The Development of Models to Identify Relationships Between First Costs of Green Building Strategies and Technologies and Life Cycle Costs for Public Green Facilities

by

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ABSTRACT

Public buildings and other public facilities are essential for the functioning and quality of life in modern societies, but they also frequently have a significant negative impact on the natural environment. Public agencies, with their large portfolios of facilities, have faced considerable challenges in recent years in minimizing their negative environmental impacts and energy consumption and coping with shortages of financial capital to invest in new facilities and operate and maintain existing ones, while still meeting their mission goals. These range from the need to provide a quality workplace for their staff to providing a public service and long term benefits to the public. The concept of green building has emerged as a set of objectives and practices designed to reduce negative environment impacts and other challenges while enhancing the functionality of built facilities. However, the prevailing belief related to implementing green building is that incorporating Green Building Strategies and Technologies (GBSTs) increases the initial cost of constructing a facility while potentially reducing its life cycle costs. Thus, this research deals with optimizing the design of individual facilities to balance the initial cost investment for GBSTs versus their potential Life Cycle Cost (LCC) savings without the need to conduct detailed life cycle cost analysis during the early capital planning and budget phases in public sector projects. The purpose of this study is to develop an approach for modeling the general relationship between investments in initial costs versus savings in LCCs involved in implementing green building strategies in public capital projects.

To address the research question, this study developed multiple regression models to identify the relationships between GBSTs and their initial cost premiums, operating costs, and LCCs. The multiple regression models include dummy variables because this is a convenient way of applying a single regression equation to represent several nominal variables, which here consist of initial, operating, maintenance, and repair and replacement costs, and ordinal variables, which in this case are the GBST alternatives considered. These new regression models can be used to identify the relationship between GBST alternatives, initial cost premiums, annual operating costs and LCC in the earliest stage of a project, when public agencies are at the capital planning and budgeting stages of facility development, without necessarily needing to know the precise details of design and implementation for a particular building. In addition, this study also proposes and tests a method to generate all the necessary cost data based on building performance models and industry accepted standard cost data.

This statistical approach can easily be extended to accommodate additional GBSTs that were not included in this study to identify the relationship between their initial cost premium and their potential LCC saving at the earliest stage of facility development. In addition, this approach will be a useful tool for other institutional facility owners who manage large facility portfolios with significant annual facility investments and over time should help them minimize the environmental impacts caused by their facilities.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Built facilities are essential for the function and quality of life in modern society. Built facilities can be divided into two categories, including private and public facilities, based on the ownership of the facilities. Even though private facilities are a major portion of built facilities ($16.7 trillion or 76% of total built facilities), public facilities ($5.3 trillion) also are essential to provide quality workplaces, public service and long term benefits to the public to help national defense, foreign policy, scientific and medical research and other aims (NRC 2004; U.S. Census 2009; USGAO 2004; Vanegas 2004). Due to the significance of facilities in the United States, significant resources are required to not only build new facilities but also operate, maintain and demolish existing facilities. In 2009 the seasonally adjusted annual construction spending was about $1,053 billion composed of $770 billion in the private sector and $317 billion in the public sector (U.S. Census 2009). Because of significant annual spending in facilities, the construction industry is one of the America's most important industries with over 12% of the nation's Gross Domestic Product (GDP) and 7.69 million jobs (Russell et al. 2007; U.S. Census 2009; USDOL 2009).

Even though facilities are a fundamental element in modern society, they have many negative impacts on the natural environment. The impact on the environment over the life of facilities includes ozone layer depletion, global warming, acidification potential, smog, solid waste, ecosystem destruction, air and water pollution, and natural resource depletion, all of which are of increasing importance in our daily life (Ahn and Pearce 2007; Ding 2004; Ding 2005; DuBose et al. 2007; Kibert 2005; Langston and Ding 2001; OECD 2003; Shah 2006; Spence and Mulligan 1995; Vanegas 2004). Through exploring more statistical data related to environmental concerns in the built environment in the United States, activities including developing, maintaining and operating facilities in the built environment are responsible for (Fisk 2000; Fisk and Rosenfeld 1997; Kats 2003a; OECD 2003; Roodman and Lenssen 1995; USDOE 2008a):

- 17 % of fresh water withdrawals
- 25 % of wood harvest

- 40 % of energy consumed
- 72 % of electricity consumed
- 50 % of fossil fuels consumed
- $60 billion in medical expenses due to sick building syndrome
- 136 million tons of building-related construction and demolition debris
- 30 % - 50 % of total waste generation
- 25 % of Chlorofluorocarbon (CFC) emissions
- 39 % of all CO_2 emission.

These environmental concerns and problems related to facilities have been recognized not only in the construction industry but also public agencies including federal, state, local governments and their agencies, both because of their missions and goals and because of their large portfolio of facilities. As a result, public agencies face considerable challenges minimizing the negative impacts caused by their facilities while still meeting mission requirements within budget constraints. Given the recognition of environmental concerns and problems associated with facilities, the concept of sustainability, sustainable development, sustainable construction, environmental friendly building or green building have emerged and are considered as potential methods of minimizing those environmental concerns and problems and maximizing potential economic and social benefits while preserving or enhancing functionality of facilities. In this study, those potential methods are called “Green Building” even though the meaning of each term is a little different. While there are many definitions related to green building, this study quotes the green building definition as defined by the U.S. Environmental Protection Agency (USEPA) because the study eventually connects to the public sector. The USEPA defines green building as (USEPA 2008b):

> *“The practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort.”.*

Implementing green building brings many benefits which are clustered in three areas: environmental, economic, and social benefits. These benefits include (Ahn and Pearce 2007; Armstrong and Walker 2002; Ding 2004; Heerwagen 2000; Kibert 2008; Public Technology Inc. 1996; USDOE 2003a; USEPA 2009b; USGBC 2006; 2008) :

- Environmental benefits
    - Enhance and protect ecosystems and biodiversity
    - Improve air and water quality
    - Reduce solid waste
    - Conserve natural resources
    - Minimize global warming

- Economic benefits
    - Reduce operating costs
    - Enhance asset value and profits
    - Improve occupant productivity and satisfaction
    - Optimize life-cycle economic performance

- Social benefits
    - Improve air, thermal and acoustic environments
    - Enhance occupant comfort and health
    - Minimize strain on local infrastructure
    - Contribute to overall quality of life
    - Improve community and social benefits.

Even though implementing green building by incorporating Green Building Strategies and Technologies (GBSTs) into facilities has many benefits, there are several concerns associated with green building. One of the major concerns related to implementing green building is the increase of the first cost of a facility because of incorporating GBSTs, even though it is possible to reduce Life Cycle Costs (LCC) over the life of the facility (Ahn and

Pearce 2007; Ahn et al. 2009; Kats 2003b; Pearce 2008; Tendler 2003; USDHHS 2006; USGSA 2004). This prevailing belief of high first cost is the one of most serious barriers of implementing green building in the construction industry including the public sector (Ahn and Pearce 2007; OFEE 2003).

In addition to the first cost barrier, the capital programming process in public agencies also relates to implementation of green building. Capital programming combines long range planning and an integrated budget process as the basis for managing a portfolio of facilities to achieve performance goals with the lowest costs and least risk (OMB 2006). For instance, in the U.S. federal government, once public agencies identify a need for a facility, agencies start facility planning by reviewing and evaluating the agency's strategic plan, performance goals, current facility portfolio, facility options, and current market condition, risks, and time and cost issues (OMB 2006). After the facility project is programmed, decision makers in public agencies prioritize it compared to other facility projects by measuring return on the basis of outputs and outcomes. Highly ranked facility projects are submitted for funding in the budget year. Public funding agencies including the Office of Management and Budget (OMB) and Congress review and evaluate the cost, schedule, and performance goals of submitted facility projects to prioritize facility funding requests and justify the funding for the project (OMB 2006).

Public sector facility planning and budgeting is also discussed as a larger and more serious barrier to green building because facility decision makers in both public agencies and funding agencies often more seriously consider the first costs as significant decision making criteria compared to LCC (NRC 2004; OFEE 2003). Main causes of this trend are (NRC 2004):

- The annual budget process in the public sector does not encourage a life-cycle perspective at the highest levels of decision making because capital and operating expenditure are not considered concurrently and come from different sources
- The project first costs are easily identifiable and open to scrutiny by the Office of Management Budget (OMB), Congress, and others, but LCC are not.

In addition, even though public agencies conduct Life Cycle Cost Analysis (LCCA) to estimate LCC during their planning and budget decision processes, the submitted budget request with LCC is disaggregated into funding for design, construction, operations, and maintenance of the facility to conform to the budget structure and limited financial resources (NRC 2004). . Public agencies have argued that in practice, OMB and Congress continually put pressure on them to reduce first costs of new facility projects without regard to the possibility of LCC savings because of the shortage of budget (OFEE 2003). Furthermore, if first costs of facilities are in excess over the prescribed budget limits for specific project types, a proposed facility project, even though it may have a low LCC, has less of a chance to be prioritized highly at the early stage of government budget decision making, according to McNiece, the director of the facilities energy program at the United States Postal Service (USPS). In addition, requiring whole LCCA or LCC considerations in all facility projects at the budget decision making inevitably increases the percentage of design fees on the basis of normal design services or requires additional LCCA consulting fees (The Associated of Consulting Engineers 2004). This additional cost associated with LCCA and LCC considerations even further increases the first costs associated with a facility project, which ultimately puts additional strain on limited financial resources in public agencies.

With the current status of public green facility investments, it is going to be beneficial to optimize the design of individual facilities to balance first cost investment vs. LCC savings at the phase of early planning and budgeting of facilities when public agencies try to allocate limited financial resources across multiple different facilities. In addition, it is necessary that public policy makers making decisions about allocating of budgets across portfolios of facilities need a way to balance investments in first costs vs. savings in LCC across multiple facilities. To clarify these issues, it is necessary to identify relationships between first costs related to GBSTs and LCCs of public facilites. With better knowledge of these relationships, public agencies can take full advantage of implementing GBSTs in public facilities and eventually maximize return to the taxpayers.

1.2 Research Question and Hypothesis

Based on identified research needs for identifying relationships between first costs related to GBSTs and LCC for the development of green facilities, it is necessary to identify specific research questions and hypotheses of this research. This research focuses on identifying the relationship between first costs for GBSTs and LCC of public green facilities in the United States. Relationships for existing facilities and cost data are developed to recognize cost relationships related to GBSTs at the planning phase of facility development in the public sector.

With the specific research interest, the research question for this research is expressed as:

> *“How do GBSTs affect project first costs and LCC of public green facilities in the United States?”*

Based on the research question, the working hypothesis (Hw) for this research is expressed as:

> *“There is a relationship between first costs related to GBSTs and LCC in developing public green facilities in the United States.”*

1.3 Research Goals and Objectives

To solve current challenges and issues associated with investing and managing facilities in the public sector in the United States, it is necessary to conduct research to solve identified research needs of determining relationships between first costs related to GBSTs and LCC when developing public facilities. Thus, the goal of this research is to:

> *“Identify relationships between first costs related to GBSTs and LCC in developing public facilities in the United States.”*

These developed relationships may logically persuade facility decision makers in the public sector to make wise facility investments at the planning and budgeting phase of the facility development considering not only first costs but also LCC in a facility’s life. Through changing decision maker’s perceptions, this knowledge may also improve the possibility of additional budget allocation for green building in the public sector. In addition, the developed relationships can also help facility project participants to more effectively consider GBSTs options while developing new facilities. Specifically, this study will promote green building implementation in the public sector and decrease issues and challenges associated with developing and maintaining facilities.

The goal of this research is achieved by the following objectives:

- Identify and examine the issues and challenges related to public facilities and green building practices in the public sector
- Identify, investigate and examine the GBSTs in the public sector
- Identify and evaluate weaknesses in existing methodologies to identify the relationship between first cost related to GBSTs and LCC
- Develop relationship models that can use incomplete/imperfect data to identify the relationship between first costs related to GBSTs and carrying LCC for built facilities
- Demonstrate the effectiveness and usefulness of the developed relationships using a public sector case study.

1.4 Overview of Approach

This study involves quantitative and qualitative data. The methodology engaged in this research therefore, consists of a combination of strategies. Background study includes a thorough review of current practices and previous research in the areas of public facilities, public sector facility planning, sustainability, green building, energy modeling, and Life Cycle Cost Analysis (LCCA) and an in-depth literature review includes the current practices of identifying the relationship between first costs related to GBSTs and LCC, and facility planning and budgeting in the public sector.

To identify and develop a relationship framework, it is necessary to collect existing facility data from public agencies. Thus, this study has chosen the United States Postal Services (USPS) as a demonstration public agency because the USPS has many similar building types among its many facilities and constructs its facilities on the basis of predefined standard drawings and specifications. Data collection was divided into three parts. The first part used interviews to obtain data from the USPS professionals for identifying features of USPS facilities and operating patterns. The second part involved retrieving building data from USPS project archives to quantify the first costs based on various GBSTs. Thirdly, additional necessary information was also collected from construction publications such as “RS Means Cost Data” and construction professionals.

This research used interviews with USPS facility professionals to obtain data on current green building practices in the USPS, general office operation of the USPS facilities, and the features and patterns of occupancy in USPS facilities. In addition to obtaining data by interviews, this study also collected data related to drawings, specifications, and cost data from the USPS archives and a developer who built several facilities of the USPS. These data were used for identifying features of built facilities and conducting energy modeling to identify how GBSTs affected built facility’s annual energy consumption.

Since there were a number of gaps related to costs such as first costs, maintenance, repair and replacement costs, etc., this study also employed data from professional publications and construction professionals such as a professional estimator and a HVAC engineer. Based on the collected data, this study conducted a Life Cycle Cost Analysis (LCCA) to calculate LCC which entailed the total cost of ownership of the facility, including its cost of acquisition, operation, maintenance, conversion, and/or decommissioning (Bartlett and Howard 2000; Fuller 2002; 2008; Fuller and Petersen 1995; Kirk and Dell'Isola 1995; State of Alaska 1999) .

With these data, this study identified relationships between first costs associated with GBSTs and LCC using regression analysis to help facility decision makers who allocate limited financial resource across multiple projects in the public sector. The resulting relationship model can help to minimize potential challenges and issues related to green facility decision making at the planning and budgeting phase of capital programming in the public sector. This practice eventually helps to maximize the benefits of green building practices and return on taxpayer investment.

1.5 Dissertation Structure

The dissertation structure and chapter descriptions are as follows:

Chapter one: Introduction

This chapter provides background information for this study. It also explains why this research was undertaken and how this research is significant to the development of facilities in the public sector in United States. In addition, this chapter included problem statements, study hypothesis and objectives, an overview of the research approach, and a dissertation structure.

Chapter Two: Background Study

This chapter describes background study in the areas of public facilities, facility decision making process, environmental challenges and issues associated with built facilities and construction activities, the public sector capital project process, sustainability, green building, and drivers, barriers to incorporating GBSTs in facilities, and current practices for making smart decisions for green facilities in the public sector. The purpose of the background study is to establish familiarity with general knowledge of relevant research areas and to clarify definitions, stipulations, and scope of this research.

