation levels are as indicated on the construction drawings.
- Available construction cost data were limited to a lump-sum figure. Published construction cost data for typical fire stations and building components were used to complete the analysis.
- Information on the specific materials used in the building was not always available so assumptions were made based upon the drawings, specifications, operation and maintenance manual, and field observations.
- The construction waste management plan was not available and the general contractor could not be reached for an interview.

5.2.2 Rating

The following tables present, by LEED™ category, the points possible for each LEED™ measure and the points earned for the existing building. The six LEED™ categories are as follows: [1]

- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation Credits

[1] Note that the sixth category, Innovation Credits, is not part of the core points under the LEED™ system, but permits a building to earn extra credit for innovative measures, practices, or use of a LEED™-certified rater.

Sustainable Sites

Table 5-2 shows the points possible for the Sustainable Sites options. It also displays the number of points that the building earned for each category based on our assessment.

Table 5-2
Fire Station 17 As-built LEED™ Rating
Sustainable Sites

Sustainable Sites	Points Possible	Points Earned
P1: Erosion and Sedimentation	0	meets
C1: Site Selection	1	1
C2: Urban Redevelopment	1	0
C3: Brownfield Development	1	0
C4: Alternative Transportation	4	1
C5: Reduced Site Disturbance	2	1
C6: Stormwater Management	2	2
C7: Landscape and Exterior Design	2	1
C8: Light Pollution Reduction	1	0
Sustainable Sites Subtotal	*14*	*6*

Detailed information on each of the options is presented below:

Site Prerequisite 1: Erosion and Sedimentation — The existing development appears to have met this prerequisite.

Site Credit 1: Site Selection — The building is located on an environmentally appropriate site.

Site Credit 2: Urban Redevelopment — The building is sited in a medium density area. The siting criteria for a fire station may conflict with the ability to locate the building in a more urban setting.

Site Credit 3: Brownfield Redevelopment — The building was not constructed on a brownfield site.

Site Credit 4: Alternative Transportation — There is only one bus line within 1/4 mile of the site. There are no apparent provisions for bicycle parking, but showers are provided. No parking spaces were added for the facility so we determined that it received a point for this option (local zoning requirements set no minimum for parking spaces).

Site Credit 5: Reduced Site Disturbance — The site was previously undisturbed and the development impacted most of the site. 35% of the site was developed as open space. No open space is required by City zoning. Other commercial zones require 15% open space. We interpreted this situation to mean that this provision would be awarded a point in LEED™.

Site Credit 6:
Stormwater Management

Although site impervious surface was increased significantly, all stormwater is taken into drywells to recharge groundwater on site. Oil separators were installed, but no other water quality treatment was provided. If built today, however, the Bureau of Environmental Services (BES) would require a Stormceptor or swale. Based on first cost, a swale probably would have been installed. Based on current requirements, we give the building credit for having such a system, even though it didn't when built, because this measure would have to be provided. Because this is not related to LEED™, we attribute no costs or benefits to the measure.

Site Credit 7:
Landscape & Exterior Design to Reduce Heat Islands

The entire non-roof impervious surface area of the site is concrete with a reflectance greater than 0.3, thus earning one point. The roof is a medium blue color and has a relatively low reflectance and is not ENERGY STAR compliant.

Site Credit 8:
Light Pollution Reduction

Five exterior light fixtures are not well shielded and are a source of glare.

Water Efficiency

Table 5-3 presents the possible points and the number of points earned for each option in the Water Efficiency category. Note that no options received points in this category.

Table 5-3
Fire Station 17 As-built LEED™ Rating
Water Efficiency

Water Efficiency	Points Possible	Points Earned
C1: Water Efficient Landscaping	2	0
C2: Innovative Wastewater Tech	1	0
C3: Water Use Reduction	2	0
Water Efficiency Subtotal	*5*	*0*

Details on each option are presented below:

Water Credit 1:
Water Efficient Landscaping

A spray type sprinkler was installed rather than a drip style. Also, the building uses the municipal water supply.

Water Credit 2:
Innovative Wastewater Technologies

No on-site wastewater treatment is performed.

Water Credit 3:
Water Use Reduction

The existing building has standard commercial toilets and low-flow faucets. Showers and urinals are all standard water usage for commercial buildings in the area.

Energy and Atmosphere

Table 5-4 presents the number of points possible for the Energy and Atmosphere options and our ratings for each.

Table 5-4
Fire Station 17 As-built LEED™ Rating
Energy and Atmosphere

Energy and Atmosphere	Points Possible	Points Earned
P1: Fundamental Commissioning	0	does not meet
P2: Minimum Energy Performance	0	meets
P3: CFC Reduction in HVAC&R Equip	0	meets
C1: Optimize Energy Performance	10	2
C2: Renewable Energy	3	0
C3: Best Practice Commissioning	1	0
C4: Elimination of HCFCs and Halons	1	0
C5: Measurement and Verification	1	0
C6: Green Power	1	0
Energy and Atmosphere Subtotal	*17*	*2*

Detailed information on each of the options is presented below:

Energy Prerequisite 1: Fundamental Building Systems Commissioning.
No commissioning plan was written or executed for this building.

Energy Prerequisite 2: Minimum Energy Performance
The building meets existing Oregon Energy Code as evidenced by its filing with the state Energy Office.

Energy Prerequisite 3: CFC Reduction in HVAC&R Equipment
The building meets this prerequisite.

Energy Credit 1: Optimize Energy Performance.
The building is rated with the "New Building" criteria. A DOE-2 simulation built up from the construction documents and observations made during a site visit indicate the existing building uses approximately 20% less electricity than a building in minimal compliance with ASHRAE Standard 90.1-1999; thus it receives 2 points. Most of the difference is in the lighting and shell insulation.

Energy Credit 2: Renewable Energy
No renewable generation capacity is installed.

Energy Credit 3: Best Practice Commissioning
As noted above, no commissioning was performed.

Energy Credit 4: Elimination of HCFCs and Halons
The standard compressors use HCFC refrigerant.

Energy Credit 5: Measurement and Verification
No M&V was performed.

Energy Credit 6: Green Power
Green power was not purchased specifically for this building.

Materials and Resources

Table 5-5 presents our rating for each option in the Materials and Resources category and the number of points possible.

Table 5-5
Fire Station 17 As-built LEED™ Rating
Materials and Resources

Materials and Resources	Points Possible	Points Earned
P1: Storage & Collection of Recyclables	0	meets
C1: Building Reuse	3	0
C2: Construction Waste Management	2	0
C3: Resource Reuse	2	0
C4: Recycled Content	2	0
C5: Local/Regional Materials	2	2
C6: Rapidly Renewable Materials	1	0
C7: Certified Wood	1	0
Materials and Resources Subtotal	*13*	*2*

Details for each option are presented below:

Material Prerequisite: Storage and Collection of Recyclables — Recycling collection and storage facilities are provided.

Material Credit 1: Building Reuse — The building is entirely new construction.

Material Credit 2: Construction Waste Management — There is no record that the General Contractor had a construction waste management plan.

Material Credit 3: Resource Reuse — No reused materials were specified.

Material Credit 4: Recycled Content — Recycled content materials comprise approximately 18% of the existing building, mostly in the form of steel building components. An additional 7% of materials would have to have been recycled content to qualify for a point under this credit.

Material Credit 5: Local/Regional Materials — We estimated that local/regional manufactured materials comprise 20% of the existing building. More than half of these were probably locally/regionally extracted.

Material Credit 6: Rapidly Renewable Materials — No rapidly renewable materials were specified.

Material Credit 7: Certified Wood — No certified wood was specified.

Indoor Environmental Quality

Table 5-6 presents the points possible for each option in the Indoor Environmental Quality category and the points we awarded in our rating.

Table 5-6
Fire Station 17 As-built LEED™ Rating
Indoor Environmental Quality

Indoor Environmental Quality	Points Possible	Points Earned
P1: Minimum IAQ Performance	0	meets
P2: Environmental Tobacco Smoke	0	does not meet
C1: Carbon Dioxide Monitoring	1	0
C2: Increase Ventilation Effectiveness	1	0
C3: Construction IAQ Mgmt Plan	2	1
C4: Low-Emitting Materials	4	0
C5: Indoor Pollutant Source Control	1	1
C6: Controllability of Systems	2	2
C7: Thermal Comfort	2	1
C8: Daylight and Views	2	2
Indoor Environmental Quality Subtotal	*15*	*7*

Details of the ratings are presented below:

IEQ Prerequisite 1: Minimum IAQ Performance — The existing building meets ASHRAE 62 recommended practice and this prerequisite.

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control — Smoking was observed inside the building during the site visit.

IEQ Credit 1: Carbon Dioxide (CO_2) Monitoring — The existing building has no permanent CO_2 sensor in the HVAC system.

IEQ Credit 2: Increase Ventilation Effectiveness — Some stuffy, stagnant air was encountered during the site visit. This is partly due to the smoking, but may also be due to poor placement of diffusers and/or lack of fresh air.

IEQ Credit 3: Construction IAQ Management Plan — The fan units were protected during construction, but no ventilation was supplied so the building receives one point.

IEQ Credit 4: Low-Emitting Materials — No low-emitting materials were used.

IEQ Credit 5: Indoor Chemical and Pollutant Source Control — The building meets the credit requirements by having ventilation in the apparatus bay and walk-off mats.