Chapter Three: Literature Review

As the purpose of literature review is to examine previous studies related to the research question, the literature review demonstrates a familiarity with this body of knowledge, shows the path of prior research and how current research is linked to this study, and clarifies the objectives of the study. Thus, this chapter investigates and examines different approaches to identify the relationship among building design features, first costs, and LCC.

Chapter Four: Research Method

This chapter describes overall research design and methodologies used in this study. First, this chapter identifies many GBSTs and systematically narrows down this larger set into a subset of specific GBSTs which can considerably affect the first cost and LCC. Second, this chapter describes how to calculate LCC using LCCA and the assumptions and limitations of LCCA. Third, this chapter explains the methods to generate costs including first, operation & maintenance, and repair and replacement costs to minimize the risks and issues related to reliability of facility data in the USPS because of many omissions, errors, duplications and contradictions in that data as maintained by the agency. Finally, this chapter describes a statistical approach to identify the relationship between first costs related to GBSTs and LCC savings. Due to significant analysis and process requirements, detailed explanation of procedures and results are described in Chapter 6 (Choosing green building strategies and technologies), Chapter 7 (Development of first, operating, maintenance, repair, and replacement costs), and Chapter 8 (Development of Life Cycle Cost).

Chapter Five: Choosing an Agency and Building Type

This chapter starts by describing the rationale for selecting the USPS as the public agency to be used as a basis for this study. In addition, this chapter describes the business of the USPS, the current status of its facilities, the green building movement in the USPS, and challenges and issues associated with incorporating GBSTs into its facilities. Finally, this chapter specifies the selection of a specific prototype post office design and its facility that will be used as a basis for the rest of the analysis.

Chapter Six: Choosing a Subset of GBSTs

This chapter describes the approach to choose a subset of GBSTs in this study. First, the chapter shows the systematic process of narrowing down to a subset of GBSTs and the outcomes of that filtering process. In addition, this chapter also defines each subset of GBSTs and its impact on first costs and LCC.

Chapter Seven: Developing Cost Estimates for Life Cycle Cost Analysis

This chapter develops necessary costs including first, operating & maintenance, and repair and replacement costs for scenarios. This chapter includes specific information on cost of the prototype, method for developing cost estimates for scenarios, and the outcomes of the method. In addition, this chapter also identifies weakness or limitation of the approach to estimating used for scenarios.

Chapter Eight: Development of Life Cycle Cost

This chapter describes the approach to develop LCC models for each scenario. In addition, this chapter also describes all detailed processes of conducting LCCA and the outcomes from LCCA. Finally, this chapter concludes with articulating limitations and weakness of the approach used in this study.

Chapter Nine: Findings and Discussion

This chapter describes research findings and outcomes from this study. In addition, this chapter also describes regression analysis and its outcome model to identify the relationship between first costs related to GBSTs and LCC. In addition, this chapter also describes limitations or weaknesses of the statistical approach founded in this study.

Chapter Ten: Conclusion and Future Research

Based on research findings and outcomes in Chapter 9, this chapter draws conclusions to answer the original research questions and describes the impacts to facility development in the public sector. In addition, this chapter identifies and describes further research opportunities related to this study.

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CHAPTER 2: BACKGROUND STUDY

2.1 Introduction

To identify relationships between first costs related to GBSTs and LCC in developing public facilities in the United States, it is crucial to examine previous studies to lay down the foundation of this study. Due to the significance and importance of background study, this research conducted background study of the following subjects:

- Public facilities in the United States
- Challenges and problems related to developing and managing public facilities
- Environmental challenges and issues associated with built facilities and construction activities
- The concepts of sustainability and green building
- Drivers for and barriers to incorporating GBSTs in built facilities
- Public sector capital project process
- Current practices of decision making for green facilities in the public sector.

2.2 Public Facilities

Public facilities including buildings, structures, and associated infrastructure are fundamental public resources and bases to provide public services to the public and to support other public activities (NRC 2008). Public facilities in this study only include buildings which support public agencies' missions and public services. Due to the magnitude and importance of public facilities, public agencies invest significant amounts of financial resources for developing new facilities and managing and operating existing ones. Thus, this section will describe the status of the construction industry, the status of public facilities, challenges and issues associated with public facilities, public sector project processes and the decision making processes related to public sector facilities.

2.2.1 Status of the Construction Industry and Public Facilities

Construction is one of America's most important industries because it is an economic and employment juggernaut, accounting for more than 12% of the nation's gross domestic product

(GDP), and providing the infrastructure and structures in which we live, work, and play (Russell et al. 2007; U.S. Census 2009). The construction industry total annual average employment in the United States was about 7.69 million in 883,000 construction establishments as of 2008 (USDOL 2009). In addition, the total value of facilities was estimated in the region of $22 trillion including both the private sector of $16.7 trillion and public sector of $5.3 trillion (U.S. Census 2002), and the seasonally adjusted annual construction spending was $1,053.7 billion (private construction: $770.4 billion and public construction $316.6 billion) as of December 2008 (U.S. Census 2009). For example, according to the U.S. Department of Defense (USDOD), one of the world's largest facility owners, the U.S. military facility services are collectively responsible for maintaining more than 343,867 facilities located on more than 5,300 sites, on over 32 million acres (USDOD 2007; USGAO 1999). Furthermore, the value of their 343,867 buildings was over $464 billion with 2.4 billion square feet (USDOD 2007). According to USDOD (2009), the federally budgeted military expenditure for military construction and family housing in 2008 are respectively about $21.2 billion and $2.2 billion.

Spending for public facilities can be divided into the three main expenditures of new facility construction, the operation and maintenance of existing facilities, and leasing facilities (Lufkin et al. 2005; NRC 2008; USGAO 1999). In the current accounting system, funding sources for new construction and major renovation, operation & maintenance (O&M), and leasing are different (NRC 2008). However, it is very difficult to clearly identify specific funding sources for O&M spending because O&M budgets come from various funding sources (USGAO 1999). Therefore, it is necessary to consider not only significant spending for new construction but also government and agency-wide expenditures for operation, maintenance, repair, and disposal of existing facilities and leasing payments (NRC 2004).

As shown by these statistics, the public sector including federal, state, and local governments and their agencies hold significant facility portfolios and spend significant amount of financial resources for new facilities, for the operation and maintenance of existing ones, and for facility leasing. The reason for the substantial spending on public facilities is to meet the public sector's missions and objectives including providing quality workplaces, public service, and long term benefits to the public (NRC 2004; USGAO 2004; Vanegas 2004). However, even though there is an enormous public budget allocation for public facilities, there are several challenges and issues associated with developing new facilities, leasing facilities, and managing existing ones.

2.2.2 Challenges and Issues Related to Public Facilities

Developing new public facilities and managing and operating existing ones are inevitably associated with many challenge and issues. These challenges and issues include:

- Many unneeded facilities
- Deterioration of facilities and deferred maintenance
- Lack of reliable and useful data on facilities
- Reliance on costly leasing
- Rapid increase of energy costs
- Shortage of financial capital.

The following sections describe these challenges and issues related to public facilities.

2.2.2.1 Many Unneeded Facilities

Despite significant changes in the size and mission needs of public agencies s in recent years, the portfolios of facilities in many ways still largely reflect the business model and technological environment of the 1950s (USDOE 2009b; USGAO 2002c; 2003a; 2007a). Due to the circumstances associated with personnel reductions and mission changes, the need for space including general-purpose office space has declined overall and necessitated a need for different kinds of spaces (USGAO 2002c; 2003a). In addition, technological advances have changed workplace needs, and many of the older buildings are not configured to accommodate new technologies (USGAO 2003a). For example, with respect to the USPS, the issue of excess and underutilized facilities needs to be part of the USPS’s efforts to operate more efficiently. Facility consolidations and closures are likely to be needed to align USPS’s portfolio more closely with its changing business model (USGAO 2002d). The magnitude of the challenges with underutilized or excess facilities puts the public agencies at significant risk for lost dollars and missed opportunities. First, underutilized or excess property is costly to maintain. For example, the U.S. Department of Defense (USDOD) estimates that it is spending $3-$4 billion each year maintaining facilities that are not needed (USGAO 2003a). Second, in addition to day-to-day operation costs, the public agencies are needlessly incurring unknown opportunity costs, because these facilities could be put to more cost-beneficial uses, exchanged for other needed facilities, or sold to generate revenue for public agencies (USGAO 2003a). Finally, continuing to hold unneeded facilities does not present a positive image of the public agency in local communities (USGAO 1998).

2.2.2.2 Deterioration of Facilities

Restoration, repair, and maintenance backlogs in public facilities are significant and sometimes reflect the public agency's ineffective stewardship over its valuable and historic portfolio of facilities (Basu 2009; NRC 1998; USGAO 2003a; 2007a). The backlogs in public facilities are alarming because of their magnitude and status. Current estimates show that tens of billions of dollars are needed to restore these facilities and make them fully functional (NRC 1998; USGAO 2008a). In addition, this problem has also accelerated in recent years due to the fact that much of the public facility portfolio was constructed over 50 years ago, and these facilities are reaching the end of their useful lives (Basu 2009; USGAO 2003a; 2007a). To solve this problem it is necessary to either modernize these facilities or to dispose of them. However, significant financial resources are necessary to modernize public facilities to provide safe, healthy, and productive environments for the American public, elected officials, public government employees, and foreign visitors who use them every day (USGAO 2002a; 2003a; 2007a). For example, USPS has a growing backlog of facility projects and has limited ability to finance the needed improvements in its facilities – an unfortunate situation, given the USPS's need to maintain its massive and growing nationwide facilities (USGAO 2002e). Problems associated with deteriorated facilities include increased operational costs, health and safety implications that are worrisome, and compromise of agency missions (USGAO 2003a). In addition, the ultimate cost of completing delayed repairs and alternations may escalate because of inflation (USGAO 2001b).

2.2.2.3 Lack of Reliable and Useful Data on Facilities

Compounding the challenges and problems with excess and deteriorated facilities is the lack of reliable and useful facility data that is needed for strategic decision making and facility management (USGAO 2002b; 2003a; 2007b). Even though many public agencies collect facility data related to space utilization, facility condition, historical significance, security, and age, the facility data is not useful for budgeting and strategic management purposes because of various weaknesses related to financial systems, fundamental recordkeeping and financial reporting, interoperability and incomplete documentation (USGAO 2003a). Due to the lack of reliable and useful data on facilities, the public agency's ability to accurately report a significant portion of its assets, liabilities, and costs is hampered; also the lack of data reduces the public agency's ability to accurately measure the full costs and financial performance of certain programs and effectively manage related operations. Finally the lack of data significantly impairs the public agency's ability to adequately safeguard certain significant facilities and properly record various transactions (USGAO 2001a; 2003a). In addition, the lack of reliable and useful data is related to excess and unneeded facilities, deterioration, and security concerns because decision makers do not have access to quality data on what facilities public agencies own; their value; whether the facilities are being used efficiently; and what overall costs are involved in preserving, protecting, and investing in them (USGAO 2003a). As a method of solving these problems, Executive Order 13423, Technical Guidance for Implementing the Five Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings, requires the U.S. Department of Energy (USDOE) and the National Renewable Energy Laboratory (NREL) to develop a "High Performance Building Database" to collect facility information related to the energy use, environmental performance, design process, finance, and other aspects of each project (USDOE 2009a). The "High Performance Building Database" requires federal public agencies to enter information about their facilities in a series of web-based data-entry tem plates (USDOE 2009a).

2.2.2.4 Reliance on Costly Leasing

One of challenges associated with public facilities is the heavy reliance on operating leases to meet long-term space needs (USGAO 1995; 2003a). In fiscal year 2006, federal agencies, especially General Service Administration (GSA) and USPS rely extensively leasing, occupying about 398 million square feet of leased building space domestically according to data from the Federal Real Property Council (FRPC) due to significant facility portfolios (USGAO 2006; 2008b). As a general rule, facility ownership options through construction or purchase are the least expensive ways to meet agencies' long-term space needs (USGAO 2003a; 2008b). For example, GSA undertook executive leases for the Federal Bureau of Investigation's (FBI) field offices in Chicago in 2006 and Tampa in 2005. These leases were estimated to cost $40 million and about $7 million more, respectively, than federal construction for similar facilities over 30 years (USGAO 2008b). However, the main reason of facility leasing is the limited funding for construction and ownership of facilities and budget score keeping rules (USGAO 2008b). Public agency scorekeeping rules required for ownership of facilities mandate recording the full first cost in the budget in the first year even though for operating leases, only the amount needed to cover yearly lease payments plus cancellation costs is required to be recorded in the annual budget (USGAO 2008b). This is a long-standing challenge in public agencies.

2.2.2.5 Rapid Increase of Energy Costs

The rapid increase of energy costs for operating the facility portfolio also affects the annual operation budget of public agencies which eventually causes a ripple effect on other spending because 40 percent of energy is consumed in the building sector. For example, the average electricity price per kilowatt-hour only increased 6.57 cents per kilowatt-hour in 1990 to 6.81 cents per kilowatt-hour in 2000. However, the average electricity dramatically increased from 7.29 cents per kilowatt-hour in 2001 to 9.82 cents per kilowatt-hour in 2008 (Figure 2.1) (EIA 2008). In addition, the price of coal also significantly increased from $24.68/ton in 2001 to $45.05/ton in 2008, the price of petroleum also dramatically rose from $24.86/barrel in 2001 to $95.94/barrel in 2008, and the price of residential natural gas also rose from $10.12/cf in 2001 to $12.09/cf in 2008 (Figure 2.2) (EIA 2008). The trend of energy prices related to key sources affects the annual operation budget for facilities in public agencies.