IEQ Credit 6: Controllability of Systems — Separate lighting and HVAC controls are accessible in most areas of the station. The station is built much like a large home, and has access to operable windows from every regularly occupied space.

IEQ Credit 7: Thermal Comfort — Humidity control is unnecessary in this building because of the climate. The building already complies with ASHRAE Standard 55 simply by being air conditioned in Portland. Despite this, the building cannot earn the second LEED™ credit in this category without installing a permanent humidity monitoring system.

IEQ Credit 8: Daylight and Views — Diffuse sunlight reaches nearly everywhere throughout the building. Because of the residential construction style, a direct line of sight to the windows is accessible from all regularly occupied spaces.

Innovation Credits and Design/Build Process

Table 5-7 summarizes the points possible in the Innovation and Design/Build Process category and our ratings.

Table 5-7
Fire Station 17 As-built LEED™ Rating
Innovation Credits and D/B Process

Innovation Credits and D/B Process	Points Possible	Points Earned
C1: Innovation Credits	4	0
C2: Accredited Professional	1	0
Innovation Credits Subtotal	*5*	*0*

Details for each rating are provided below:

I & D/B Credit 1 — We did not identify any options in the building that would earn innovation credits.

I & D/B Credit 2 — An accredited professional was not involved in this project.

Overall Rating

Table 5-8 summarizes the LEED™ points possible and points earned by category. Note that the most points and the highest percentage of points earned were for Indoor Environmental Quality section. The lowest points and the lowest percentage of points earned for the core categories was under the Water Efficiency, Energy and Atmosphere, and Materials and Resources categories.

The total core points possible using the LEED™ criteria is 64; Fire Station 17 earned 17 points (based on the assumption that it were being built under current requirements). The total points necessary for certification is 32; thus, 15 additional points would be needed for certification.

Table 5-8
Fire Station 17 As-built LEED™ Rating
Grand Total

LEED™ Totals	Points Possible	Points Earned	% of Points Earned
Sustainable Sites	*14*	*6*	*43%*
Water Efficiency	*5*	*0*	*0%*
Energy and Atmosphere	*17*	*2*	*12%*
Materials and Resources	*13*	*2*	*15%*
Indoor Environmental Quality	*15*	*7*	*47%*
Total Core LEED™ Points	**64**	**17**	**27%**
Innovation Credits	*5*	*0*	*0%*
Total Score	**69**	**17**	**27%**

5.3 CANDIDATE LEED™ MEASURES

In this section, we present the measures that we considered to be candidates for inclusion in a hypothetical building with the same location, shape, and function as Fire Station 17. Candidate measures are ones that passed an initial screening process and were then considered for further analysis. The screening process utilized discussions with City of Portland staff, past experience with cost-effective measures in other projects, and recommendations within the LEED™ guidelines.

Ideally, the initial screening provided a way to condense the potential measures to a reasonable set of options that could then be assessed. As with the other buildings studied, our screening took into account the following criteria:

- excessive first costs or potentially large life cycle costs compared to potential benefits and the respective costs of other measures;
- inapplicability or lack of feasibility for the site;
- requirements for major redesign or siting changes (e.g., major construction changes to accommodate daylighting or relocation to a Brownfield site); and
- unresolved ecological benefits for the site (e.g., elimination of HCFCs and Halons[2]).

Nineteen measures survived the screening, allowing a possible 26 incremental points. As noted above, 15 points were required for certification of this building.

[2] This measure is controversial because of the confusing message it conveys: switching to the use of HCFC refrigerants is ecologically beneficial. In our opinion, the most ecological way to meet this requirement is to eliminate mechanical cooling entirely, and that option was not considered because of the necessity to significantly alter the shell and floor plate design to achieve a comfortable climate in a building of this size.

The candidate measures are discussed in the following subsections by LEED™ category. Tables similar to those presented earlier summarize the information for the candidate measures. Note that each specific measure is assigned a number in the tables that is used for future reference in this section. The tables show the number of points possible under LEED™ for the measure, the rating we gave to the existing building, and the incremental points that we considered to be achievable for the option.

5.3.1 Candidate Measures—Sustainable Sites

Table 5-9 shows the candidate measures that passed our screening criteria in the Sustainable Sites category.

Table 5-9
Fire Station 17 Candidate LEED™ Measures
Sustainable Sites

Candidate Measure #	**Sustainable Sites**	Points Possible	Existing Building	Incremental Points Considered
1	C4: Alternative Transportation	4	1	2
2	C7: Landscape and Exterior Design	2	1	1
3	C8: Light Pollution Reduction	1	0	1
	Sustainable Sites Subtotal			*4*

More detailed information is presented below for each measure selected for further consideration, as well as those that were eliminated because they failed to meet our screening criteria:

Site Credit 2: Urban Redevelopment — Assessment of siting the building in a different location was beyond the scope of our study and, as noted earlier, the siting criteria for a fire station may conflict with the ability to locate the building in a more urban setting.

Site Credit 3: Brownfield Redevelopment — Assessment of the brownfield option was beyond the scope of our study, but we believe that it should be considered by the City for future facilities.

Site Credit 4: Alternative Transportation — Add one bike rack inside the building and consider adding one alternative fueling station. Only one bus line serves Hayden Island. The fire station could not be relocated closer to another bus line while still serving the island.

Site Credit 5: Reduced Site Disturbance — Achieving additional credit would have required major design changes that were beyond the scope of our study to analyze.

Site Credit 7: Landscape & Exterior Design to Reduce Heat Islands — Change specified color of the pre-painted metal roof to increase its reflectance.

Site Credit 8: Light Pollution Reduction — Install shade skirts on exterior fixtures and reduce overall exterior lighting levels by about half (energy reduction credit taken in the Optimize Energy measure).

5.3.2 Candidate Measures—Water Efficiency

Table 5-10 summarizes the candidate measures that we considered in the Water Efficiency category.

Table 5-10
Fire Station 17 Candidate LEED™ Measures
Water Efficiency

Candidate Measure #	**Water Efficiency**	Points Possible	Existing Building	Incremental Points Considered
4	C1: Water Efficient Landscaping	2	0	2
5	C2: Innovative Wastewater Tech	1	0	1
6	C3: Water Use Reduction	2	0	1
	Water Efficiency Subtotal			*4*

Details of the candidate options are presented below:

Water Credit 1: Water Efficient Landscaping — It is possible to get a single credit for installing a drip style irrigation system. However, this adds to the project cost, whereas eliminating the irrigation system entirely reduces the cost of landscaping and earns a second credit. Because of the increasing interest in native landscaping, the financial savings available, and the water savings that earn the LEED™ credit, the option to eliminate the entire irrigation system was chosen.

Water Credit 2: Innovative Wastewater Technologies — Install a rooftop rainwater catchment system for truck and driveway washing. Install collection plumbing and storage tank with changeable filtration and booster pump.

Water Credit 3: Water Use Reduction — Specify low-flow toilets and faucets, and use collected rainwater for truck washing. The second credit for a 30% reduction appears to be much more difficult to obtain because of the large amount of water used for truck washing and we did not consider it further.

5.3.3 Candidate Measures—Energy and Atmosphere

Table 5-11 presents the candidate measures in the Energy and Atmosphere category.

Table 5-11
Fire Station 17 Candidate LEED™ Measures
Energy and Atmosphere

Candidate Measure #	**Energy and Atmosphere**	Points Possible	Existing Building	Incremental Points Considered
	P1: Fundamental Commissioning	0	meets	
7	C1: Optimize Energy Performance	10	2	4
8	C2: Renewable Energy	3	0	1
9	C3: Best Practice Commissioning	1	0	1
10	C6: Green Power	1	0	1
	Energy and Atmosphere Subtotal			*7*

Detailed information is presented below on each candidate measure as well as those that were screened out:

Prerequisite 1: Fundamental Building Systems Commissioning.

We include in the prerequisite meeting the fundamental requirements plus the Energy and Atmosphere Credit 3: Best Practice Commissioning (the more stringent commissioning credit). We do not include Energy and Atmosphere Credit 5: Measurement and Verification because of the small size and relative simplicity of the systems in this building.

Energy Credit 1: Optimize Energy Performance

Annual electrical consumption was 39,360 kWh. The estimated consumption based on just meeting the ASHRAE Standard would be 48,790 kWh. To achieve the 30% reduction over the ASHRAE level (34,153 kWh), the four measures below were considered:[3]

1) Reduce exterior lighting levels by 50%, especially away from main entry driveway. 2) Specify electronic ballasts for linear fluorescent fixtures. 3) Specify high efficiency cooling with SEER of 14.0 or better. 4)Provide radiant heaters in garage instead of heating air space with the doors open.

Table 5-12 presents information on the energy submeasures for the first energy credit. Table 5-13 presents details on the proposed lighting fixtures.

Table 5-12
Optimize Energy Submeasures

Submeasure	Description	Incremental Cost
Lighting	Reduce exterior lighting levels by 50% (450W reduction 8hrs/day)	-$280
	Use electronic ballasts in 4-ft and 8-ft linear fluorescent fixtures (Total of 16 fixtures)	$80
HVAC	Specify high SEER cooling system (approx $50/ton more)	$350
	Install four wall-mounted radiant heaters in truck bay with dial timers for control.	$1,100
	Total	**$1,250**

[3] Energy consumption was estimated by calibrating a DOE-2 simulation with the actual billing data and adjusting the estimate to standardized weather conditions.