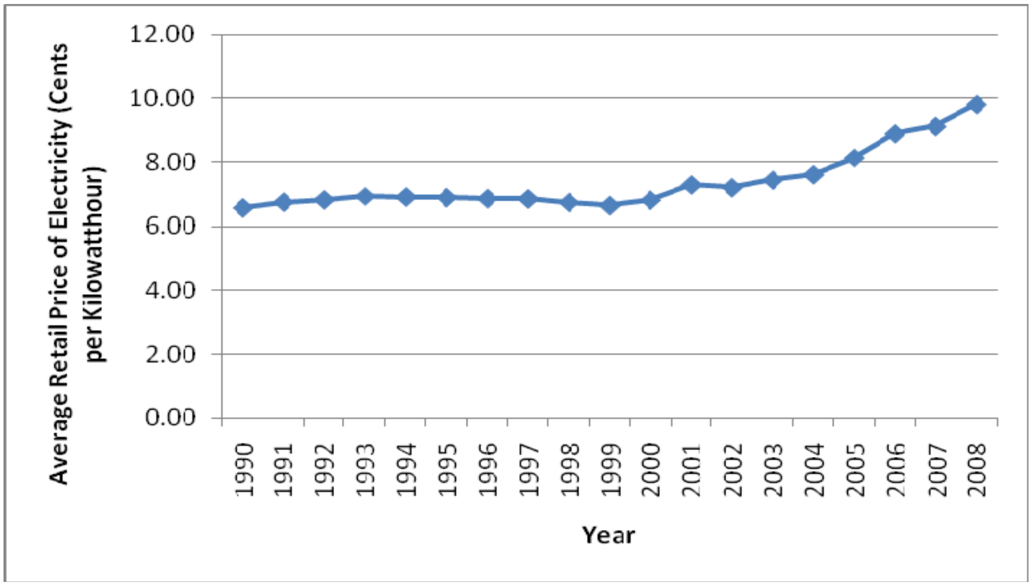

Figure 2.1 Average retail price of electricity (assembled based on Energy Information Administration data (EIA))

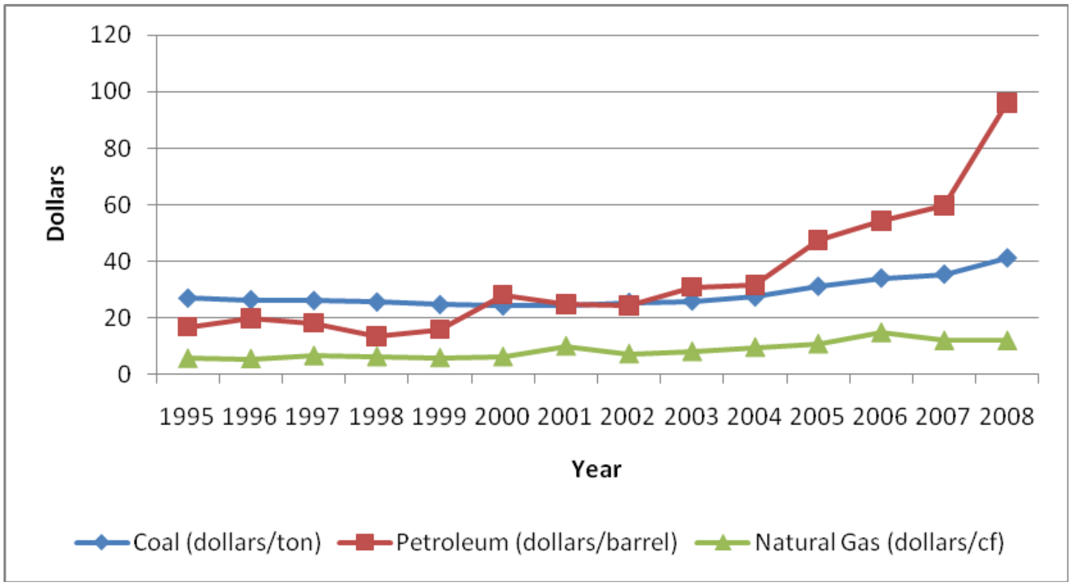

Figure 2.2 Average cost of coal, petroleum, and natural gas (assembled based on EIA data)

2.2.2.6 Shortage of Financial Capital

The shortage of financial capital not only for new construction and major renovations, but also for operation and maintenance, leads to many challenges and problems in the public sector. Due to the strong relation between challenges and problems associated with public facilities and the shortage of financial capital, for many public agencies, the current status of facilities has worsened. For example, the U.S. Department of the Interior has a deferred maintenance backlog that its Inspector General estimated in April 2002 to be on the order of $8 billion to $11 billion, and GSA is reported to have a $5.7 billion repair and maintenance backlog in its buildings (GAO 2003). In addition, insufficient funding to adequately address the existing federal facilities portfolio has accelerated facility deterioration and aging of facilities (NRC 2004).

Along with these many challenges and problems, public facilities are also major contributors to environmental issues and problems. The following section discusses environmental issues and problems associated with construction activities and built facilities.

2.3 Environmental Problems and Issues Related to the Construction Activities and Built Facilities

Since the construction industry and activities significantly influence the nation's economy, construction activities also have a major impact on physical development, government policies, community activities and welfare programs (Ding 2004). In addition, they are also connected with the broader issues of resource depletion, social services quality and equity, and environmental contamination or pollution (OECD 1994; Ridlhe and Lenormand 2009). For example, construction projects can improve social welfare and quality of life. However, from an environmental perspective, more construction projects mean more damage to the natural world and depletion of scarce renewable and non-renewable resources. In addition, construction activities and operation of built facilities, mainly consuming electricity, are also a main cause of global warming because producing electricity releases massive quantities of CO_2 which is a major contributor to global warming (CAA 2006; Heerwagen 2000; Lechner 2009). The following subsections discuss specific environmental issues related to construction activities over the life of built facilities.

2.3.1 Construction Activities, Built Facilities, and their Impacts on the Environment

Construction activities including the construction, operation, maintenance and demolition of facilities substantially impact our environment and people's health. According to Ding (2004), construction activities affect the environment throughout the life cycle of a project from first work both off and on-site through the operational period and to the final demolition when a building comes to the end of its life. In addition, Myers (2005) emphasized that the significant environmental and social impacts created by the construction industry and the construction industry is behind other sectors to manage these impacts. These environmental impacts caused by construction activities and built facilities have been identified and widely recognized (Augenbroe and Pearce 2009; Bartlett and Howard 2000; Cole 1998; Ding 2004; Fisk 2000; Fisk and Rosenfeld 1997; Hill and Browen 1997; Kibert 2005; 2008; OECD 2003; Weizsäcker et al. 1998). The major environmental impacts include global warming, climate change, ozone depletion, soil erosion, desertification, deforestation, eutrophication, acidification, loss of diversity, land pollution, water pollution, air pollution, and consumption of valuable resources such as fossil fuels, minerals, gravels, etc. (Augenbroe and Pearce 2009; CIOB 2004; Kibert 2005; 2008; SBTF&SCSA 2001; Shah 2006; Shu-Yang et al. 2004; TCPA 2006; Weizsäcker et al. 1998).

Levin (1997) indicated that facilities including buildings are very large contributors to environmental deterioration. Some researchers including Kein et al. (1999) have described the building industry as uncaring and profit motivated, and its participants as destroyers of the environment rather than its protectors. Uher (1999) stated that the construction industry has a significant irreversible impact on our environment across a broad spectrum of its activities during the off-site, on-site, and operation activities, which alter ecological integrity.

In addition, many scholars state that the construction industry is one of the largest industries to consume both renewable and non-renewable natural resources (Augenbroe and Pearce 2009; Curwell and Cooper 1998; Shah 2006; Spence and Mulligan 1995; Spiegel and Meadows 1999; Uher 1999). According to Roodman and Lenssen (1995), the building sector in the United States consumes 3 billion tons of raw materials, 40 percent of the world’s raw stones, gravel and sand, and 25 percent of the virgin wood per year (Table 2.1).

Table 2.1: Impact of modern buildings on people and the environment (Roodman and Lenssen 1995) (developed a table based on Roodman and Lenssen's data)

Problem	Building's Share of Problem	Effects
Use of Virgin Materials	40 percent of raw stone, gravel, and sand; comparable share of other processed materials such as steel	Landscape destruction, toxic run-off from mines and tailings, deforestation, air and water pollution from processing
Use of Virgin Wood	25 percent for construction	Deforestation, flooding, siltation, biological and cultural diversity losses
Use of Energy Resources	40 percent of total energy use	Local air pollution, acid rain, damming of rivers, nuclear waste, risk of global warming
Use of Water	16 percent of total water withdrawals	Water pollution, competes with agriculture and ecosystems for waster

In the United States, the U.S. Department of Energy's (USDOE) Office of Energy Efficiency and Renewable Energy has developed the Building Energy Data Book to provide a current, and accurate, and comprehensive set of building related data (including energy and electricity consumption) (USDOE 2008a). Based on the Building Energy Data Book, in 2008 the building sector consumed (USDOE 2008a):

- 38.9 percent of primary energy
- 74.2 percent of electricity
- 19 percent of natural gas
- 6 percent of petroleum
- 9 percent of total water uses (38.34 billion gallons per day).

In Europe, the heating and operating of buildings in Austria consumed about 40 percent of Austria's primary energy and the construction industry has about 50 percent of material turnover (about 100 million tons) induced by the society as a whole per year (Rohracher 2001). In Sweden, the building sector uses 155 TWh annually, representing 39 percent of the total energy use, and consumes 44 percent of the total amount of materials (Ecocycle Council 2000; Sterner 2002). From these statics, it is clear that the construction industry including the building sector extracts, processes, and consumes significant amounts of our natural resources. This extraction and consumption of natural resources causes irreversible changes to the natural environment of the countryside and coastal areas, both from an ecological and scenic point of view (Curwell and Cooper 1998; Langston and Ding 2001; Ofori 1998).

Construction activities, materials processes, and raw material extraction also contribute to air pollution in the atmosphere. According to Energy Information Administration (EIA) (2009), buildings are among the heaviest consumers of natural resources and account for a significant portion of the greenhouse gas emissions that affect global warming and eventually climate change. The average surface temperature caused by the result of the increasing concentration of greenhouse gases has increased by 0.6ºC during the twentieth century and is expected to rise further by 1.4ºC by 2100 (IPCC 2001; Shah 2006). The most important anthropogenic GHG is Carbon Dioxide (CO_2) (IPCC 2007). CO_2 annual emissions have grown between 1970 and 2004 by about 80 percent, from 21 to 38 gigatonnes (Gt), and they represent 77 percent of total GHG emissions. The major cause of GHG emissions is strongly related to construction activities (Shah 2006).

In the United States, built facilities including buildings account for 38 percent of all CO_2 emissions or 2,236 million metric tons as of 2006 (USDOE 2008a). In addition, CO_2 emissions for U.S. buildings have been steadily increasing since 1980 because of the growth of CO_2 emissions from electricity generation (USDOE 2008a). This trend is similar to growth of global GHG emissions. Figure 2.3 clearly shows the growth of CO_2 emissions by U.S. construction.

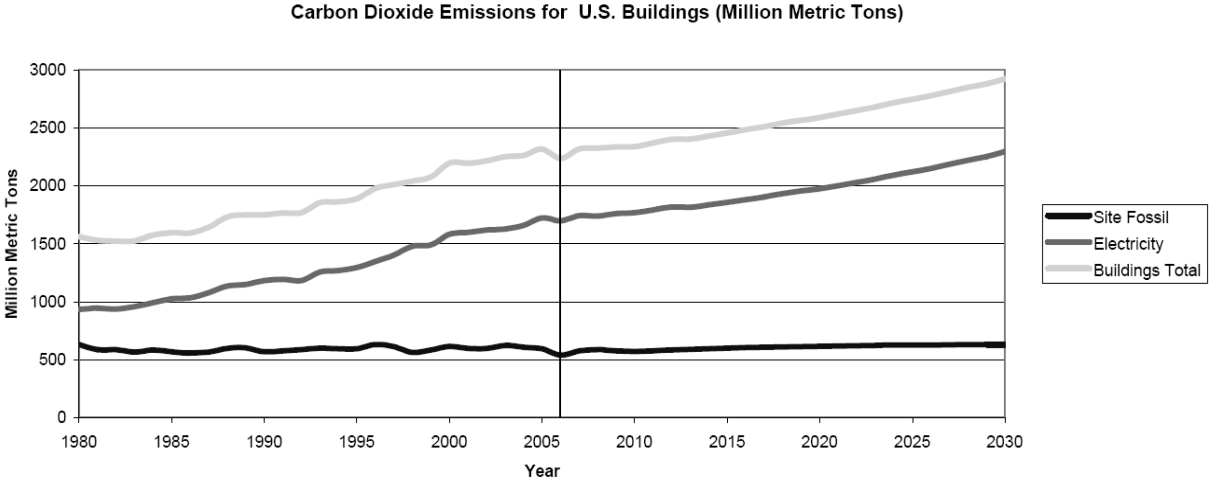

Figure 2.3 Growth of CO_2 emissions by U.S. construction (USDOE 2008a)

In addition, according to Levin (1997), in the U.S. construction is responsible for 40 percent of atmospheric emissions, 20 percent of water effluents and 13 percent of other releases. Dust and other emissions including some toxic substances such as nitrogen and sulphur oxides are summarized in Table 2.2 (Energy Information Administration 2008; USDOE 2008a). Those pollutants also affect global warming, smog, and human health. For example, a study at the University of Southern California tracked the health of almost 23,000 people from 260 Los Angeles neighborhoods and found the death toll from fine particles could be up to three times greater than previously thought (di Rado 2005).

Table 2.2 Emissions summary in the U.S. construction (Energy Information Administration 2008; USDOE 2008a) (thousand tons) (assembled based on EIA and DOE data)

	Buildings			**Bldgs % of**
	Wood/Site Fossil[1]	**Electricity**	**Total**	**U.S. Total**
SO2	561	6,964	7,525	55%
NOx	723	2,597	3,320	18%
CO	3,265	490	3,755	4%
VoCs	1,364	37	1,401	8%
PM-2.5	388	362	750	16%
PM-10	439	448	887	5%

In addition to those pollutants, harmful materials such as chlorofluorocarbons (CFCs) which are directly depleting the ozone layer are largely a result of building systems such as air conditioning, refrigeration plants, and fire suppression (Clough 1994). According to USDOE (2008), even though the emission rate of halocarbons was dramatically decreased by the phase out schedule of the Montreal Protocol, building activities have still emitted these harmful pollutants. Table 2.3 shows the estimated U.S. emission of Halocarbons from 1987 to 2001 (USDOE 2008a). Pollutants are released during the production and transportation of materials as well as from site activities and have caused serious threat to natural environment and human health (Ding 2004; Rohracher 2001; Spence and Mulligan 1995).

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[1] Site and wood burning (Energy Information Administration 2008)

Table 2.3 Estimated U.S. emissions of halocarbons, 1987-2001 (MMT CO_2 equivalent) (USDOE 2008a)

GAS	**1987**	**1990**	**1992**	**1995**	**1998**	**2000**	**2001**
Chlorofluorocarbons							
CFC-11	391	246	207	167	115	105	105
CFC-12	1166	1194	853	549	223	182	226
CFC-113	498	158	103	52	0	0	0
CFC-114	NA	46	29	16	1	NA	NA
CFC-115	NA	30	27	22	19	NA	NA
Bromofluorocarbons							
Halon-1211	NA	1	1	1	1	NA	NA
Halon-1301	NA	12	12	12	13	NA	NA
Hydrochlorofluorocarbons							
HCFC-22	116	136	135	123	128	134	137
HCFC-123	NA	0	0	0	0	NA	NA
HCFC-124	0	0	0	3	4	NA	NA
HCFC-141b	NA	0	0	14	19	4	4
HCFC-142b	NA	0	2	18	22	26	26
Hydrofluorocarbons							
HFC-23	48	36	36	28	41	31	22
HFC-125	NA	0	1	2	4	5	6
HFC-134a	NA	1	1	19	35	44	41
Total	**2219**	**1861**	**1408**	**1024**	**624**	**532**	**566**

Contaminants and pollutants are also discharged into the biosphere which causes serious land and water pollution, frequently due to on-site negligence resulting in toxic spillages which are then washed into aquatic systems and reservoirs (Ding 2004; Kein et al. 1999). Pollution of water can lead to disease which potentially can kill people and limit water supplies, hindering development (Shah 2006). For example, 5 liters of oil poured into a lake can spread to cover an area the size of two football fields and just one liter of solvent is enough to contaminate 100 million liters of drinking water (Shah 2006). In addition, Langford et al. (1999) indicated that about one third of the world's land is being degraded by construction, and pollutants are depleting environmentally quality and interfering with the environment's capacity to provide a naturally balanced ecosystem.