Table 5-13
Existing and Proposed Lighting Fixtures

No. of	Existing			Proposed		
Fixtures	Type	W/fix.	Total Watts	Type	W/fix.	Total Watts
6	F43LE	106	636	F43LL	88	528
4	F82LE	140	560	F82LL	111	444
6	F42LE	70	420	F42LL	60	360
16			1616			1332

The other options are discussed in more detail below:

Energy Credit 2: Renewable Energy — Install single-axis tracking, pole-mounted photovoltaic system with 1.8 kW of nominal peak capacity to supply approximately 1,708 kWh, annually.

Energy Credit 3: Best Practice Commissioning — This measures requires a third-party review of the commissioning plan and tying final payment to successful commissioning and implementation of a performance-based fees contract. We combine this measure with the prerequisite commissioning requirement and estimate commissioning costs based on including this measure.

Energy Credit 4: Elimination of HCFCs and Halons — The most ecological way to meet this requirement would be to eliminate mechanical cooling entirely. We did not consider that option, however, because of the necessity to significantly alter the building design, which was beyond our analysis scope.

Energy Credit 5: Measurement and Verification — This measure requires implementing a comprehensive measurement and verification plan and meeting the installed equipment requirements for continuous metering described in the IPMVP Option B. As noted earlier, we did not believe this option would be suitable for this building.

Energy Credit 6: Green Power — Engage in a 2-year contract to purchase power with a minimum of 30% generated from renewable sources that meet the CRS Green-E requirements. PGE currently charges a 5 mil/kWh premium for green power within its territory.

The following table presents the emissions reductions that would occur by switching to green power. Thirty percent of the annual usage of the proposed building is 10,245 kWh. The emissions numbers are based on avoided emissions from that amount of electricity production.

Table 5-14
Impact of 30% Green Electricity
Purchase on Emissions Reductions

Compound	Annual Reduction
CO_2	16,904 lbs/yr
NO_x	36 lbs/yr
SO_2	29 lbs/yr

5.3.4 Candidate Measures—Materials and Resources

Table 5-15 presents the candidate measures that we considered in the Materials and Resources category.

Table 5-15
Fire Station 17 Candidate LEED™ Measures
Materials and Resources

Candidate Measure #	**Materials and Resources**	Points Possible	Existing Building	Incremental Points Considered
11	C2: Construction Waste Management	2	0	2
12	C3: Resource Reuse	2	0	1
13	C6: Rapidly Renewable Materials	1	0	1
14	C7: Certified Wood	1	0	1
	Materials and Resources Subtotal			*5*

Details on the candidate measures and those that were eliminated from further consideration are presented below:

Material Credit 1: Building Reuse — It would have required a major change in the project to reuse an existing building and consideration of this change was beyond the scope of our study.

Material Credit 2: Construction Waste Management — With increased awareness and markets today, more than 75% of construction debris could be recycled at no additional cost or perhaps as a savings.

Material Credit 3: Resource Reuse — Specify salvaged hollow metal doors that are readily available in the Portland market.

Material Credit 4: Recycled Content — We determined that it was unlikely that enough additional recycled materials could have been used to receive points for this option and that available options might have negative effects.

Material Credit 6: Rapidly Renewable Materials — Substitute wheatboard in cabinets and linoleum for sheet vinyl and VCT. Cork flooring could also replace some carpeting. The linoleum has a life expectancy four times that of sheet vinyl.

Material Credit 7: Certified Wood — Specify certified wood for wall/roof framing, plywood sheathing, and wood siding. Use advanced framing to reduce wood use and improve thermal envelope. Certified wood truss joists are not currently available.

5.3.5 Candidate Measures—Indoor Environmental Quality

Table 5-16 presents the candidate measures that we considered further in the Indoor Environmental Quality category.

Table 5-16
Fire Station 17 Candidate LEED™ Measures
Indoor Environmental Quality

Candidate Measure #	**Indoor Environmental Quality**	Points Possible	Existing Building	Incremental Points Considered
	P2: Environmental Tobacco Smoke	0	does not meet	
15	C2: Increase Ventilation Effectiveness	1	0	1
16	C3: Construction IAQ Mgmt Plan	2	1	1
17	C4: Low-Emitting Materials	4	0	3
18	C7: Thermal Comfort	2	1	1
	Indoor Environmental Quality Subtotal			*6*

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control
A non-smoking policy should be implemented or, if one is in place, should be enforced.

IEQ Credit 1: Carbon Dioxide Monitoring
We determined that this option would be unsuitable for a building of this size with the systems included and operable windows.

IEQ Credit 2: Increase Ventilation Effectiveness
Stuffy, stagnant air was encountered during the site visit. This is partly due to the smoking, but may also be due to poor placement of diffusers and/or lack of fresh air. To achieve this credit, the building should be designed for good mixing in 90% of the occupied areas.

IEQ Credit 3: Construction IAQ Management Plan
The fan units were protected during construction, but no ventilation was supplied. The recommendation would have been to provide continuous ventilation during the construction period.

IEQ Credit 4: Low-Emitting Materials
Specify low-VOC adhesives, paints, and coatings and Green Label carpet for 3 points. Alternatives to composite wood structural elements may not be feasible, but wheatboard included in Materials Credit 6 also improves IEQ.

IEQ Credit 7: Thermal Comfort
Install a full-time temperature and humidity monitor to achieve the second credit in this measure.

5.3.6 Candidate Measures—Innovation Credits and Design/Build Process

Table 5-17 summarizes our assessment of credits that could have been obtained through either building or siting decisions or through the use of a LEED™-trained professional. The details of our consideration of the measures are discussed below the table.

Table 5-17
Fire Station 17 Candidate LEED™ Measures
Innovation Credits and Design/Build Process

Candidate Measure #	**Innovation and Design/Build Process**	Points Possible	Existing Building	Incremental Points Considered
19	C2: Accredited Professional	1	0	1
	Innovation and Design/Build Process Subtotal	*5*	*0*	*1*

I & D/B Credit 1 We found it impractical to propose innovations at this point without knowing whether they would have been limited by project constraints. Nevertheless, we believe that it is important for designers and planners to consider possible innovations that would receive LEED™ credit.

I & D/B Credit 2 We believe that it would be useful to include a LEED™-trained professional in the project team for projects like this in the future. We do not rely on this option as one of the credits that we analyze for this building, however, because it is useful to determine first whether the building could meet the LEED™ requirement with specific building measures alone.

5.3.7 Candidate Measures—Summary Information

Table 5-18 summarizes the measures that we retained for further analysis to attain the basic LEED™ certification level. The most incremental points available for further consideration were in the Energy and Atmosphere and Indoor Environmental Quality categories, although at least 4 points were possible in each category. As noted earlier, the candidate measures yielded a total of 26 points that could be applied to certification.

Table 5-18
Fire Station 17 Candidate LEED™ Measures
Grand Total

LEED™ Totals	Points Possible	Existing Building	Incremental Points Considered
Sustainable Sites Subtotal	*14*	*6*	*4*
Water Efficiency Subtotal	*5*	*0*	*4*
Energy and Atmosphere Subtotal	*17*	*2*	*7*
Materials and Resources Subtotal	*13*	*2*	*5*
Indoor Environmental Quality Subtotal	*15*	*7*	*6*
Total Core LEED™ Points	**64**	**17**	**26**
Innovation Credits Subtotal	5	0	0
Total Score	**69**	**17**	**26**

5.4 MEASURES TO MEET THE LEED™ CERTIFICATION REQUIREMENT

This subsection presents the results of two cost-benefit analyses that we used to select measures to meet the basic LEED™ certification requirement. The first set of results discussed is based on meeting LEED™ by selecting measures that would do so at minimum first cost. The second set of results is based on meeting the requirement by selecting measures that would minimize the life cycle costs. Life cycle costs are defined as the net present value of first costs and future costs and benefits[4]. In both cases, the analysis is based on the perspective of the building owner/operator, but broader impacts are assessed.

4 As noted in Section 2, the real discount rate used is 3%, and the life-cycle period assumed is 25 years. See Section 2 for a more detailed discussion of life cycle cost assumptions.

5.4.1 Measure Selection Based on Lowest First Costs

This section presents the candidate measures described above ranked in order by first cost per LEED™ point earned ($FC/Pt.), starting with the lowest cost measures.

Measures Required for LEED™ Certification

Table 5-19 presents the results of applying the least first cost criterion to the candidate measures. The first column shows the tracking number assigned earlier to each measure. The second column identifies the measure. The third column indicates the number of LEED™ points that apply to that measure. The fourth column shows the cumulative points earned by the measures. The fifth column indicates the incremental first cost per point earned by the measure. The sixth column shows the incremental Direct and Regional System first cost for the measure. The seventh column presents the incremental Direct and Regional System life cycle cost for the measure. As noted earlier, the Direct and Regional System costs would differ if the marginal costs of supplying energy or water or treating waste differed from the average costs as reflected in customer rates. In our study, however, we were unable to obtain reliable estimates of these marginal costs over the 25-year time horizon examined. Therefore, we used marginal costs equal to the average costs projected throughout the period and, consequently, the Direct and Regional System costs and benefits were assumed to be equivalent.

The eighth column shows the Societal incremental life cycle costs. These values take into account societal impacts that we were able to monetize. The ninth column identifies some of the benefits that were not estimated in our analysis.

As shown in Table 5-19, 13 of the candidate measures are needed to earn the 15 incremental points required for LEED™ certification. The two prerequisites that are not met must be met, so they are included.

Table 5-19
Fire Station 17 Candidate Measures Sorted By First Cost, Incremental Impacts

Candidate Measure Number	Measure	Pts.	Cum. Pts.	$FC/Pt.	Direct/Regional First cost	Direct/Regional LCC	Societal LCC	Societal Non-monetized benefits
	Fundamental Commissioning*	0	0	n/a	$5,863	-$82,880	-$82,880	
	Environmental Tobacco Smoke	0	0	n/a	$0	$0	$0	Health benefits from eliminating smoking.
12	Resource Reuse	1	1	-$8,040	-$8,040	-$8,040	-$8,040	Reduced pollution from producing new materials
4	Water Efficient Landscaping	2	3	-$1,500	-$3,000	-$4,740	-$4,740	
6	Water Use Reduction	1	4	$0	$0	-$547	-$547	
9	Best Practice Commissioning	1	5	$0	$0	$0	$0	
10	Green Power	1	6	$0	$0	$890	-$892	Fish/wildlife habitat
11	Construction Waste Management	1	7	$0	$0	$0	$0	
15	Increase Ventilation Effectiveness	1	8	$0	$0	$0	$0	Worker health benefits
3	Light Pollution Reduction	1	9	$100	$100	$100	$100	Darker night sky; less glare
18	Thermal Comfort	1	10	$250	$250	$250	$250	Worker comfort
17	Low-Emitting Materials	3	13	$360	$1,080	-$1,708	-$1,708	Worker health benefits
7	Optimize Energy Performance	2	15	$585	$1,170	-$4,484	-$5,626	
	Total needed		***15***		*-$2,580*	*-$101,200*	*-$102,300*	
	Simple payback = 0 months							
	Measures Not Needed							
14	Certified Wood	1		$590	$590	$590	$590	Forest ecosystem benefits
16	Construction IAQ Mgmt Plan	1		$2,000	$2,000	$2,000	$2,000	Worker health benefits
13	Rapidly Renewable Materials	1		$2,300	$2,300	$200	$200	Fish/wildlife habitat
1	Alternative Transportation	2		$2,300	$4,600	$4,600	$4,600	Reduced air pollution
5	Innovative Wastewater Technologies	1		$3,690	$3,690	$1,467	$1,478	
2	Landscape and Exterior Design	1		$5,000	$5,000	$3,371	$3,042	Heat island effects
8	Renewable Energy	1		$16,443	$16,443	$14,589	$14,214	Reduced air pollution

*The Fundamental Building Systems Prerequisite is required, regardless of cost. The costs and benefits of Best Practice Commissioning are included in this measure.

Note: Prerequisite measures are shaded. Direct and Regional System values are assumed to be the same in this analysis because no marginal cost data were available. They would be different if estimated marginal costs were higher than average costs.

Measures Required for LEED™ Certification

The options that were selected based on lowest first cost are shown in the top part of the table. Most of the selected options were described earlier, but additional information is provided here.

For the first option listed, the prerequisite Fundamental Building Systems Commissioning, we assumed that it included the Best Practice Commissioning. We did not include the Measurement and Verification option, like we did with the other two buildings, because it would not be justified with such a small, relatively simple building. Because the commissioning activity would be more limited in this building, we estimated the cost to be 0.7% of the building cost, which is near the low end of the range of typical commissioning cost estimates.

Costs and benefits for complete commissioning are shown for the first entry. We do not attribute any energy savings to this combined measure because the energy performance measure receives full credit for the energy savings that we estimated with our building simulation model. We constructed our analysis so that complete commissioning would be included with energy-efficiency improvements as a way to ensure that the estimated energy savings were achieved. The substantial benefits shown in the table that were estimated for the combined Building Systems Commissioning measure were a result of an estimated increase in employee productivity. We assumed an average annual salary of $30,000 for the 17 employees. We then assumed a minimal productivity increase of 1%, leading to annual productivity economic savings estimated to be $5,100.[5]

The Resource Reuse measure assumes that salvaged doors would have been installed. Each door would have reduced first cost by about $335 (including offsetting preparation costs) and 24 doors would have been replaced.

The Water Efficient Landscaping measure eliminates the irrigation system so it has a negative first cost. It also provides long-term life benefits from water savings as well.

A green power purchase is included because it would not have increased first cost; it would have increased electricity costs, however. Over the 25-year life cycle, this measure would have reduced emissions sufficiently to provide societal benefits valued at about twice the added cost of the electricity.

The Low-Emitting Materials option includes paints and adhesives, and a higher quality carpet that is also green rated; these measures all increase first cost. The upgraded carpet, however, has a longer lifetimes and this has the net effect of reducing life cycle cost.

The energy-efficiency improvements would have increased first cost about $1,200. This efficiency increase would have produced life cycle utility bill discounted savings of about $5,600, or nearly 5 times the original investment. These energy savings would have reduced the air quality impacts an amount valued at about $1,200.

In summary, if the objective had been to meet the LEED™ requirements by selecting those measures with the lowest first cost, the first cost could have been *decreased by about $2,600*. Because they lowered both first cost and life cycle cost, these measures would have had a simple

[5] This economic value is conservative because the indirect and overhead costs have not been included. Productivity increases associated with green buildings have been estimated to range from a few percent to 20% or more. Values attributable to improved air quality alone are typically about 3%. Because this building is small and has operable windows, we made a conservative assumption that only a 1% improvement would be achieved.

payback of zero time, and produced a net reduction of about $100,000 in the life cycle cost of constructing and operating the building.

Additional Measures Not Required for LEED™ Certification

Some of the measures shown in Table 5-19 that would not have been required for LEED™ certification are discussed below. These measures are listed in the lower part of the table.

The Rapidly Renewable Materials include wheatboard in cabinets and linoleum flooring to replace vinyl and VCT. The longer lifetime of the linoleum decreases its life cycle cost, but not quite enough to offset the added first cost of the linoleum and wheatboard.

The Alternative Transportation measure cost is based on $150 for a bike rack and $4,622 for a natural gas fueling station.

The Innovative Wastewater Technologies rainwater catchment system reduces the cost of potable water and, thus, has life cycle benefits. Note that it increases energy use slightly for water pumping and this results in a slight negative air emissions impact.

Non-Quantified Benefits

The comments in Section 3 on non-quantified benefits apply in this analysis as well. The most difficult to quantify benefits would probably be those associated with reducing impacts on ecosystems and fish and wildlife habitat. These benefits could be significant and very important in the City's efforts to address Endangered Species Act requirements, particularly if spread over a large number of buildings. We note here the importance of considering these impacts and the need for ways to analyze them.

5.4.2 Measure Selection Based on Lowest Life Cycle Costs

This subsection presents the candidate measures ranked according to their impacts on life cycle cost. Our ranking was based on costs and benefits that would affect the building owner/operator or occupants. As before, we dealt partially with different perspectives by presenting those Societal impacts that we could quantify and identifying non-quantified benefits.

This discussion focuses on the differences from the results presented earlier for the lowest first cost ranking. Table 5-20 presents the results of ranking the candidate measures using the least life cycle cost criterion. Thirteen of the measures would be required to meet the LEED™ certification under the least life cycle cost criterion.

Table 5-20
Fire Station 17 Candidate Measures Sorted By Life Cycle Cost, Incremental Impacts

Candidate Measure Number	Measure	Pts.	Cum. Pts.	$LCC/Pt.	Direct/Regional First cost	Direct/Regional LCC	Societal LCC	Societal Non-monetized benefits
	Fundamental Commissioning*	0	0	n/a	$5,863	-$82,880	-$82,880	
	Environmental Tobacco Smoke	0	0	n/a	$0	$0	$0	Health benefits from eliminating smoking.
9	Best Practice Commissioning	1	1	$0	$0	$0	$0	
12	Resource Reuse	1	2	-$8,040	-$8,040	-$8,040	-$8,040	Reduced pollution from producing new materials
4	Water Efficient Landscaping	2	4	-$2,370	-$3,000	-$4,740	-$4,740	
7	Optimize Energy Performance	2	6	-$2,242	$1,170	-$4,484	-$5,626	
17	Low-Emitting Materials	3	9	-$570	$1,080	-$1,708	-$1,708	Worker health benefits
6	Water Use Reduction	1	10	-$547	$0	-$547	-$547	
11	Construction Waste Management	1	11	$0	$0	$0	$0	
15	Increase Ventilation Effectiveness	1	12	$0	$0	$0	$0	Worker health benefits
3	Light Pollution Reduction	1	13	$100	$100	$100	$100	Darker night sky; less glare
13	Rapidly Renewable Materials	1	14	$200	$2,300	$200	$200	Fish/wildlife habitat
18	Thermal Comfort	1	15	$250	$250	$250	$250	Worker comfort
	Total needed		***15***		*-$277*	*-$101,850*	*-$103,000*	
	Simple payback = 0 months							
	Measures Not Needed							
14	Certified Wood	1		$590	$590	$590	$590	Forest ecosystem benefits
10	Green Power	1		$890	$0	$890	-$892	Fish/wildlife habitat
5	Innovative Wastewater Technologies	1		$1,467	$3,690	$1,467	$1,478	
16	Construction IAQ Mgmt Plan	1		$2,000	$2,000	$2,000	$2,000	
1	Alternative Transportation	2		$2,300	$4,600	$4,600	$4,600	Reduced air pollution
2	Landscape and Exterior Design	1		$3,371	$5,000	$3,371	$3,042	Heat island benefits
8	Renewable Energy	1		$14,589	$16,443	$14,589	$14,214	Reduced air pollution