In addition to many pollutants to air, water and land, the construction industry inevitably produces a significant amount of waste from the production, transportation and use of materials (Ding 2004; Ofori 1998). In the United States, the construction industry has the following impacts (OECD 2003; USDOE 2008a):

- Two to seven tons of wastes (a rough average of 4 pounds of waste per square foot) are generated during the construction of a new single-family detached house
- 15 to 70 pounds of hazardous waste are generated during the construction of a single-family house. Hazardous wastes include paint, caulk, roofing cement, aerosols, solvents, adhesives, oils, and greases
- Each year, U.S. builders produce between 30 and 35 million tons of construction, renovation, and demolition (C&D) waste
- Annual C&D debris accounts for roughly 24 percent of the municipal solid waste stream.
- Wastes consist of wood (27 percent by weight) and other waste including cardboard and paper, drywall/plaster, insulation, siding, roofing, metal, concrete, asphalt, masonry, bricks, dirt, waterproofing materials, and landscaping material.

In other countries, construction activities contribute more than 50 percent in the United Kingdom and 20-30 percent in Australia to the overall landfill volume (Teo and Loosemore 2001). In the European Union, the construction industry contributes about 40-50 percent of wastes per year (Sterner 2002). Construction waste can be dramatically reduced because many construction and demolition materials have high potential for recovery or reuse (Sterner 2002). According to USDOE’s Buildings Energy Data book (2008a), as much as 95 percent of building-related construction waste is recyclable, and most materials are clean and unmixed. Thus, Sterner (2002) indicated that implementing a waste management plan during the planning and design stage can reduce waste on-site by 15 percent, with 43 percent less waste going to the landfill through recycling, and it delivers cost savings of up to 50 percent on waste handling.

In addition to generating waste, construction activities including building activities also irreversibly transform valuable land such as farmland and forests into physical assets such as buildings, roads, dams or other civil infrastructure (Spence and Mulligan 1995). About 7 percent of the world’s farmland was lost between 1980 and 1990 mainly due to construction activities (Langford et al. 1999). According to Ding (2004), arable land is also lost or destroyed through quarrying and mining the raw materials used in construction. In addition, construction contributes to the loss of forest through timber use in construction and in providing energy for manufacturing building materials (Ding 2004). For example, ten million hectares of ancient forests are being cleared and destroyed every year – the equivalent size of a soccer field every two seconds (Shah 2006; Uher 1999). By reducing and destroying agricultural land and farmland, construction affects biodiversity, crop production, photosynthesis which purifies the air, and global warming.

From the background study in the areas of environmental issues and problems associated with construction activities and built facilities, there is an identified need for the construction industry to consider the concept of sustainability or sustainable development to reduce or mitigate its impacts. All construction activities should be sustainable construction or green building.

2.4 Sustainability and Sustainable Construction

This section presents a general definition of sustainability and derives its definition with respect to the built environment, called green building in this study. In addition, this section also describes benefits of green building, the history of the green building movement in the United States, and challenges and issues with the green building movement.

2.4.1 Sustainability

The concept of 'sustainability or sustainable development' has gained popular momentum over the last twenty years even though it is not a new concept. The root of sustainability was the publication of "Silent Spring" written by Rachel Carson in the early 1960s describing a world affected by chemicals (Woodson 2002). Since then, the debate about sustainability was promoted by the Club of Rome's report "The Limits to Growth" during the 1970s (Harding 1998). This debate led to the First United Nations Conference on Human Environment held in Stockholm in 1972 where the international agreement on desired behavior and responsibilities to ensure environmental protection was discussed (Ding 2004). In addition, the term of 'sustainable development' was first expressed at the World Conservation Strategy in 1980 (Rees 1999) and the most widely accepted definition of 'sustainable development' was derived from the Brundtland Commission on Environment and Development (WCED 1987). This definition of sustainable development is:

> *"Development that meets the needs of present generations without compromising the ability of future generations to meet their needs and aspirations" (WCED 1987)*

The concept of sustainable development was further discussed at the Earth Summit held in Rio de Janeiro in 1992 by the United Nations Conference on Environment and Development (UNCED 1992). The primary goals of the Summit were to "come to an understanding of "development" that would support socio-economic development and prevent the continued deterioration of the environment, and to lay a foundation for a global partnership between developing and the more industrialized countries, based on mutual needs and common interests, that would ensure a healthy future for the planet" (UNCED 1992). In Rio, the governments of 108 countries adopted three major agreements aimed at changing the traditional approach to development:

- Agenda 21 – a comprehensive program for global action in all areas of sustainable development
- The Rio Declaration on Environment and Development – a series of principles defining the rights and responsibilities of States
- The Statement of Forest Principles – a series of principles to underline the sustainable management of forests worldwide (UNCED 1992).

From three these agreements, the implementation of Agenda 21 (sustainable development action plan) was a key role given by the United Nations (UN) because it helped governments to take steps to integrate the concept of sustainable development into all relevant policies and areas (Curwell and Deakin 2002; Langston and Ding 2001; UNCED 1992). The purpose of Agenda 21 is to balance environmental with economic development needs in this century (Postle 1998; UNCED 1992). Since then, many scholars have become fascinated with the concept of sustainable development in all fields. The following several paragraphs describe previous studies related to the concept of sustainable development.

Based on the most widely accepted definition of sustainable development derived from the Brundtland Commission on Environment and Development, the following four aspects are emphasized (Ding 2004; WCED 1987).

- Eliminate poverty and deprivation
- Conserve and enhance natural resources
- Encapsulate the concepts of economic growth, social, and cultural variations into a development
- Incorporate economic growth and ecological decision-making.

These four aspects clearly give apparent guidelines to achieve the goals of 'sustainable development'.

According to Pearce (2006), 'sustainable development' or 'sustainability' for short, appears to be a good thing and is all about making individual well-being rise over time. In addition, Pearce not only said that "sustainable' simply means lasting or perpetual", but also that "there hardly seems any point to developing if the effort to do so is not sustained." He also stated that "the definition of sustainable development is fairly straightforward even though how to achieve that goal is altogether more complex" (ibid). Because of this situation, Pearce said that "the term of sustainable development is defined differently by different people" (ibid).

According to Cooper (2002), sustainable development remains both an oxymoron and fiercely contested because 'sustainable' implies being capable of being maintained indefinitely within limits while 'development' implies the pursuit of continuous growth. Elkington (1998) has introduced the notion of 'triple bottom line' which is that equal weight should be given to the social, economic and environmental components of sustainable development. Richardson and Gatto (1995; 1992) read 'sustainable development' to mean that as long as development is sustained, economic growth will continue and environmental issues will be dealt with through technology. Correspondingly, Boughey (2000) defined 'sustainability' as "… economic activities which could continue without long-term damage to the natural environment or general human well-being". In addition, O'Connor (1994) stated that "sustainable development means forms of economic development which can proceed without damage to the natural environment, since those which would cause irreversible damage or exhaust non-renewable resources would ultimately undermine the conditions for production, and hence retard economic development”. Those definitions indicate that sustainable development should continue to grow economic wealth while minimizing negative social and environmental impacts caused by development.

Shan (2006) defined sustainable development as “a process and a framework for redefining social progress and redirecting our economies to enable all people to meet their basic needs and improve their quality of life, while ensuring that the natural systems, resources and diversity upon which they depend are maintained and enhanced, both for their benefit and for that of future generations.” In addition, Shan argues that sustainability drives us to seek continuous improvements, in a way that integrate economic, environmental and social objectives into both our daily personal and business decisions and future planning activities (Figure 2.4) (Shah 2006).

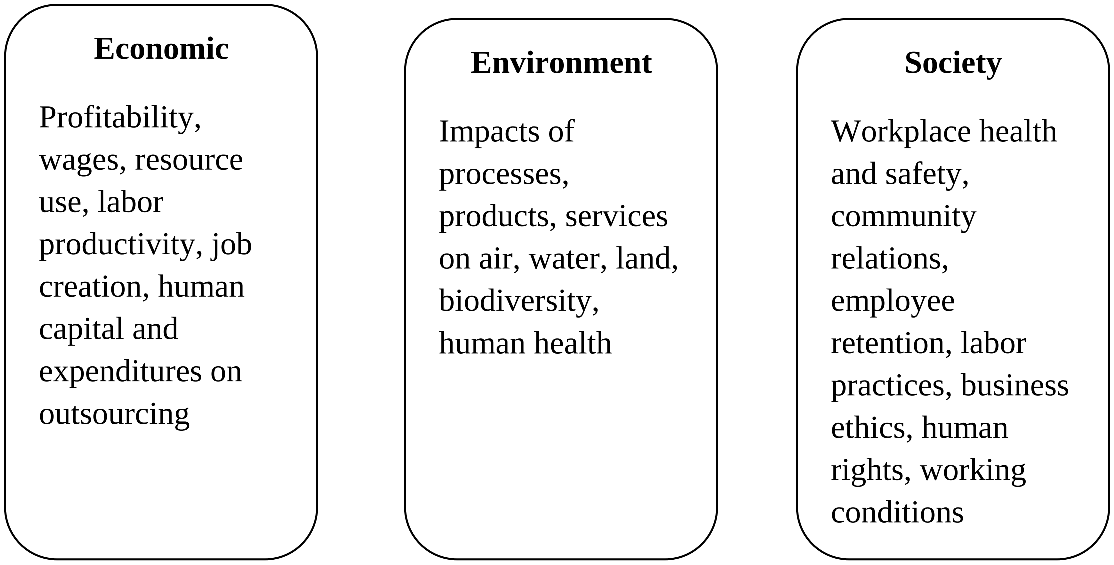

Figure 2.4: Typical issues and criteria comprising sustainable development (Shah 2006)

According to du Plessis (1999), sustainable development firstly attempted only to address the conflict between protecting the environment and natural resources, and answering the development needs of the human race. However, du Plessis stated that sustainable development would not be possible without certain social and economic changes such as a reduction in poverty levels and greater social equity, both between people and between nations. Spence and Mulligan (1995) indicated that “sustainable development in the poorest countries is to accelerate human development and to remove the gross inequities present in the world today while at the same time avoiding the depletion of the resources and biological systems of the planet to such an extent that future generations will be impoverished.” In addition, WCED in “Our Common Future” pointed out that the notion of physical sustainability implies a concern for social equity between generations which is a concern that must logically be extended to equity within each generation (WCED 1987). These definitions of sustainable development state that social components of sustainable development such as poverty and equity have to be managed and improved to achieve economic growth and to minimize environmental problems.

In addition to these definitions of sustainable development and sustainability mentioned above, there are over 200 different definitions in the published literature. From synthesizing the definitions of sustainability collected by Dr. Annie R. Pearce (SFI 2009), it is clear that the concept of sustainability consists of the examination of economic, environmental, and social aspects of a development. Table 2.4 classifies key components of sustainable development or sustainability into the three domains of environment, society and economy.

Table 2.4: Approaches for achieving sustainable goals in the three domains

Environmental	Social	Economic
• Protecting air, water, land ecosystems • Conserving natural resources (fossil fuels) • Preserving animal species and genetic diversity • Protecting biosphere • Using renewable natural resources • Minimizing waste production or disposal • Minimizing CO2 emission and other pollutants • Maintaining essential ecological processes and life support systems • Pursuing active recycling • Maintaining integrity of environment • Preventing global warming	• Improving quality of life for individuals, and society as a whole • Alleviating poverty • Achieving satisfaction of human needs • Incorporating cultural data into development • Optimizing social benefits • Improving health, comfort, and well-being • Having concern for inter-generational equity • Minimizing cultural disruption • Providing education services • Promoting harmony among human beings and between humanity and nature • Understanding the importance of social and cultural capital • Understanding multidisciplinary communities	• Improving economic growth • Reducing energy consumption and costs • Raising real income • Improving productivity • Lowering infrastructure costs • Decreasing environmental damage costs • Reducing water consumption and costs • Decreasing health costs • Decreasing absenteeism in organizations • Improving Return on Investments (ROI)

2.4.2 Green Building and Its Benefits

Green Building is considered as a way for the construction industry to achieve the objectives of sustainability. Implementing green building is identified as minimizing environmental problems and issues associated with built facilities and construction activities while maximizing the potential benefits to society (Ahn and Pearce 2007; Ahn et al. 2009; Ding 2004; Ding 2005; Heerwagen 2000; Hill and Browen 1997; Kibert 2005; Ofori et al. 2000; Pitney 1993).

As previously pointed out, the construction industry has a major role in both maintaining economic growth and quality of life and as a major contributor of negative impact on resources such as land, materials, energy and water. By implementing green building practices in the construction industry, it is possible to increase sustainability which can accomplish economic growth and quality of life and decrease environmental damage (Ball 2002; Graber and Dailey 2003; Miyataka 1996).

Before identifying Green Building Strategies and Technologies (GBSTs) in the construction industry, it is necessary to provide definition of green building. However, there are many definitions related to green building or sustainable construction because there is no consensus on what sustainable construction or green building really means (Ofori 1998). Therefore, the following Table 2.5 describes several different definitions of green building and sustainable construction relevant for public facilities to synthesize the components of green building in the construction industry (Table 2.5).

Table 2.5 Definition and components of green building

Sources	Definition	Components
(Kibert 1994; 2005; 2008)	"Healthy facilities designed and built in a resource efficient manner, using ecologically based principles."	• Reduce resource consumption • Reuse resources • Use recyclable resources • Protect nature • Eliminate toxics • Apply life-cycle costing • Focus on quality
(OFEE 2003)	"The practice of increasing the efficiency with which buildings and their sites use energy, water, and materials and reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal – the complete building life cycle."	• Adopt a holistic design approach • Reduce energy consumption • Reduce water consumption • Reduce material consumption • Improve indoor air quality
(USEPA 2009a)	"The practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction"	• Increase energy efficiency and renewable energy use • Improve water efficiency • Use environmentally preferable building materials and specifications • Reduce waste • Reduce toxics • Improve indoor air quality • Achieve smart growth and sustainable development
(USGBC 2007)	"The practice which reduces or eliminates the negative impact of buildings on the environment and on the building occupants"	• Improve sustainable site development • Improve water efficiency • Improve energy efficiency • Conserve materials and resources • Improve indoor environmental quality

By synthesizing the definition and components of green building from the previous definitions, green building can be defined as "integrated design and construction practice to improve sustainable site development, improve water and energy efficiency, increase renewable use, conserve materials and resources, reduce waste and toxics, and improve indoor environmental quality."