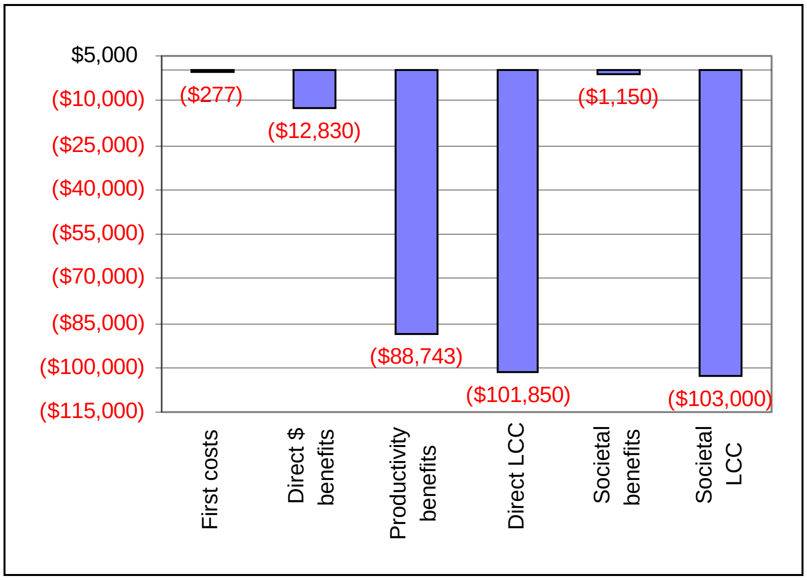
*The Fundamental Building Systems Prerequisite is required, regardless of cost. The costs and benefits of Best Practice Commissioning are included in this measure.
Note: Prerequisite measures are shaded. Direct and Regional System values are assumed to be the same in this analysis because no marginal cost data were available. They would be different if estimated marginal costs were higher than average costs.

The only change from the results based on the lowest first cost options was the deletion of the Green Power option and replacement with the Thermal Comfort measure. This change occurred because of the price premium for green power, which would increase life cycle costs slightly. It is important to note, however, that the green power air pollution benefits to society would have decreased the overall life cycle costs to society.

Figure 5-1 summarizes the costs and benefits if the objective had been to meet the LEED™ requirements by selecting those measures that had the lowest life cycle cost. Fire Station 17 could have been constructed for a cost slightly less than the original cost. The proposed changes would have reduced the total life cycle costs incurred by the City by almost $102,000. The bulk of the savings would be attributable to the increased productivity of workers in the building.

Because the first cost would have decreased in this case also, no payback period would have been required.

Figure 5-1
Summary of Fire Station 17 Costs and Benefits



5.5 OVERALL FINDINGS AND DISCUSSION

This subsection presents key overall observations about the findings from analyzing Fire Station 17.

5.5.1 Costs and Benefits to the City of Greening Fire Station 17

Our analysis indicates that a building like Fire Station 17, if built today and designed to qualify as LEED™ certified, could have met the requirements with a small decrease in first cost.

In addition, significant direct economic benefits would have accrued to the City over the building's lifetime. As with all three buildings, the major savings that we estimated were due to worker productivity improvements, which are difficult to quantify (these are discussed later). For a building of such a small size, the productivity savings that could have been realized were very significant because the building is used 24 hours a day, 7 days a week.

> *In addition to significant economic savings associated with worker productivity increases, the use of salvaged materials, water efficient landscaping, and increased energy efficiency would have paid substantial dividends to the City over the long term.*

5.5.2 Key Findings about Selected Measures

This analysis provided insights about the measures that could have been selected to LEED™-certify this building if it were being designed today.

> *LEED™ certification could have been achieved by implementing a large number of measures that would have cost very little or actually reduced construction costs. The use of a single salvaged material (doors) had the largest effect on reducing both first cost and life cycle costs. Investments in energy efficiency and the use of native vegetation to alleviate the need for an irrigation system also had substantial life cycle cost benefits. Converting to a higher grade, green carpet also would have produced economic benefits over the life cycle that would more than offset the initial cost increase.*

5.5.3 Significance of Productivity Improvements

As noted above, the estimated benefits due to improved worker productivity dominated the life cycle cost impacts that we estimated for constructing Fire Station 17 to meet the LEED™ requirements. These results are consistent with the limited research available and conventional wisdom about the benefits of greening buildings.

> *Consistent with other studies, our results demonstrated that, because the largest costs associated with operating a building are the labor costs, productivity improvements can overwhelm other potential green building benefits.*

Although the actual effect on productivity that would be achieved is debatable, we believe that the 1% increase that we assumed is a conservative estimate. As noted earlier, the limited number of studies that have documented productivity effects have produced estimates from a few percent to 20% or more. We assumed in our analysis a small effect that would be related to the thorough commissioning of the building's systems and modifications that would improve indoor air quality and comfort.

> *It is important to note that even if no productivity increases were included, both the lowest first cost and lowest life cycle cost scenarios would have led to life cycle cost savings, and first cost savings, to the City. In both the lowest first cost and lowest life cycle cost cases, the savings would have been about $13,000.*

5.5.4 Energy Efficiency

The as-built Fire Station 17 performed well based on a simulation of its energy consumption. Its estimated consumption was about 20% less than the level estimated for a building built to the ASHRAE 90.1 Standard. Our analysis showed that the energy efficiency could have been improved even more to provide energy savings cost-effectively over many years. We estimated that a 30% improvement over the ASHRAE Standard level could have been achieved at an incremental first cost of about $1,200 or about 0.2% of the construction cost.

Our analysis of this building suggested that low cost ways to improve energy efficiency should be investigated, even for buildings that are designed to perform better than required by code. A life cycle cost analysis should be conducted to select efficiency measures that achieve savings that optimize life cycle cost given reasonable limits on the incremental first cost.

5.5.5 Building Commissioning

The effects of all the measures that we analyzed were predicated on their being installed correctly, meeting performance expectations, and being operated correctly. LEED™ establishes fundamental commissioning as a prerequisite for buildings that are rated using the LEED™ system. We carried this a step further in our analysis by assuming that Best Practice Commissioning would be implemented as a way to ensure that the predicted impacts were achieved. We attempted to incorporate the effects of full commissioning in our analysis by factoring in commissioning costs of 0.7% of construction costs, which is a little below the mid-range of typical estimates. Although we believe that this estimate was conservative, without a rigorous analysis of this building and its systems, it is uncertain whether the actual commissioning costs, in fact, would have been more or less than our estimate.

We believe, based on the extensive studies that have been conducted, that commissioning can have large benefits in terms of the proper performance of buildings, particularly green buildings. To receive full credit for the estimated effects of green measures installed in buildings, we believe that appropriate commissioning should occur even in relatively small buildings to ensure that key systems are installed and operating properly.

5.5.6 Societal and Non-quantified Impacts

Although our analysis indicated that the direct economic impacts of building Fire Station 17 to be LEED™-certified would have been economically beneficial to the City over its life cycle, benefits beyond those that were quantified for the City would have been provided. Air pollution reductions would have occurred that would have avoided negative effects on public health and global warming. Using recent estimates of the economic value of these benefits, we estimated that associated savings valued at more than $1,000 would have accrued to society at large. Second, benefits on the health of building occupants due to reduced indoor air pollutants and the benefits on fish and wildlife habitats would have occurred, but we were unable to estimate them in this study.

Because Fire Station 17 is relatively small, the estimable societal benefits of designing and operating the building as a green building would not be large. Our analysis suggested that an option such as purchasing green power could have societal benefits that outweighed the direct incremental budgetary costs incurred by the City. For those green building impacts that were difficult or impossible to quantify, we have identified them so that the reader can take them into *consideration. Despite the fact that the green building benefits that would fall on society at large would be relatively small in this case, the benefits aggregated across all of the City's buildings could be very large.*

5.5.7 Regional System Impacts

As with the other two buildings studied, we were unable to estimate the green building benefits of reduced energy, water, and water treatment demand on the regional systems required to provide these utilities. These benefits of building green would be distributed across all customers in the Portland region and would be larger than the direct benefits to the green building occupant.

Nevertheless, we believe that analyses of green buildings should estimate the impacts on the customers of those regional systems that are required to provide the energy, potable water, and water treatment that the customers require. In those cases where projections of marginal costs are available that take into account anticipated system cost increases, these projections should be used. In cases where no such projections are available, the possibility and likely magnitude of such impacts should be addressed.

6 OVERALL FINDINGS AND RECOMMENDATIONS

This section presents the key findings from our study and recommendations to the City based on these findings. It first presents findings based on the three buildings that we analyzed. It then presents our findings about the LEED™ system. The last subsection discusses our recommendations.

6.1 MAJOR FINDINGS

As noted in Section 1, our primary study objectives were the following:

1. Determine how "green" the three City buildings are as built.
2. Assess how each City building **could have been built** to qualify as "green" and determine the costs and benefits that would have occurred.

This study accomplished both objectives. First, it demonstrated that the LEED™ rating system could be used to asses how green each of these buildings was as built. For each building, we were able to apply the system successfully to provide a relative measure of how green each building was based on the LEED™ system.

Second, this study also showed that LEED™ can be used to provide insights into what types of measures and practices could have been implemented to qualify as a green building. We found that it was necessary to develop other criteria to use in conjunction with LEED™ to guide the selection of green options. By identifying key impact categories that would be affected by the different measures, we were able to estimate a broad range of costs and benefits associated with achieving LEED™ certification.

As this report was being prepared, the final Version 2 of LEED™ was published. We were not able to conduct a complete review of the differences between the final version and the version we used in this study. A preliminary review suggested, however, that there were few areas in which we assigned points that would not still qualify. The biggest change in the final version was that *only 26 points are now required for basic LEED™ certification.* Because we used 32 points as the minimum for certification, it is likely that the changes we proposed for each building would permit each to be qualified at nearly the Silver level, rather than the basic certification level.

The next subsection provides more details on the study's major findings.

6.2 FINDINGS BASED ON THE BUILDING ANALYSES

There were several findings that applied to all three buildings and these are discussed first. Next, findings that varied across the buildings are discussed. Finally, findings are presented about regulatory and policy issues that arose in our analysis that could impede the implementation of green building practices.

6.2.1 General Findings that Applied to All Buildings Studied

Recently Built City Buildings Are Unlikely to Qualify Automatically for LEED™ Certification

Table 6-1 shows that all three buildings fell short of the 32 points required for basic LEED™ certification.[1] The newest building, the 1900 Building, scored the most points. This was due primarily to measures that increased energy efficiency and improved indoor environmental quality. Generally, the LEED™ categories in which the biggest percentage gaps existed between the rating and points possible were Water Efficiency, Energy and Atmosphere, and Materials and Resources.

Table 6-1
LEED™ Ratings of Three City Buildings

Building	Total Points Scored As Built
1900 Building	20
East Precinct	12
Fire Station 17	17
Points Required = 32	

Given that the 1900 Building, which incorporated several innovative features, would have received only 60% of the required points, it seems unlikely that many new City buildings would qualify for LEED™ certification under standard practices.

New City Buildings Could Meet LEED™ for Little Added Cost

Despite the fact that these three buildings fell short of the point total required for certification, our analysis suggested that they could have been designed to meet the requirements for a relatively small (if any) increase in first cost. Table 6-2 shows the amount that the original construction cost would have increased if the buildings had been designed to meet LEED™ based on 1) the lowest first cost and 2) the lowest life cycle cost. These estimates probably overstate the actual costs if an integrated approach to meet the requirements were implemented beginning in the design and planning phase.

[1] As noted, the requirement has been reduced to 26 points in the final Version 2 of LEED™.

Table 6-2
Summary of Costs Required to Qualify as LEED™ Certified

Building	% Increase in First Cost	
	Lowest First Cost Approach	Lowest Life Cycle Cost Approach
1900 Building	0.3%	1%
East Precinct	1.3%	2.2%
Fire Station 17	-0.3%	0%

Building to LEED™ Could Reduce City Life Cycle Costs Significantly

For all three buildings, we estimated that significant direct economic benefits would have accrued to the City over each building's lifetime if they had been built to meet LEED™.[2] The savings ranged from 13% to 16% of the building's construction cost. The major savings were due to worker productivity improvements, which, however, are difficult to quantify accurately (these are discussed below). The areas in which savings would occur that can be estimated with the most certainty would be associated with measures to reduce water and energy consumption.

Table 6-3
Summary of Estimated Direct Life Cycle Cost Savings

Building	Change in Life Cycle Cost	(Life Cycle Savings)/(Construction Cost)
1900 Building	-$3,047,000	16%
East Precinct	-$516,000	14%
Fire Station 17	-$101,900	13%

Green Buildings Could Reduce Life Cycle Costs, Even With No Increases in Worker Productivity

As noted above, the estimated benefits due to improved worker productivity dominated the life cycle cost savings. This finding is consistent with the limited research available and conventional wisdom about the benefits of greening buildings. Although the actual effect on productivity that would be achieved is debatable, we believe that the increases we assumed were very conservative estimates. The studies that have documented productivity effects have produced estimates from a few percent to 20% or more. We assumed increases between 1% and 2% and attributed them to thorough commissioning of the building's systems and modifications that would improve indoor air quality and comfort.

Even *under the assumption that no productivity increases occurred*, our results showed that life cycle costs would decrease, primarily due to reductions in energy and potable water consumption and stormwater runoff. The use of salvaged materials also offered both first cost and life cycle

[2] As described in Section 2, we considered only the first 25 years of a building's lifetime in our analysis. Since these buildings are likely to last longer than 25 years, the eventual savings could be even larger.

cost savings opportunities. Table 6-4 shows that these estimated savings ranged from about $13,000 to over $170,000 over a 25-year period.

Table 6-4
Change in Life Cycle Cost (Neglecting Productivity Increases), Lowest Life Cycle Cost Alternative

Building	Change in Life Cycle Cost (no productivity benefits included)
1900 Building	-$173,000
East Precinct	-$36,000
Fire Station 17	-$13,100

Specific Measures Should Be Emphasized

The results provided useful insights about the most effective ways to meet LEED™ while decreasing direct life cycle costs to the City. Other than options that increase productivity, the primary opportunities to reduce life cycle costs are the following:

- investments in measures to improve energy efficiency,
- measures that reduce water consumption, and
- use of salvaged materials.

Low cost ways to improve energy efficiency should always be investigated, even for buildings that are designed to perform better than required by code. A life cycle cost analysis should be conducted to select efficiency measures that have the largest payoff. Ideally, all measures should be implemented that reduce life cycle costs; in reality, some cost-effective measures may have to be eliminated because of construction budget limits. It is important, however, to conduct a life cycle cost analysis initially to determine the tradeoffs between current investments and future savings and to establish appropriate requirements and targets.

Water consumption, both in the building and for landscaping, often can be reduced through measures that have little or no incremental costs. For example, native vegetation can eliminate the need for irrigation, thus reducing *both* first cost and future costs, as well as earning credits under LEED™.

The use of salvaged materials, another option that receives LEED™ green building credits, offers opportunities to reduce first cost and overall life cycle costs. Options with impacts as large as the one we proposed for the 1900 Building are probably not likely to be very common, but such opportunities may increase as salvaged material markets expand.

Our analysis also revealed that green roofs may be a desirable option from the City's life cycle cost perspective. The largest economic effect of green roofs comes from eliminating the requirement to replace conventional roof materials as often as every 12 years. Green roofs also provide life cycle benefits from reduced energy consumption and stormwater runoff, and provide difficult to quantify, but important, aesthetic and heat island benefits. In general, it would appear to be worthwhile to evaluate a green roof option on a case-by-case basis.

Other measures should be considered on a regular basis because of their other benefits. In particular, those measures that target improvements in indoor air quality, reduced use of toxic materials, and decreased negative environmental impacts should be emphasized, even though their direct life cycle economic impacts may be difficult to quantify.

An Integrated Systems Approach Can Be Beneficial

Our results show that using a system, such as LEED™, to broaden the objectives used in the design/build process can produce significant benefits that are not likely to occur under the conventional process. As stressed earlier, evaluating measures based on their life cycle costs can produce significant long-term benefits for the building owner and occupants. Explicitly recognizing societal impacts can lead to decisions that have significant payoffs beyond the building owners. In addition, an integrating framework such as LEED™ can promote the use of measures that have multiple benefits, such as green roofs.

Criteria Must Be Established for Selecting Measures under LEED™

These case studies illustrated the need to develop criteria to guide the selection of measures to comply with the requirements of LEED™. The minimum first cost criterion was applied successfully to a wide range of feasible options to select those that could have been packaged together to achieve LEED™ certification at lowest first cost. The minimum life cycle cost criterion also was applied successfully, leading to a slightly different combination of measures that would minimize the life cycle cost of meeting the LEED™ requirement. In keeping with the intent of the City's Green Building Initiative and the fundamental principles underlying the concept of green buildings, we believe that using the life cycle cost criterion is the preferred approach.

Building Commissioning

Our analyses assumed that the measures analyzed were installed and operated correctly. We believe, based on the extensive studies that have been conducted, that commissioning should be implemented to ensure the proper performance of buildings, particularly green buildings. To help ensure that our estimates of energy savings and other impacts were reliable, we carried the LEED™ Fundamental Commissioning prerequisite requirement further by assuming that Best Practice Commissioning would be implemented in all three buildings and Measurement and Verification would be implemented in two of the buildings.

A recent report indicates that full commissioning costs range from about 0.5% to 1.5% of total construction cost.[3] Representatives of Portland's Bureau of General Services indicated that the Bureau typically conducts a review process similar to commissioning for its new buildings. Because the City already conducts a similar process, we believe that it was reasonable to use 1% of construction costs as a conservative estimate of the commissioning costs.[4] Without a rigorous analysis of each building and its systems, it is uncertain what the actual commissioning costs would have been, but our estimates are realistic and probably relatively conservative.

Since no formal, systematic commissioning process has been established by the City, using an approach patterned after the commissioning process LEED™ defines could lead to a formalized and standardized approach for all new City buildings with potentially large benefits.