By implementing green building practices, including employing green building ratings for not only developing new buildings but also managing existing ones, it is possible to achieve three categories of benefits (Fisk 2000; Fisk and Rosenfeld 1997; Graber and Dailey 2003; Hawken et al. 1999; Heerwagen et al. 1997; Kats 2003a; b; 2006; Kibert 2005; 2008; Romm and Browning 1995; SBTF&SCSA 2001; Shu-Yang et al. 2004; USDOE 2003a; USEPA 2009b; USGBC 2009c; Yudelson 2008):

- **Environmental benefits**
  - Enhance and protect biodiversity and ecosystems
  - Improve air and water quality
  - Reduce waste streams
  - Conserve and restore natural resources
  - Minimize global warming

- **Economic benefits**
  - Reduce operating and maintenance costs
  - Create, expand, and shape markets for green product and services
  - Improve occupant productivity
  - Minimize occupant absenteeism
  - Optimize life-cycle economic performance
  - Improve the image of building
  - Reduce the civil infrastructure costs

- **Social benefits**
  - Enhance occupant comfort and health
  - Heighten aesthetic qualities
  - Minimize strain on local infrastructure
  - Improve overall quality of life

With the potential benefits associated with implementing green building, the following section examines the green building movement in the construction industry aiming to achieve these potential benefits.

2.4.3 Green Building Movement

This section describes the green building movement and green building rating systems in the United States. In addition, this section includes an overview of the green building movement in the public sector, and problems and issues associated with the green building movement in the public sector.

2.4.3.1 Green Building Movement in the United States

The green building movement is the response of the construction industry to the environmental and resource impacts of the built environment. As the definition and components of green building is synthesized in Section 2.4.2, the practice of green building is to improve sustainable site development, improve water and energy efficiency, increase renewable use, conserve materials and resources, reduce waste and toxics, and improve indoor environmental quality. To achieve these components of green building, the construction industry in the United States has implemented green building practices even though its philosophical roots are traceable to the late nineteenth century. Some notable dates of the green movement in the United States include (Barnett and Browning 1995; Kibert 2005; 2008; USGBC 2006; WCED 1987; Wison and Lear 1962):

- The publication of Rachel Carson’s landmark book Silent Spring in 1962
- The creation of the first Earth Day and the U.S. EPA in 1970
- The Arab-Israeli conflict and “oil-shocks” of the early 1970s
- The publication of “Our Common Future” in 1987
- The United Nations Conference on Sustainable Development in 1992
- The White House green project initiated in 1993
- The creation of the U.S. Green Building Council in 1993
- The Publication of “Environmental Resources Guide” by the AIA in 1994

- The publication of “A Primer on Sustainable Building” by the Rocky Mountain Institute in 1995
- The development of the USGBC’s LEED green building rating system in 1998
- The development of Green Globes in 2002

In addition to key dates related to green building movement, one of the significant motivations for green building was interest by or creation of key American organizations including the U.S. Green Building Council (USGBC), the U.S. Department of Energy, the U.S. Environmental Protection Agency, the National Association of Home Builders, the Department of Defense, and other public agencies and nonprofit organizations promoting green building practices (Kibert 2008). The creation of the USGBC and its development and implementation of the Leadership in Energy and Environmental Design (LEED) green building rating system were significant in the major green building movement in the United States (Ahn and Pearce 2007; Ahn et al. 2009). Due to various efforts for promoting the green building movement in the United States, the value of green building has significantly grown from a small, burgeoning market, of approximately 2 percent of both nonresidential and residential construction, valued at a total of $10 billion ($3 billion for nonresidential and $7 billion for nonresidential) to $36 - $49 billion in 2008 (McGraw Hill Construction 2008) . In addition, the 2009 Green Outlook report published by McGraw Hill Construction estimates that green building construction starts could triple over the next five years and reach $96 - $140 billion (McGraw Hill Construction 2008). From this prediction of the green building movement in the United States, it can be seen that green building is moving toward the general practice for developing new facilities and operating and maintaining existing ones.

2.4.3.2 Green Building Rating Systems

Since green building rating systems, including LEED (http://www.usgbc.org/) and Green Globes (http://www.greenglobes.com/), have been supportive to the green building momentum, this section describes the LEED green building rating systems because they are the most widely accepted green building rating systems in the construction industry. The first LEED green building rating system (LEED for New Construction - LEED NC) was developed by the USGBC in 1998. The LEED green building rating system identified criteria that specified not only whether a building was “green” but what specific “shade” of green it was (Kibert 2005; 2008). The LEED rating systems emphasize state-of-the art strategies for sustainable site development, water savings, energy efficiency, materials and resources, and indoor environmental quality (USGBC 2009a). Since the introduction of LEED NC, the green building movement has gained tremendous momentum. For example, the number of LEED registered projects has significantly grown from 41 projects with 7.38 million square feet in 2000 to 8962 projects with 1,958 million square feet in 2008 (Figure 2.5 & Figure 2.6) (Ahn et al. 2009). This fact also indicates that the green building movement has penetrated into the construction industry.

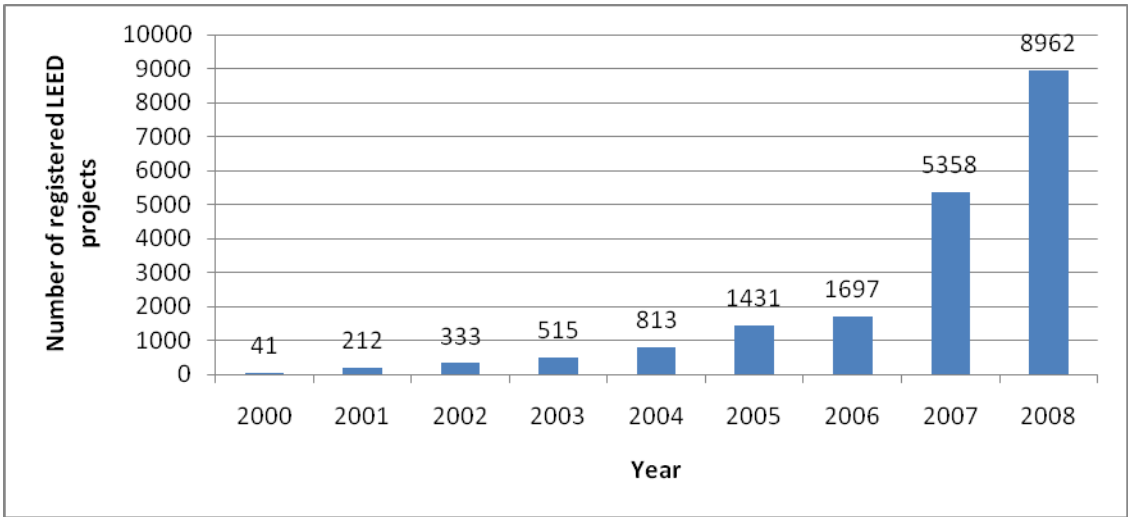

Figure 2.5 Number of LEED registered projects (assembled based on USGBC LEED data)

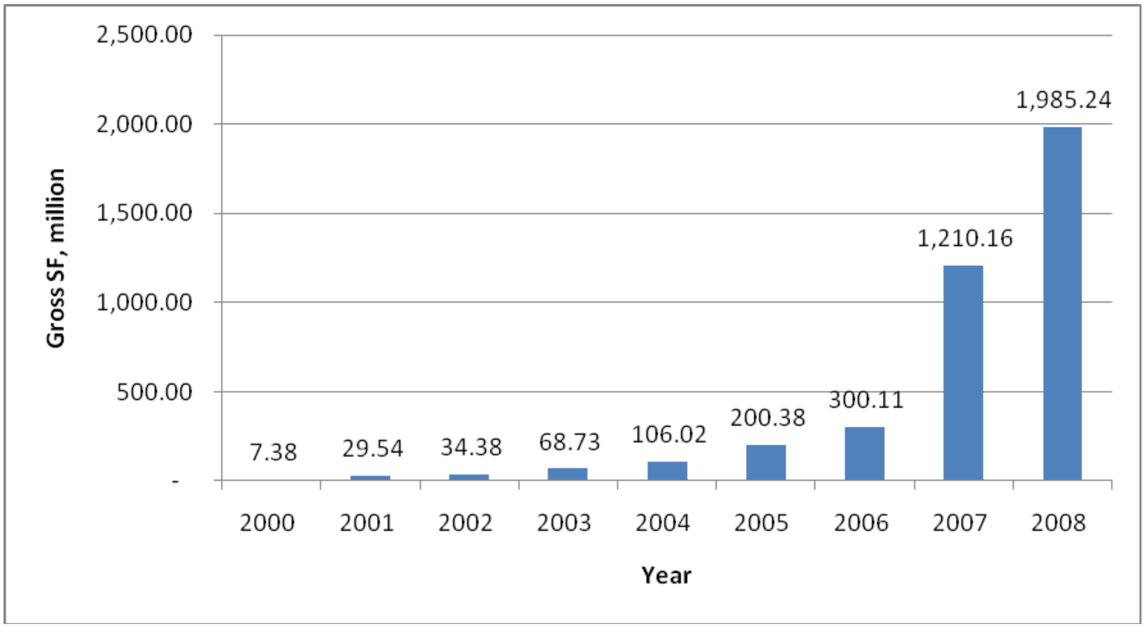

Figure 2.6 Gross square foot area of LEED registered projects (assembled based on USGBC LEED data)

The LEED green building rating systems include LEED for New Construction, Existing Buildings (Operation & Maintenance), Commercial Interiors, Core & Shell, Schools, Retail, Healthcare, Homes, and Neighborhood Development in Figure 2.7 (USGBC 2009g). The LEED rating systems apply for different building types and different phases of a building's life from design to operation (USGBC 2009f; g). However, this study primarily uses the LEED for New Construction which is specifically developed for new construction and major renovation.

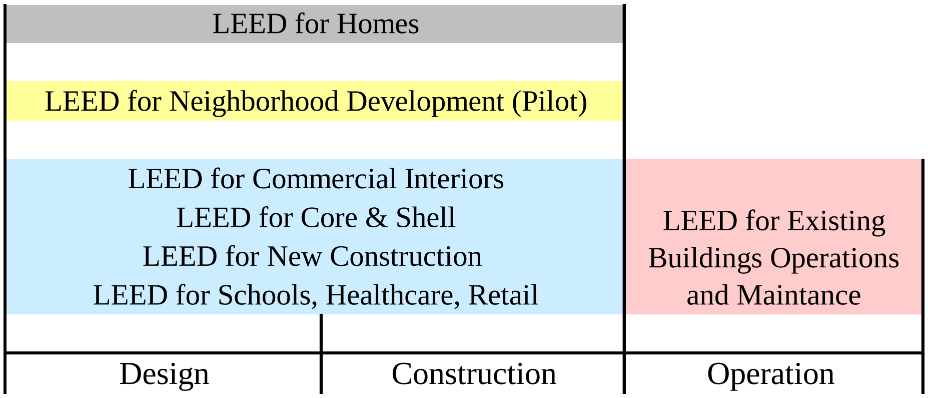

Figure 2.7 Various LEED green building rating systems (USGBC 2009g) (assembled based on USGBC LEED data)

The LEED NC has evolved from version 1.0, which was the first LEED rating system in 1998, to version 3.0 launched in 2009. The LEED version 3.0 has seven categories, eight prerequisites, 42 credits and 110 potential points including (USGBC 2008):

- Sustainable sites (26 possible points)
- Water efficiency (10 possible points)
- Energy and atmosphere (35 possible points)
- Materials and resources (14 possible points)
- Indoor environmental quality (15 possible points)
- Innovation in design (6 points)
- Regional priority (4 points).

The individual credits, prerequisites, and points are listed in Appendix A. In addition to LEED, Green Globes is also a green building rating system used in Canada and the United States. The objectives of the Green Globes rating system are to encourage building practices which (ECD Energy and Environment Canada 2004):

- Consume fewer fossil fuels
- Reduce Green House Gas (GHG) emissions
- Conserve water
- Reduce other forms of pollution
- Minimize impact on the land surrounding the building
- Offer a better working environment for occupants (ECD Energy and Environment Canada 2004).

The detailed points are also listed in Appendix B. Establishing and implementing green building rating systems motivate stakeholders in the construction industry to move forward with green building because these rating systems help to identify possible GBSTs.

2.4.4 Green Building Movement in the Public Sector

Public agencies are leading the green building movement in order to maximize benefits of implementing green building and minimize negative environmental impacts associated with construction activities and built facilities (DuBose et al. 2007; Kibert 2005; 2008; Pearce et al. 2007; USDOE 2001; USGBC 2003). To achieve the benefits of green building, many public agencies have adopted green building rating systems, especially the LEED rating systems developed by U.S. Green Building Council, as standard green building practice even though there are other competing green building rating systems such as Green Globes and the Building Research Establishment Environmental Assessment Method (BREEAM) (Kibert 2005; 2008; USGBC 2009b). Furthermore, public agencies also embrace green building guidelines including New York’s high performance building guidelines(City of New York 1999), (Kobet et al. 1999), and others (Kibert 2005; 2008; USGBC 2009b).

In addition to employing the green building rating systems in the public sector, many public governments have attempted to boost the use of green building practices by legislation, executive orders, resolutions, ordinances, policies, and incentives (USGBC 2009h). For example, the U.S. federal government, which is the single largest facility owner with about 500,000 facilities worldwide, has been instructed by many federal policies to implement certain aspects of green building in its own facilities, including energy and water efficiency, use of recycled content, bio-based or other environmentally preferable building products, and waste recycling, including demolition debris (NRC 2004; 2008; OFEE 2003; USDOE 2003a). Table 2.6 and Table 2.7 describe U.S. federal government’s executive orders and legislation currently in place as of the time of this writing. In addition, Appendix C describes many different types of policies in public agencies.

Table 2.6 U.S. federal government’s policies (Executive Orders) for green building

EO Number (Year)	Name of Executive Order	Content
Executive Order 13514 (2009)	Federal Readership in Environmental, Energy , and Economic Performance	The order builds on and expands the energy reduction and environmental requirements of EO 13423 by making reductions of greenhouse gas emissions a priority of the federal government, and by requiring agencies to develop sustainability plans focused on cost-effective projects and programs. It also requires agencies to meet a number of energy, water, and waste reduction targets, including 30% reduction in vehicle fleet petroleum use by 2020; 26% improvement in water efficiency by 2020; 50% recycling and waste diversion by 2015; 95% of all applicable contracts will meet sustainability requirement; implementation of the stormwater provisions of the Energy Independence and Security Act (EISA) of 2007; and development of guidance for sustainable Federal building locations.
Executive Order 13423 (2007)	Strengthening Federal Environmental, Energy and Transportation Management	The order sets goals in the areas of energy efficiency, acquisition, renewable energy, toxics reductions, recycling, renewable energy, sustainable buildings, electronics stewardship, fleets, and water conservation. It requires federal agencies to improve energy efficiency, reduce greenhouse gas emissions, and reduce water consumption intensity. It also requires organizations to ensure that new construction and major renovation of federal facilities comply with the Guiding Principles for Federal Leadership in High Performance and Sustainable Building and that 15% of the existing building inventory by the end of fiscal year 2015 incorporate the sustainable practices in the Green Principles.

Table 2.7 U.S. federal government's legislative policies for green building

Law (Year)	Name of Federal Law	Content
EISA 2007	Energy Independence and Security Act of 2007	The EISA of 2007 is the energy legislation to save energy in areas including the automotive, fuels production, agribusiness, appliance manufacturing, and building design and construction sectors. Vehicle fuel economy must improve substantially by 2020 to meet prescribed standards. Biofuel production must increase nine fold by 2022 to meet the renewable fuel standard for gasoline. Numerous electric appliances and products are subject to new minimum efficiency standards. Federal agencies must reduce their energy consumption by 30 percent within eight years, and new commercial buildings are targeted to produce as much energy as they consume by 2030.
EPACT 2005	Energy Policy Act of 2005	The EPACT of 2005 contains legislation to change energy issues in the United States. The major provisions affecting Federal facilities include: • Energy management goals • Energy use measurement and accounting • Procurement of energy efficient products • Energy efficient products in federal categories • Federal building performance standards • Enhancing efficiency in management of federal lands • Federal purchase requirements (renewable) • Use of photovoltaic energy in public buildings • Installation of photovoltaic systems • Study of energy efficiency standards • Renewable energy on federal land

In addition to federal Executive Orders and legislative orders, there were 77 cities, 24 counties, 19 towns, 28 states, 12 federal agencies, and 12 public school jurisdictions, and 36 public institutions of higher education across the United States as of 2008 which actively support the use of GBSTs for facilities (USGBC 2009h). Furthermore, governments at all levels also provide various incentives to give support to implementing green building by private sector organizations. The incentives include (USGBC 2009h):

- Tax abatement
- Density bonus

- Grants
- Expedited permitting
- Permit/zone fee reduction
- Loans
- Fee rebates
- Tax credits
- Technical assistance.

With various incentives for implementing green building from governments, green building has gained strong momentum for implementing green building in the construction industry. Even though there are many benefits and incentives from governments to implementing green building, there are problems and issues with green building movement.

2.4.5 Problems and Issues with Green Building Movement in the Public Sector

Public agencies can benefit by implementing green building while developing their facilities. However, there are barriers and challenges to the greater implementation of green building practices across public agencies beyond the facilities-related challenges already discussed in Section 2.2. The Office of the Federal Environmental Executive organized these green building barriers for the public sector into four major categories (OFEE 2003):

1) Financial and budgetary structure challenges
2) Lack of clear public policy
3) Education needs
4) Limited research for GBSTs.

Other studies also found that both the perception and the actuality of high first costs for green building are significant for implementing green building (Ahn and Pearce 2007; Ahn et al. 2009; Kats 2003a; b; 2006; Langston and Ding 2003; Pearce 2008; Suttell 2006; USGSA 2004; Wilsor 1999). The following subsections describe these challenges and issues of green building movement in the public sector in greater detail.

2.4.5.1 First Cost Issues and Financial and Budgetary Structure

The most widely discussed barrier to implementing green building is that green building is perceived to increase first costs compared to conventional buildings, even though studies have demonstrated that green building may only slightly increase the first costs or may actually reduce first cost. In one study, the average premium from 33 green buildings across the U.S. compared to conventional designs for those same buildings were only slightly higher (about 2%, or $3 - $5/ft^2) because of increased architectural and engineering design time, modeling costs and time necessary to integrate GBSTs into projects (Kats 2003b). Other studies have found a range of results ranging from an average of less than 1% cost premium for projects at the lowest level of LEED certification to 7% or more for buildings at the higher levels of certification (Hawken et al. 1999; Kats 2003b; 2006; USDHHS 2006; USGBC 2003).

Despite these quantitative studies, there is still a common perception among project managers, field staff, contracting officers, and others that green buildings cost significantly more than their traditional counterparts (Ahn and Pearce 2007; Ahn et al. 2009; OFEE 2003). A recent study of 87 leading construction companies in the United States asked what level of cost premium respondents believed green buildings would carry compared to conventional construction (Ahn and Pearce 2007). 61 percent of respondents believed the cost premium would be greater than 10 percent. Less than one percent of the respondents indicated a belief that green building costs the same or less than conventional construction. These respondents demonstrated that the construction industry still believes that green building costs significantly more than conventional construction, despite the growing body of evidence to the contrary. This cost perception of green building may influence the implementation of green building in the public sector even though many public policies and legislation have provided motivation to implement green building for developing new facilities and managing and operating existing ones.

A larger and more serious barrier to green building is the planning and budgetary structure of facility development in public agencies. Decision makers in both public agencies and funding organizations seriously consider first costs as a decision making criteria rather than LCC, which considers costs incurred from a project’s initiation through the whole life cycle to project decommissioning. This is the case even though public agencies have issued policies and directives to recommend the use of LCCA (NRC 2004; OFEE 2003). Main causes of this trend are (NRC 2004):

- The annual budget process in the public sector does not encourage a life-cycle perspective at the highest levels of decision making because capital and operating expenditure are not considered concurrently
- The project first costs are easily identifiable and open to scrutiny by the Office of Management Budget (OMB), Congress, and others, but LCC are not.

In addition, even though public agencies conduct Life Cycle Cost Analysis (LCCA) during their budget decision process, the submitted budget request with LCCA is disaggregated into funding for design, construction, operations, and maintenance of the facility to conform to the budget structure (NRC 2004). Public agencies argue that in practice, OMB and Congress continually put pressure on them to reduce first costs of new facility projects without regard to life cycle cost savings (OFEE 2003). Furthermore, if first costs of a facility are in excess over the prescribed budget limits for specific project types, a proposed facility project with low LCC has less of a chance to be prioritized highly at the early stage of public budget decision making, according to McNiece, the director of the facilities energy program at the United States Postal Service (USPS). In addition, based on the conversation with McNiece, a facility project with both high first costs and low LCC also requires additional documentation and requirements to pursue the facility project. This circumstance and the shortage of budget make facility decision makers consider first costs more seriously than potential LCC savings.

Based on these considerations to which public agencies are subject, proposed facility projects with high first costs due to incorporating GBSTs are less likely to receive funding than their conventional counterparts even though those proposed green facilities may save LCC (Pearce 2008). The facility investment decision is made at the detail analysis in the public agency planning and budgeting decision process shown in Figure 2.8.

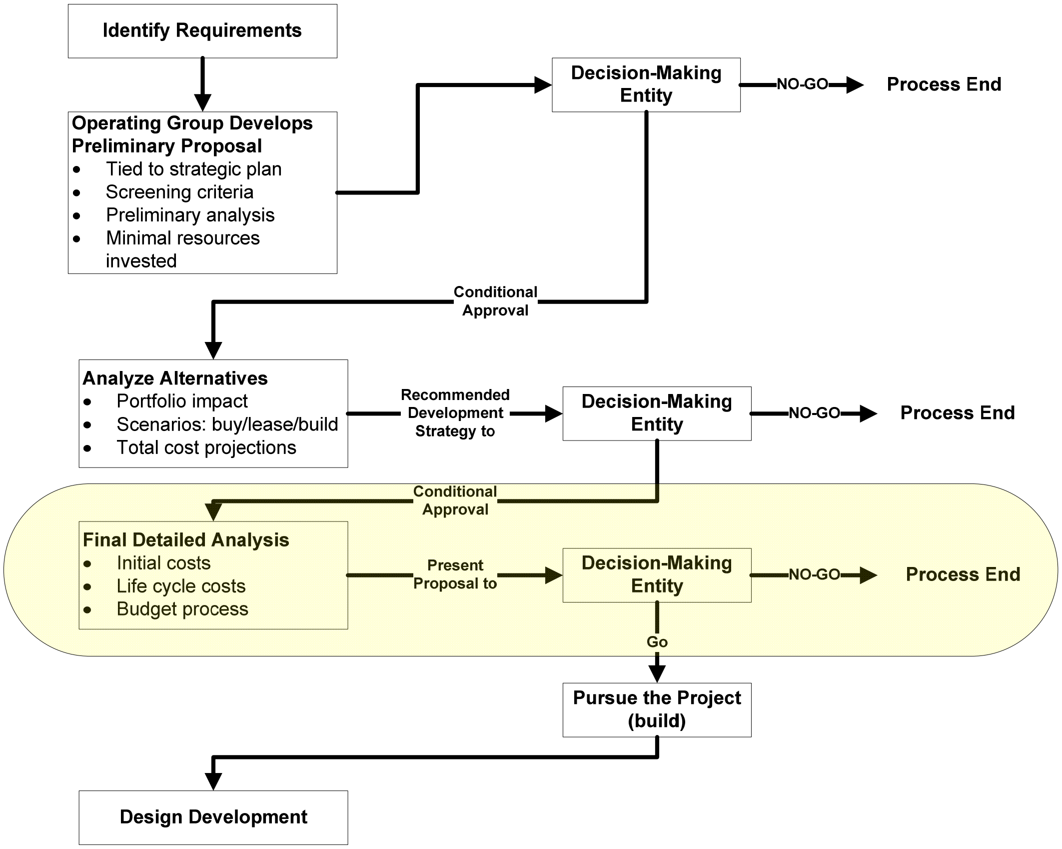

Figure 2.8 Public agency's planning and budget decision making process (USDOE 2003b)

A related problem with budgets is that the budget for operations and maintenance (O&M) is not typically a line item considered during the budgeting process so that it is very difficult to compare first costs with LCC and to track the results of using different technologies including GBSTs (OFEE 2003). In addition, the Brooks Act which concerns the selection of firms and individuals to perform architectural, engineering, and related services for the Federal Government has been interpreted to constrain design budgets to six percent of construction costs, and could potentially limit the use of more in-depth integrated and environmental design approaches, including charrettes (OFEE 2003).

2.4.5.2 Lack of Clear Policy, Education Needs, and Limited Research

Policy can be used to further encourage and/or require agencies to implement green buildings by promulgating standards and measurement systems to guide efforts, and to direct public agencies to resources and assistance (DuBose et al. 2007; Pearce et al. 2007). As previously mentioned, there is a mixture of diverse green building mandates in law, regulation, and Executive Orders, but not one definitive, clear, and unified policy statement on green design (OFEE 2003; USDOE 2001; USGBC 2009h). Even though the EO 13423 recently issued address this problem, many uncoordinated policies related to green building have the potential to confuse facility decision makers and project managers in the public sector.

One of the barriers to increased green building is the lack of proper knowledge of green building at all levels including decision makers such as facility executive officers, budget officers, program and project managers, and headquarters, regional, and field staff (OFEE 2003). This lack of green building knowledge by participants can negatively affect the incorporation of GBSTs in facility projects because decision makers hesitate to allocate additional budget and incorporate GBSTs when implementing green building. In addition, there are not enough hard data, statistics, and case studies which support green building (OFEE 2003).

2.5 Current Practice of Decision Making for Public Facilities

This section describes general procedure of capital programming in the public sector. In addition, this section induces the capital programming procedure in the public sector, mainly federal government.

2.5.1 General Procedure of Capital Programming

Facility project investment decision making is one of the key components in capital programming which is an integrated process within an public agency for planning, budgeting, procurement and management of the agency's portfolio of capital assets including facilities to achieve strategies, goals, and objectives with the lowest LCC and least risks (OMB 2006). Capital planning and budgeting are the first two phases which involve several stages of facility project investment decisions using the well-established disciplines of finance theory and engineering economics including cost-benefit analysis (OMB 2006; Park 2003). Capital planning, the first stage of capital programming focuses on planning, cost-benefits analysis for alternatives, and risk management for acquisition of the facility (OMB 2006). After going through the phase of capital planning in public agencies, the agency capital plan is created as the principal output of the planning phase. The agency capital plan is used for its capital asset planning and budget justifications to OMB, congressional authorizations of projects, and justifications for appropriations to Congress (OMB 2006).

The next step of capital programming is budgeting. The budgeting step process occurs when the OMB works with the agencies to devise a funding plan to allocate resources among various priorities. At the budgeting phase, the agency capital plan and a project's Return on Investment (ROI) are two key items to increase its likelihood of funding from funding agencies (OMB 2006). After they receive funding for projects from their funding agencies, public agencies move to the acquisition phase. At this phase, Integrated Project/Program Team (IPT) including a program manager and project manager in a public agency has a responsibility to manage acquisition of the facility project with specific cost, schedule, and performance goals. From this capital programming process, it is possible to identify several key decision making situations in capital planning and budgeting steps while developing a facility project in the public sector. At the key decision making situations discussed, the first cost and LCC of the proposed project are eventuated to make "GO" and "NO-GO" decision.

2.5.2 Capital Programming Procedure for Green Facilities

Since public agencies are motivated by Executive Orders and legislation related to sustainability with the goals of protecting the environment, conserving energy, minimizing waste and promoting public leadership as good stewards of natural resources, public agencies incorporate the concept of sustainability into capital programming. The currently considered practice in public agencies is to embrace green building rating systems or incorporate GBSTs into facility projects while developing a new facility (Memorandum of Understanding 2006). At the planning and budgeting phases in capital programming, public agencies may request additional budget to achieve the specified level of green building rating system performance or otherwise incorporate GBSTs into the development of the facility (NAVFAC 2003; Pearce 2008).

2.6 Conclusion

Green building has gained momentum to minimize challenges and risks in the built environment including rapid increase of energy costs and environmental degradation caused by built facilities, and to maximize social and economic benefits. Despite the growth of green building policies and implementing green building rating systems in the development of public sector facilities, the background study in this chapter identifies that the first construction cost premiums and budgetary structure of public agencies are two major barriers to implementing green building in the public sector. These two barriers are related to the relationship between first costs and LCC because incorporating GBSTs into the facility commonly requires (or is perceived to require) additional first costs even though it is often possible to achieve LCC savings over the facility life cycle as a result. Failure to recognize the relationship between first costs related to GBSTs and LCC may inhibit facility decision makers from making wise decisions for green facilities in the public sector.

Background study in the areas of public facilities, sustainability, the green building movement in the public sector and barriers to green building implementation illustrate the current status of green building in the public sector. This background study concludes that it is necessary to identify the relationship between first costs related to GBSTs and LCC savings to minimize cost- and budget-related barriers to green building in the public sector. The identified issue becomes the objective of this study: to achieve the goals of balancing first cost premiums related to GBSTs with life cycle cost savings, thereby helping facility decision makers to make wise and sensible decisions about implementing green building strategies and technologies in their capital projects.

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

To identify relationships between first costs related to GBSTs and LCC in public sector capital projects in the United States, it is crucial to examine previous studies related to the issues of first costs of green building and LCC savings. By reviewing this literature, it is possible to:

- Demonstrate a familiarity with a body of knowledge and establish credibility of this study
- Show the path of prior research leading to the current research to identify the relationship between first costs of GBSTs and LCC saving
- Integrate and summarize what is known in this domain
- Learn from others and stimulate new ideas (Neuman 2003).