It is also important to note that we have not included any construction or corrective action savings resulting from commissioning in our estimates of benefits. Such economic benefits can be substantial. For example, a recent $100 million project benefited from commissioning even though it was implemented late in the process. For a cost of $120,000, commissioning produced value engineering and constructability savings of more than $5 million. In another case, a $40 million project incurred $6.5 million in costs to resolve comfort complaints, moisture and mildew problems, and material degradation that could have been avoided if commissioning had been implemented.[5] It would be useful to document what problems were encountered in the three City buildings studied here and others to determine how commissioning might have reduced direct project construction and operating costs.

Societal and Non-quantified Impacts

Our analyses provided estimates of some of the societal benefits of designing these buildings to meet the LEED™ requirements. In particular, we estimated the economic value associated with air quality impacts from reduced electricity generation. We were unable, however, to estimate the economic value of several other benefits, including improved health of building occupants and improved fish and wildlife habitat.

Table 6-5 presents the value of the life cycle cost impacts that we were able to estimate that would fall on society at large. These impacts are often referred to as externalities. Although these impacts are not extremely large compared with the cost of the buildings, they are very comparable to the direct life cycle economic benefits (excluding productivity effects) that would have accrued to the City if the buildings had been designed to meet LEED™.

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[3] Portland Energy Conservation, Inc. as summarized in *Environmental Building News*, Vol. 9, No. 2, February 2000, p. 13.

[4] The commissioning costs for Fire Station 17 were estimated to be a smaller percent because we did not include M&V and the building is relatively small and uncomplicated.

[5] *Environmental Building News*, Vol. 9, No. 2, February 2000.

Table 6-5
Change in Estimated Externalities,
Lowest Direct Life Cycle Cost Alternative

Building	Change in externalities
1900 Building	-$91,000
East Precinct	-$31,000
Fire Station 17	-$1,200
Note: Direct costs on building owner/occupants are not included.	

If the effect on societal impacts, rather than the direct impacts on the building owner/occupants, were used to select green building options, a different set of measures might have been chosen for each building. These choices would have produced larger societal and environmental benefits and might be in the interest of the City to pursue because its commitment to and reputation for implementing policies that benefit the environment.

The purchase of green power is one example where the benefits to society could be increased substantially, although the direct life cycle costs to the City would be higher. The recent decision by the City to purchase green power demonstrates the City's commitment to improving the environment and fulfilling its public role. By specifying purchases of green power for new buildings, the City could fulfill its commitment as well as receive credit under the LEED™ system.

Regional System Impacts

Although we were unable to take into account the cost effects that green buildings would have from reducing the demand for energy, water, and water treatment, such effects should be analyzed. These analyses require data on the marginal costs of added capacity for providing energy, water, and water treatment. When the marginal costs exceed average rates for these services, the benefits of green buildings to regional customers would exceed the savings to the building owners. In those cases where projections of marginal costs are available that take into account anticipated system cost increases, these projections should be used. In cases where no such projections are available, the possibility and likely magnitude of such impacts should be addressed.

6.2.2 Findings that Varied by Building

There were some variations in our findings across the three buildings studied. This sample of buildings was too small to identify any patterns adequately, but the following differences were worth noting:

1. *The LEED™ ratings varied significantly across the three buildings.* The rating varied by almost a factor of two between the East Precinct building and the 1900 Building. The

1900 Building received the highest rating, largely because of efforts made to increase its energy efficiency and incorporate an innovative floor air system. The LEED™ ratings of the buildings as built did not appear to be correlated with when a building was constructed (although these buildings were all relatively new) or its size.

2. *The cost of meeting the LEED™ requirements, as a percent of construction cost, varied across the buildings, but was a relatively small percent of construction cost in all cases.* The costs varied from a slight savings to a little over 2% of the construction cost. Fire Station 17 could have been designed to meet LEED™ for no cost increase or a slight decrease. An important factor that appeared to cause some of the difference was whether opportunities were identified to use salvaged materials that reduced construction costs.
3. *The life cycle cost savings (excluding productivity benefits) from building to be LEED™-certified varied considerably; they increased with building size, but less than the size increased.* The life cycle cost savings (without productivity benefits included) varied by a factor of about 13 between the smallest and largest building. The size varied by a factor of over 30. Thus, larger green buildings would be expected to have larger life cycle benefits, but not necessarily in proportion to their size.
4. *The life cycle productivity benefits from building to meet LEED™ varied substantially across these buildings—they increased with the number of employees and the intensity of building use, and depended on the baseline conditions used for comparison.* Potential productivity increases obviously depend on how many people work in a building and the occupancy schedule. Another factor that is at least as important in estimating the productivity benefits of green buildings, and is harder to determine, is what conditions should be assumed for the "non-green" building that is used for comparison purposes.

6.2.3 Regulatory and Policy Issues

There were several regulatory and policy issues identified that could affect the viability and effectiveness of efforts to implement green building practices in Portland. The key ones that emerged during this study are presented below.

1. *Recycling requirements for businesses are insufficient to obtain credit under LEED™*. The City requires businesses to recycle 50% of materials from buildings, but does not specify what must be recycled. LEED™ requires that a location be provided to separate, at a minimum, paper, glass, plastics, and metals for recycling. The City requirement can be met in some cases by recycling only one or two materials and is less stringent than the LEED™ requirement. Recycling of all four materials can probably be implemented, but for an additional cost. Based on the recycling centers provided in the buildings studied, we gave them credit for meeting this LEED™ prerequisite, although they did not technically meet the requirement. More extensive recycling requirements should be considered by the City.
2. *Codes do not allow the use of greywater.* Current local codes would prevent the use of greywater for toilet flushing, which is one of the measures considered in our study. We

were unable to investigate all the pros and cons of this technology, but because of its potential benefits it merits review for possible code changes.

3. *The stormwater rate structure may not provide appropriate economic incentives for green roofs.* The City's current stormwater rate structure assesses charges based on the area of impervious surfaces. A green roof reduces peak and average runoff, so it lessens the amount of stormwater runoff that must be handled, and acts, in effect, as a reduction in the impervious surface area. We are not aware of City stormwater rates that provide a credit for a green roof, but such rates would appear to be justified.
4. *Construction and demolition waste recycling appears to be inadequately tracked and enforced.* Although there are requirements for jobsite demolition and construction waste recycling, we found that the staff allocated to enforcing this requirement are very limited. There is also no requirement to submit a formal report on the recycling that actually occurred. Consequently, it is very difficult to determine how much recycling occurred on a project.

6.3 FINDINGS ON THE LEED™ SYSTEM

In the course of conducting this study, we applied the LEED™ system to a diverse group of buildings. This diversity allowed us to assess how well the system worked with a wide range of building sizes, a variety of building systems, and a range of possible building design options. The buildings we studied, however, did not vary substantially in terms of their function (two were basically office buildings and the third was a quasi-residential building), so we did not test the applicability of the system against a wide range of building types.

Based on these applications, we were able to make some observations about the system that we offer primarily to the City for use in its assessment of rating systems that could be implemented under the Green Building Initiative. We reiterate that the version of LEED™ that we used was the Version 2 issued in January for balloting and it does differ some from the final version adopted by the USGBC. We note also that the Reference Manual was unavailable when we did our study, so some of the information or clarifications that we needed to implement the system might be addressed in this document. In addition, it is important to stress that we were applying LEED™ retrospectively to buildings that had already been designed and sited; thus, the scope of green building options that we could consider in our study was necessarily limited by key decisions that had been made already.

6.3.1 Overall LEED™ Is an Effective Green Building Rating System

Overall, we found that *LEED™ provided a comprehensive tool for taking into account the major impacts that should be addressed in a green building assessment.* The five core categories in which green building options are organized appeared to cover all the key areas. The typology implied by the LEED™ categories appears to be consistent with other systems that address building impacts comprehensively.

We believe that the version we used is a notable improvement over Version 1. This is primarily because it is now more performance, and less prescriptive, oriented. Establishing requirements in terms of performance specifications generally allows for more ingenious solutions and promotes creativity, and both outcomes are desirable in promoting green buildings.

A very significant benefit of the structure of the LEED™ system is that it requires the designer, builder, and owner to consider impacts and options in several categories to achieve certification. The system requires the building to score points in almost every category so that emphasizing just one or two areas would be inadequate to achieve LEED™ certification. We found that using LEED™ required us to think very creatively about opportunities to score points. We believe that the system will motivate the building community to take a more holistic and systems-oriented perspective when designing, building, and operating buildings; this is a necessary step to make our buildings more environmentally sound.

6.3.2 Overall LEED™ Is Relatively Easy to Apply

The scorecard approach of LEED™ makes it relatively easy to use. It should be fairly straightforward for most architects and engineers to implement and for clients to integrate into their specifications.

The organization of options into categories also facilitates applying the system. The major LEED™ categories should be useful to designers who are considering different types of green building options. The categories help identify potential measures that can substitute for one another and should help the building community align the consideration of different options with the various types of expertise in the design team.

6.3.3 The LEED™ Prerequisites Establish Sound Practices

Generally, we believe that *the prerequisites established by LEED™ are consistent with good green building practices*. Establishing minimum erosion and sedimentation controls, minimum energy-efficiency requirements, minimum IAQ performance, and the other prerequisites is in keeping with the objectives of green building practices.

Establishing fundamental requirements for building commissioning is one of the most important prerequisites. This is especially true with green buildings, where what are now non-standard materials and practices may be required of the building community. Effective commissioning will be required to ensure that specified green materials were installed, and installed properly. It will require that systems work as advertised to ensure that energy savings, water savings, and indoor environmental quality improvements are achieved. Despite the fact that many clients and members of the building community are not knowledgeable about the need for and benefits of commissioning, we believe that there is adequate evidence that commissioning should be a key component of good green building practices. By establishing basic commissioning as a prerequisite, LEED™ will help promote this practice, demonstrate its benefits, and possibly help reduce its costs.

6.3.4 LEED™ Provides Little Information for Choosing Among Green Building Options

The only feedback that the LEED™ rating system provides to building decision-makers is which measures earn more credits toward certification. The analysis conducted in our study demonstrates how key criteria that are important to building designers, owners, and others can be used to choose between different green options. It is possible that the Reference Manual will provide some guidance when it's available, but for now we believe *that the LEED™ rating system by itself provides little guidance to the building community about how to select among green building options*.

6.3.5 LEED™ Provides Little Information about Life Cycle Stages Other Than the Design/Build Phase

LEED™ is fairly narrowly limited to being a tool that is applicable to the design/build process. We note that *LEED™ could be expanded to take a more comprehensive life cycle perspective*. Beyond some system controls, training, and measurement and verification options, LEED™ does not address the operations or salvage of buildings. A building's impacts extend over its lifetime and operation, maintenance, remodeling, and salvage activities can have significant environmental effects. Future efforts by the USGBC may provide guidance for these components of the life cycle, but the current LEED™ system provides few requirements that would improve these processes.

6.3.6 The Principles Underlying LEED™ Need to Be Clearly Articulated

Although the LEED™ system generally presents sound requirements, *the fundamental principles upon which LEED™ is based are not fully stated.* As an example of how basic principles could be applied, The Oregon Natural Step Network has been working to apply The Natural Step System Conditions to green buildings.[6] Clearly defining and stating the principles behind LEED™ would make the intent clearer to users and help identify what green building options would be preferable and why, and reveal the implications of making tradeoffs.

6.3.7 The Relationship between Some LEED™ Options Is Unclear

We found in applying LEED™ that *the format does not always clarify that some options are substitutes for or additions to others*. For example, Water Credit 1 has two options: reducing potable water by 50% (1 point) and reducing potable water by 100% (1 point). Clearly, the second option is an alternative to the first and it should provide 2 points in the rating. It would be erroneous to award the second option a single point as the scoring system suggests, so the user has to determine that the options are additive. The system correctly assigns points on other measures, such as the Energy Credit 2, where one option (such as 10% renewable energy for 2 points) is clearly a substitute for another option (such as 5% renewable energy for 1 point).

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[6] Oregon Natural Step Construction Industry Group. 2000. "Using The Natural Step as a Framework Toward the Construction and Operation of Fully Sustainable Buildings." Draft paper. Portland, Oregon.

6.3.8 Potential Conflict Areas Exist in LEED™

A few credits contained in LEED have been questioned for putting emphasis on one environmental factor while ignoring or downplaying another that might be more important. One example is Energy Credit 4 which awards a point for eliminating HCFCs from the building's HVAC system. Some critics have pointed out that, with current technology, HVAC equipment designed to use alternative refrigerants tends to be less energy-efficient and that the increased global warming effect of this lost efficiency is more harmful than the benefits of reduced ozone depletion. Another example is in Indoor Environmental Quality Credit 4. One LEED point is available for using composite wood products with no added formaldehyde resins because high levels of formaldehyde off-gassing can be detrimental to indoor air quality. However, the environmental impacts of alternatives currently available can be detrimental. For example, some "formaldehyde-free" alternatives substitute cyanates in the resin, increasing hazards to workers in the manufacturing process.[7]

6.3.9 Some Modifications to LEED™ May Be Needed

To use a rating system based on LEED™, some modifications may be necessary to apply it equitably. The rating conducted for the 1900 Building raised several issues that could justify fine-tuning the requirements. For example, despite the fact that this building was built on an existing structure, there was no straightforward way to award credits under LEED™. Also, this building utilized the HVAC equipment in an adjoining building to partially meet heating/cooling requirements, so it was possible to install a smaller new system. An argument could be made that an existing system was recycled, but there was no clear way to get credit in the existing LEED™ system for this. Despite these limitations, though, it was possible to identify ways to meet the LEED™ requirements. The issue this raises is a two-pronged policy question of how to award credit for unusual building features and how far to use a rating system to promote green building practices.

6.4 RECOMMENDATIONS

This subsection presents our recommendations for the City based on this study.

6.4.1 Develop a Green Building Rating System

The Green Building Initiative's deliverables include green buildings rating criteria and an evaluation tool. The existing LEED™ system appears to be a relatively easy to use tool to provide rating criteria for commercial buildings and a consistent framework for conducting ratings. This tool also has the advantage of being the most commonly used rating system in the U.S. For these reasons, we believe the City should develop a commercial green building rating tool based on LEED™. As noted above, however, there are areas in which we believe LEED™ could be improved and we recommend that the City take the following actions:

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[7] We note that the final LEED™ Version 2 at least partially alleviated this concern by eliminating language related to the use of phenol-formaldehyde.

1. Conduct a thorough review of other rating tools to determine if they offer other features that should be included in a tool for use in Portland.
2. Identify areas in which LEED™ should be modified to take into account conditions unique to this region and environment.
3. Provide a broad set of principles upon which the ratings should be based, such as those underlying The Natural Step.
4. Develop an evaluation tool to complement the rating system to assist the City and the building community in selecting among measures and documenting their probable impacts. This tool should identify first cost, direct life cycle cost, and other key impacts, such as societal costs, that would affect the selection of measures.
5. Develop tools for assessing the operating impacts of buildings and to provide guidance on decisions made during the operational life of buildings.

We note also that the existing version of LEED™ applies only to new commercial buildings. The City will have to develop another tool that could be applied to green residential buildings. The USGBC is in the early stages of developing a residential rating system and the City should stay informed about this process, while examining other possible systems.

6.4.2 Implement the Other Steps in the Green Building Initiative

The GBI proposed a number of other steps designed to accelerate the adoption of green building practices. We believe that our study has demonstrated the feasibility of building green buildings, at least to the LEED™ requirements, and has shown that using creative approaches can keep first cost increases to a minimum. This study has shown also that green buildings can provide significant long-term benefits to the City and society at-large.

Nevertheless, additional steps are needed to make green building practices the standard. Consequently, we recommend that the following steps, as detailed in the GBI, be instituted by the City:

1. Develop and adopt a green building policy and ordinances applying to City buildings and voluntary guidelines for the private sector.
2. Conduct demonstration projects to get "hands-on" experience implementing green options.
3. Provide technical resources and outreach.
4. Develop and implement incentives to encourage green building practices.

6.4.3 Put Green Building Practices in Place as Soon as Possible

Although formal, full-scale implementation of green building policies and procedures will have to await the steps described in Section 6.4.2, we believe that the City should begin benefiting from the design and construction of green buildings. This study should provide adequate information to guide the preliminary implementation of green building practices and we recommend the following to the City:

1. Begin including in specifications for new commercial buildings the types of measures that are included in LEED™. Contractors should be rewarded for proposing building features and siting practices that are consistent with LEED™. Contractors should be encouraged to identify opportunities that would minimize (or even lower) incremental first costs and should provide information about the life cycle costs and benefits of their designs.
2. Document experiences gained from green building projects. Information from new projects that incorporate green building practices should be collected and used in future projects to help design specifications that will promote improved practices. This information can become a technical resource useful to the building community as well as the City.

6.4.4 Research Commissioning and Productivity Benefits

Commissioning can be extremely important, but its costs can be significant. We used in this study typical values for commissioning costs from prior research. However, the City already implements some commissioning practices so the incremental costs of commissioning City buildings might be less than typical values. Current commissioning practices for the City need to be documented and the costs of implementing full commissioning need to be determined. The City could benefit from consistent, systematic commissioning practices. Also, the benefits of commissioning that do or could result from reduced change orders, corrective actions, remedial fixes, and occupant complaints and improved system operations and worker productivity need to be determined.

Numerous studies have shown that improved building design, materials, and operations can enhance worker productivity. Since labor costs are the largest component of costs associated with a building, even small changes in productivity can have major effects on the City's expenses. In this study, we used data from the literature to determine a likely range of productivity effects and we assumed conservatively that the effects of building to meet LEED™ requirements would be at the low end of the range. More research should be directed at defining the mechanisms in City buildings that would lead to productivity changes and assessing their magnitude.

Based on these observations, we recommend the following:

1. The City should investigate in detail the practices required by full commissioning and compare them with current City practices. The differences should be identified and consistent policies and practices should be defined for commissioning new City buildings on a regular basis.
2. The costs and benefits of commissioning should be researched in detail. There is an extensive body of literature on commissioning that could be reviewed and the findings that would be relevant to different types of City buildings could be documented. Based on the difference between current City practices and full commissioning requirements, the incremental costs of commissioning should be estimated. Data on existing City buildings and new buildings, as they are constructed and occupied, should be compiled and analyzed to determine what costs could have been avoided if commissioning had occurred.
3. A detailed study of potential productivity benefits should be conducted. The existing literature should be reviewed fully to determine what factors increase productivity and which ones would be associated with green buildings incorporating different features. Full labor costs (i.e., including relevant indirect costs and benefits) should be included in the estimates of productivity benefits.

4.

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