Due to significance and importance of literature review, this chapter presents a literature review pertaining to:

- Identifying the relationships between first cost of projects and the level of green building rating achieved in those projects
- Identifying the relationship between first cost premium of green building projects and their LCC
- Identifying the relationship between GBSTs and LCC savings.

The following sections describe these areas of inquiry in more detail.

3.2 Identifying the Relationship between Project First Costs and the Level of Green Building Rating

Several scholars have attempted to identify the relationship between the level of green building rating and project first costs. These studies, shown in Table 3.1, identified the relationship between first cost premiums and each LEED credit of the USGBC green building rating system. From synthesizing these studies, most LEED buildings require at least some first cost premiums to achieve a rating under the USGBC LEED rating system even though the first cost premiums were the ranges between -0.4% and 8.1%. However, the method of identifying first cost premiums of LEED buildings required significant time and resources because of the necessity of cumbersome cost analysis. This approach is impractical for the problem of identifying the relationship between first cost premium of GBSTs and LCC because limited populations of relevant buildings exist. Moreover, of these, many were prototypes for their organizations and thus received additional attention and resources from the organization, thereby making them atypical from a cost standpoint.

Table 3.1 First cost premiums of the USGBC green building rating system

Author	Building Type	Method	% of Increase
(Stegall and Dzombak 2004)	Residential hall building (LEED Silver)	The study mapped the comparison of the cost for the constructing Silver LEED certified building with a similar but conventional building constructed at the Carnegie Mellon University.	First cost premium of 1-2.5%
(XEnergy and Sera Architects 2000)	Three office and mixed use buildings (LEED certified)	This study identified the first cost premium of LEED projects by identifying the incremental costs compared to the costs of measures in the building as-built.	First cost premium of 0% to 2.2%
(Enermodal Engineering 2006)	Eleven buildings (LEED certified)	This study identified the first cost premium of LEED projects by identifying the incremental costs compared to the costs of measures in the building as-built.	Average first cost premium of 1% to 6%
(USGSA 2004)	Two building types (LEED certified, silver and gold) 9 Scenarios	This study conducted detailed cost studies to identify first cost premiums of LEED rated projects.	Average first cost premium of -0.4% to 8.1%
(USDHHS 2006)	Medical facility (LEED certified and silver) 2 Scenarios	This study conducted a cost analysis to identify first cost premiums of LEED rated buildings.	Average first cost premium of 3.0%
(Northbridge Environmental Management Consultants 2003)	Public sector buildings (LEED certified)	This study collected the first cost premiums of LEED certified public buildings.	Average first cost premium of 4.5% to 11%
(Kats 2003a)	33 building projects (Certified, silver, gold, and platinum)	This study gathered the first cost premium of LEED projects by identifying the incremental costs compared to similar types of conventional buildings.	Average first cost premium of 0.66% to 6.50%

3.3 Identifying First Cost Premiums of Specific LEED Credits and Associated LCC Savings

Several scholars also conducted studies to identify the relationship between specific credits in the LEED green building rating system and LCC. These studied identified the first cost premiums of LEED buildings along with their expected or predicted LCC savings. These studies are summarized in Table 3.2. These studies also required analysis to identify the relationship between the first cost premiums of LEED buildings and LCC savings. Furthermore, these studies showed the LCC savings associated with specific LEED credits instead of each individual GBST.

Table 3.2 First cost premiums and LCC savings of LEED buildings

Author	Building Type	First Cost and LCC Impact
(XEnergy and Sera Architects 2000)	Three office and mixed use buildings (LEED certified)	• First cost premium in the range of 0% to 2.2% • LCC savings including societal and productivity benefits of 15% over 25 years • Best performer: Fundamental building system commissions • Worst performer: Innovative wastewater technologies
(Enermodal Engineering 2006)	Eleven buildings (LEED certified)	• First cost premium of 1% to 6% • LCC savings of -$1.5/SF to $4.2/SF over 20 years • Analysis for projects (Not LEED credit analysis)
(USDHHS 2006)	Medical facility (LEED certified and silver)	• First cost premium of 1% to 7.6% • LCC savings of 0.2% to 8.3% over 20 years

Although these studies are useful because they identify first cost premiums of LEED credits and their potential LCC saving opportunities, they are still not useful for solving the research question being investigated in this study because there are many GBSTs needed to meet each LEED credit requirement. In programming public sector facilities, information is required about specific technologies to be employed on the project to justify budget requests. Therefore, estimates of LEED credit cost impacts do not provide sufficient information to provide this justification (SWA 2006).

3.4 Identifying the Relationship between Specific GBSTs and LCC Savings

Several studies in the building sector have also attempted to identify the relationship between individual building features or technologies and associated LCC savings. For example, studies identified the relationship between energy and cost efficiency by comparing different glass facades (Cetiner and Oxkan 2005), rooftop gardens (Wong et al. 2003), between district heating and heat pumps (Gustafsson and Bojic 1997) and among rooftop units with gas heat & Direct-

Expansion (DX) cooling, air-source heat pumps, and geothermal heat pumps (Chiasson 2006). These are summarized in Table 3.3.

Table 3.3 Summary of previous studies characterizing the relationship between building features and LCC

Author	Objectives	Input Variables & Source of Data	Analysis/Modeling method
(Cetiner and Oxkan 2005)	• To generate standard façade alternatives in the context of performance approach and evaluate their energy and cost efficiency.	**Glass facades in high-rise buildings** Glazing type • Double skin glass façade • Single skin glass façade Glass type • Clear glass • Reflective glass • Low-E glass (One office building in Istanbul, Turkey)	• Life cycle cost analysis to calculate energy load • Energy consumption – Simple calculation based on heat gain and losses. (Turkey)
(Wong et al. 2003)	• To examine the first cost implications of having a green roof • To compare LCC of roof garden vs. average flat roofs • To evaluate economic benefits by incorporating energy costs into LCC	**Roof type** Inaccessible roof • Exposed roof • Green roof (100% turf) Accessible roof • Built-up roof • 80% shrubs • 50% trees (Theoretical estimation based on Housing Development Board Structural Engineering Department)	• Life cycle cost analysis taking into consideration the first cots as well as the maintenance, replacement costs of the different roof types. (Using Building Life-Cycle cost (BLCC) programs). • Energy consumption – PowerDOE (Singapore)
(Gustafsson 2000)	• To optimize the renovation strategy for an existing building by comparing district heating and heat pump • To compare LCC by comparing different weather-stripping • To compare LCC by varying different U-value of windows • To compare LCC by varying the thickness of insulation on the attic floor	**Heating type** • District heating • Heat pump Weather-stripping U-value of windows • 3.0 W/ºC m^2 • 1.5 W/ºC m^2 • 1.2 W/ºC m^2 (Theoretical cost assumption)	• Mixed Integer Linear Programming using mathematical formulas and special software such as ZOOM, LAMPS or CPLEX programs (Sweden)
(Gustafsson and Bojic 1997)	• To optimize heating-system-retrofit strategy for existing buildings by varying heating systems • To compare LCC by varying heating systems	**Heating type** • Heat pump • District heating system (Theoretical cost assumption)	• ZOOM optimization software to develop the Mixed Integer Linear Programming (MILP) model (Sweden)
(Chiasson 2006)	• To compare three alternatives in terms of first costs and LCC	**HVAC Systems** • Rooftop units • Air-source heat pumps • Geothermal heat pumps	• Life cycle cost analysis taking into consideration the first cots as well as the maintenance, replacement costs of the different roof types • DOE-2 program

In addition, two studies by Verbeeck and Hens investigated the life cycle optimization of low energy dwellings using the techniques of Genetic Algorithms (GA) with the Pareto concept (Verbeeck and Hens 2007a; b). These studies optimized the design of low energy dwellings, taking into account energy use, environmental impact, and financial costs over the life cycle of the dwelling by varying insulation level, glass area, and existence and nonexistence of a heat recovery system (Verbeeck and Hens 2007a; b). In addition, these studies simulated energy consumption using an energy simulation tool called TRNSYS.

A research team in Concordia University in Canada developed multi-objective genetic algorithms in green building design optimization (Wang et al. 2005a; Wang et al. 2005b). In Wang et al.'s studies, the researchers wanted to indentify the optimum green design based on several variables including orientation, shape, window type and ratio, structural configuration such as concrete frame and steel frame, and floor type (Wang et al. 2005a; Wang et al. 2005b). In addition, Caldas (2008) studied energy-efficient architecture solutions through GA; Tan (2006) developed a parametric building energy cost optimization tool based on a GA (Tan 2006); and Fong and Chow developed optimal design of solar water heating system in a high-rise residential building by using GA (Fong and Chow 2007). Based on those previous studies, GA has been used as an optimization modeling approach to identify the relationship between first cost investments and LCC savings as a research objective. In addition, GA has been applied in other construction-related contexts including optimizing civil infrastructure including road and bridge maintenance and rehabilitation (Elbehairy 2007; Fwa et al. 1996) and infrastructure networks (Morcous and Lounis 2005).

Even though GA has been receiving increasing attention regarding its potential as an optimization technique for complex problems (Michalewicz et al. 1996; Verbeeck and Hens 2007b), GA is still rare in application of building-related design and engineering (Asiedu et al. 2000; Verbeeck and Hens 2007b; Wang and Jun 2000) and has several weaknesses, including (Miller 2000):

- If there are many input parameters in optimization, GA requires much computational time to find optimum solutions because of evaluating every possible solution (Tan 2006).

- Designing a good genetic algorithm is very difficult with sophisticated variables and very large design spaces because algorithm designers have to consider the knowledge base, engineering principles, analysis tools, invention heuristics and common sense in their algorithm design.

In addition, a GA approach is impractical to apply to actual project development because it requires developing accurate mathematical algorithms considering all variables. Thus, it is necessary to introduce other methodologies which can be applicable to public agencies which have limited mathematical computation capabilities. In addition, the method has to be able to model the relationship between first costs related to GBSTs and LCC for a building in general, without necessarily knowing the precise details of design and implementation of a particular building. Based on those needs, this study has selected statistical analysis, specifically regression analysis, as a method to achieve the goal of this study.

3.5 Statistical Analysis for Cost Prediction

Statistical analysis models, mainly multiple regression models, have been used for predicting construction costs in the construction industry (Dysert 2001; Hwang 2009; Phaobunjong 2002). In addition, multiple regression models also have been used to identify impact of building shapes and features and their annual energy consumption (AlAnzi et al. 2009; Ling et al. 2007; Ourghi et al. 2007). For example, one of studies conducted by Alanzi et al. (2009) successfully identified the relationship between different building shapes of office building and thermal performance of the office building. In addition, Ourghi et al.(2007) also conducted research to develop a simple regression model to predict the impact of shape on annual energy use for office building. One study conducted by Ling et al. (2007) identified the effect of geometric shape and building orientation on minimizing solar insolation on high-rise buildings in hot humid climates using a regression model. Even though these studies have been successfully used to identify the relationship between building shape and orientation and annual energy consumption or thermal performance, there are limitations to use as a decision making tool in public green facilities because these studies did not incorporate the issues of first cost and LCC.

3.6 Conclusion

Previous studies related to identifying relationships among GBSTs or LEED green building, first cost premiums and LCC savings are limited because the methods used in the studies shown in Table 3.1 and 3.2 all require heavy analysis to calculate first cost premiums and LCC savings. In addition, these approaches identify the relationship between LEED credits and their first cost premium and LCC savings instead of each GBST, and require significant amount of facility project information which has not been confirmed at the earliest stage of the project. Therefore, this approach is not practical to identify the relationship between first costs related to GBSTs and LCC at the planning and budgeting phases of capital programming in the public sector. The second approach used by studies shown in Table 3.3 to optimize design features which can minimize LCC requires using detailed modeling techniques. This approach also has limitations because it requires mathematical computation capabilities such as Genetic Algorithms to develop a model. These modeling capabilities are not effective at the earliest stages of project planning because of limited knowledge about the design and implementation of a particular project. Regression analysis models have been used for identifying the relationship between building types and annual energy consumption. However, this approach does not incorporate the issues of first costs and their LCC saving opportunities. As a result, this study proposes a simple and broadly applicable model which can identify the relationships between the first cost premiums of GBSTs and LCC for public sector projects. This developed model can help public facility decision makers to make wise decisions when making early planning and budgeting decisions in implementing green facilities.

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CHAPTER 4: RESEARCH METHOD

4.1 Introduction

This chapter presents the full and detailed methodology of this study. In this chapter, the research approach is developed to test the hypothesis that it is possible to model the relationship between first cost related to GBSTs and LCC for a building in general, without necessarily knowing the precise details of design and implementation of a particular facility. There are various ways this analysis could be done to identify relationship between first cost of building features and LCC including genetic algorithms and life cycle analysis. Of these approaches, this study proposes that statistical analysis which makes the most sense for facilities in the public sector because once developed, statistical models do not require complex mathematical algorithms and computer programming skills, which are required in genetic algorithms and agent-based models. Developing statistical models requires facility data including design and construction data, operating and maintenance data, annual utility consumption data etc. In an ideal situation with no resources or data constraints, a regression model could be derived from large pools of existing data about facility first costs and LCC.

However, existing facility data in the public agency is incomplete and of poor quality because of many errors, omissions, duplications, and contradictions, even though public agencies are taking aggressive steps to improve the quality of data collected (Section 2.2.2.3). In addition, although the green building movement is gaining significant momentum as discussed in Chapter 2, the number of green facilities actually in operation is still comparatively small. It will be many years before quality life cycle data for a representative pool of real facilities is available to serve as a basis for statistical modeling. Thus, the objective of this research is to develop and test a method for addressing this problem using statistical analysis of simulated data based on building performance models. The use of simulated data instead of historical data to develop models is a technique that has precedent in other domains (AlAnzi et al. 2009; Ourghi et al. 2007) and is appropriate in cases where historical data is incomplete or of poor quality and where suitable simulated data can be developed and properly validated.

To develop and test the feasibility of this approach, this study focuses on a specific subset of all possible cases for demonstration purposes, as follows:

- Choosing a specific public agency and a particular building prototype within that agency (Chapter 5)
- Focusing on a subset of GBSTs applicable to the selected building type and developing them into a set of scenarios representing possible feasible combinations of GBSTs (Chapter 6)

After the demonstration population is scoped in this way, the method is developed and demonstrated by:

- Developing first cost estimates for each scenario using incremental estimates (Chapter 7)
- Developing estimates of operating, maintenance, repair and replacement costs and other costs for each scenario using building performance modeling (Chapter 7)
- Developing life cycle cost models for each scenario (Chapter 8)
- Identifying the relationship between the first cost of each GBST and corresponding LCC savings, and conducting regression analysis across the population of scenarios to model the relationship between first cost and LCC (Chapter 9).

The final chapters of the dissertation then draw conclusions based on this analysis, make recommendations for future research, and describe specific lessons learned as a result of this work (Chapter 10).

4.2 Choosing a Specific Public Agency and a Building Type

In an ideal world, this research would consider all agencies and all building types as the basis for developing the model. However, to initially demonstrate the viability of this modeling approach, it is necessary to choose a narrower scope of possible cases to make the task of modeling these cases feasible. Thus this study selects a public agency which has massive facility portfolios with significant annual investments for its facilities. In addition, this public agency needs to incorporate GBSTs into its new facility projects to maximize benefits associated with implementing green building. Furthermore, it is also desirable to identify a public agency which spends substantial amount of financial resources to operate and maintain its facilities. Several U.S. federal agencies meet these criteria, including the U.S. Department of Defense (USDOD), the U.S. General Service Administration (USGSA), and the United States Postal Service (USPS) because these three public agencies have significant facility portfolios, consume significant energy including electricity, and undertake substantial annual investments for facility projects (Table 4.1).

Table 4.1 Public agencies with many facilities (OFEE 2003; USPS 2008d)

Public Agency	Size of Facility Portfolio	Annual Investments for Facilities	Annual Energy Use (Trillion Btu)
USDOD	316,000 facilities	$7,200 million	244.0
USGSA	8,300 facilities	$658 million	17.4
USPS	36,723 facilities	$459 million	25.8

Among these public agencies which have many facilities with significant annual facility investments and energy consumption, this study has selected the USPS to provide a sample of public agencies in general because of the following reasons:

- New post office facilities are generally designed and constructed on the basis of standard design and specification of the post office facility. Thus, it is possible to normalize the developed relationship and comparatively easy to apply the findings to other post office projects.
- The USPS is a quasi-government agency even though it follows public policies and legislation related to green building movement. Therefore, the development framework may more easily be generalizable to projects in the private sector.
- The USPS has some experience with building post office facilities which incorporated GBSTs into their design. In addition, the USPS also actively considers incorporating GBSTs into their post office facility projects. Thus, previous and existing projects are available for comparison and validation purposes.

The USPS has several standard designs and specifications of post office facilities which follow the Medium Standard Building Designs (MSBD) guide and the Small Standard Building Designs (SSBD) guide (USPS 2008a). These design guides give project managers and architects a guide to the design and construction of post office faculties (USPS 2008a). Thus, nearly all new post office facilities are designed and constructed based on one of these two design guides, which includes a specification and drawings. Among two standard building design guides, this study has selected the SSBD guide after considering the applicability of the developed framework, the number of post office facilities, and recommendations from Mrs. Teresa Schubert, an energy analyst, and Mr. Robert McNiece, the director of the facilities energy program at HQ Facilities Energy Management Program in Greensboro, NC. The next step was to identify the prototype post office which was used as a prototype post office facility in this study for the purposes of cost estimating and energy modeling. Based on consulting with Mrs. Schubert, one post office prototype was selected as the baseline post office facility in this study. The selected prototype post office is located in the Washington Metropolitan Area (WMA) and built in 2007 based on the SSBD for the purpose of serving as a general post office. Chapter 5 provides a more detailed description and outcomes associated with these choices.

4.3 Narrowing Down Green Building Strategies and Technologies

The scope of what constitutes “green building” is very large and uncertain, and consists of a large variety of GBSTs. For example, the Sustainable Facility Asset Management (SFAM) research team at Virginia Tech led by Dr. Annie R. Pearce has identified over 200 GBSTs to achieve LEED NC credits by reviewing USGBC reference guides and a variety of studies related to green building costs and GBSTs (Appendix D) (Pearce et al. 2009). Ideally, the framework developed in this study will be able to consider a wide variety of such strategies, but for purposes of demonstrating the viability of approach, this study systematically narrowed down the whole set of GBSTs into a subset by two stages shown in Figure 4.1. The first criterion to narrow down GBSTs was to identify widely implemented GBSTs by reviewing credits in green building rating systems such as LEED and Green Globes, green building design guides, green building policies and legislation, and regulations. The second criterion was to identify several GBSTs which typically require additional first cost premiums for design and construction. The difference between the criterion 1 and 2 was that the first criterion was to trying to pick a relevant LEED credit, and the second criterion was to pick specific GBSTs that could be applied to achieve that LEED credit. In the third criterion, LCC impacts of GBSTs were identified by reviewing LCC studies of GBSTs. The fourth criterion was to identify GBSTs which were likely to have a significant relationship between first cost premiums and LCC savings from literature. The fifth criterion examined the applicability of each specific GBST to the selected public agency, the USPS. The final step of narrowing the whole set of GBSTs down to specific GBSTs was to check with public legislation, policies, and regulations related to incorporating GBSTs into facilities. Through this process, the single LEED credit of “optimize energy performance” was selected.

The second stage started identifying GBSTs that could be employed on a project to optimize energy performance in the building sector including passive and active strategies and technologies. First, this study examined the three tier approach suggested by Norbert Lechner to identify GBSTs which could optimize energy performance in the building (Lechner 2009). In addition, this study conducted in-depth literature search to identify GBSTs to optimize energy performance and reviewed public legislation, policies, and requirements to find GBSTs. Through these two stage processes, this study identified a subset of GBSTs which would be concentrated in this study. The detailed procedures and processes for this step are discussed further in Chapter 6.

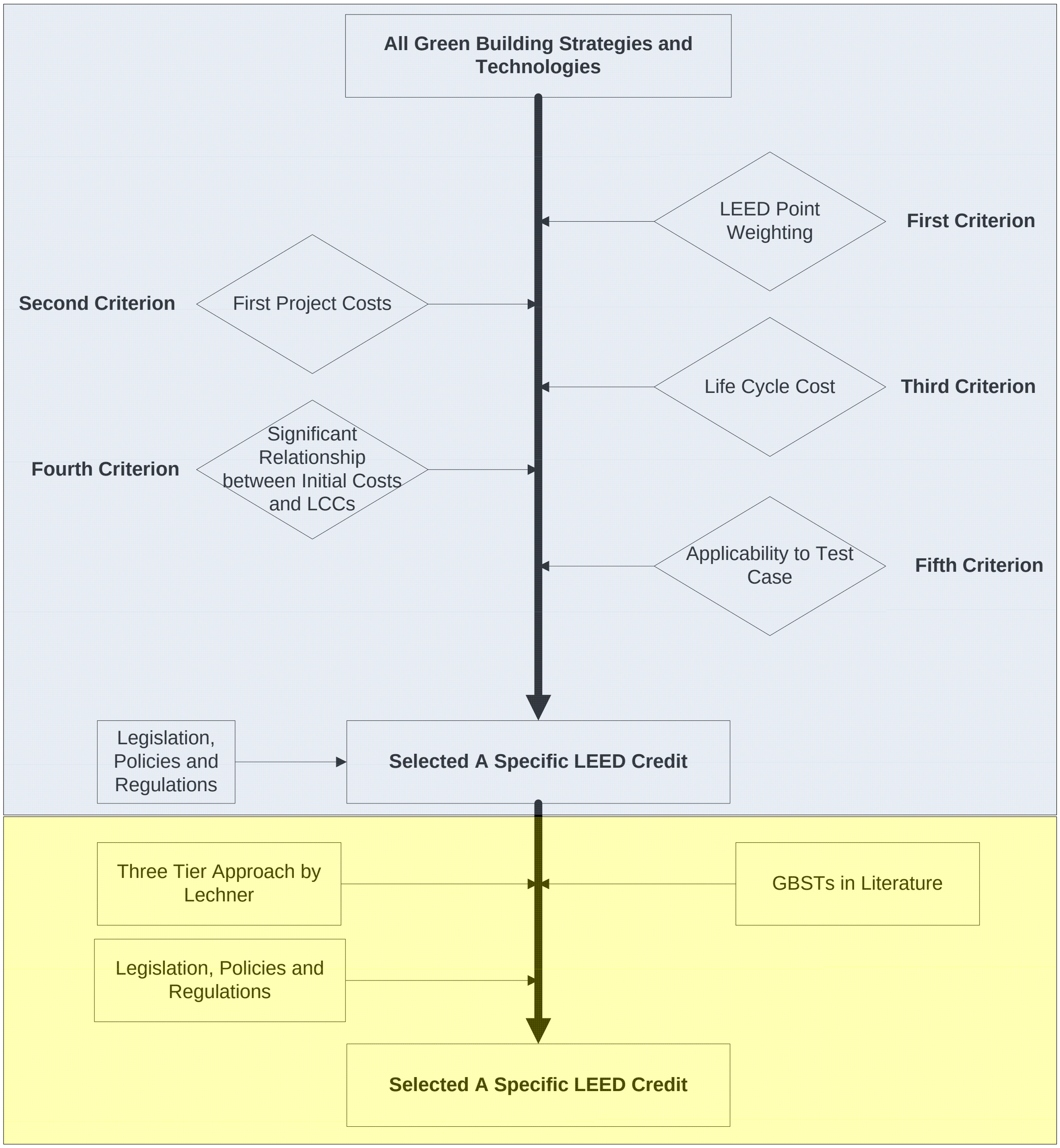

Figure 4.1 Approach to narrow down a subset of GBSTs

After selecting a subset of GBSTs to be used in this study, the method of developing first cost estimates associated with those GBSTs is described next.

4.4 Development of First Cost

As construction estimating only includes cost data of installed building components, it is not possible to obtain the cost differences for various alternatives of each building system from construction estimating data. Thus, this study developed first cost estimates for each scenario using incremental estimates and also adopted an estimating expert validation approach to increase the reliability and validity of the adopted approach. The method chosen was to simulate first cost estimates for building scenarios that combined GBSTs into the selected prototype facility design in the USPS. As a result, the first cost of the selected prototype post office facility became an essential baseline of the first cost in this study. First costs for scenarios were to be estimated by varying alternatives in a subset of GBSTs including orientation, the levels of wall and roof insulation. The estimating process used here was called incremental estimating (SWA 2006) which could identify first cost differences between a prototype post office facility and the same facility incorporating combinations of GBSTs. This approach has been used in similar projects such as “Naval Facilities Engineering Command (NACFAC) Energy Policy Act of 2005 Study for the Academic and Headquarters Buildings” and “The Business Case for Sustainable Design in Federal Facilities” is therefore an appropriate approach to use in this study. Even though this approach is not the best estimating approach(SWA 2006; USDOE 2003a).

The proposed procedure for estimating the first costs is as follows (Figure 4.2). The first step was to get the facility data of the prototype post office facility including cost data, drawings, specifications, etc. from the United States Postal Service’s facility department, the Eastern Facility Service Office (FSO) located in Greensboro, NC, and Gauthier Alvarado & Associates, Inc., a construction firm located in Falls Church, VA. The second step was to define the number of alternatives for the subsets of GBSTs and the identified cost impacts of alternatives defined by those subsets of GBSTs. The first cost data was based on the cost data of R. W. Brown & Associates located in Washington, DC. Robert W. Brown, president of R. W. Brown Associates who provided expert input to this process, has have over thirty years of experience in estimating and also had previously completed over 10 USPS facility projects. This established experience makes Mr. Brown an appropriate choice of expert to provide review and validation for this project.

The third step was to generate first costs based on many scenarios with different alternatives in green building features. The generated data and its estimating were validated by Robert W. Brown, president of R. W. Brown Associates, to establish the validity and reliability of first cost data. The full detailed description of procedures and outcomes are discussed in Chapter 7.

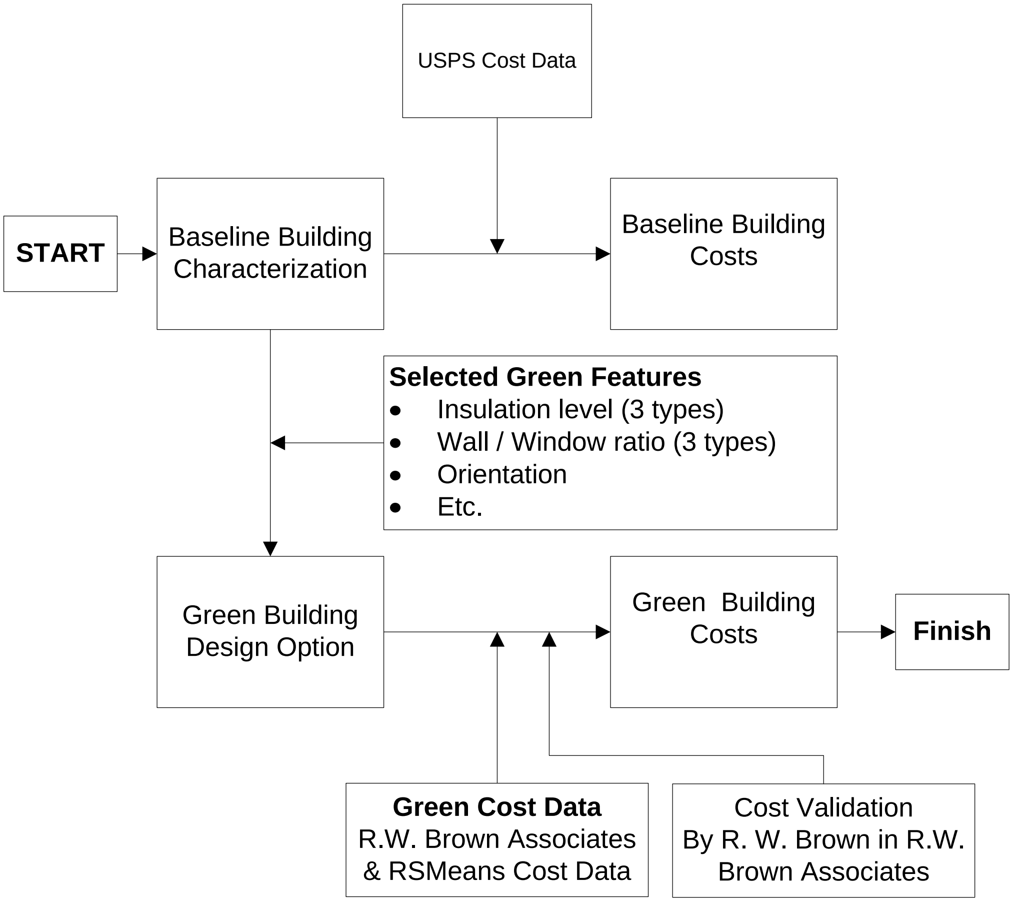

Figure 4.2 First cost data collection diagram

4.5 Development of Operating, Maintenance, Repair and Replacement, Other Costs

This section describes detail methods of developing operating, maintenance, repair and replacement and other costs which are used in calculating LCC. Thus, this chapter starts with the development of operating cost.

4.5.1 Operating Costs

Since this study is focused on GBSTs to optimize energy performance, the primary operating cost of interest in this study was the annual cost of energy consumption. The annual energy consumption for each building scenario was predicted through computer energy modeling of the energy behavior of the building over time. The computer energy model can simulate the time-based phenomena that affect a building's energy use (State of Washington 2005). There are several computer energy simulation models or tools such as DOE-2.2, eQUEST, PowerDOE, Energy 10, EnergyPlus, etc. In this study, eQUEST was selected and used to model energy consumption after consultation with an Associate Professor at Virginia Tech. The associated professor was selected to provide assistance in choosing an appropriate tool due to his more than 15 years of experience in the areas of energy efficiency, architectural system integration, indoor air quality, and thermal comfort.

To determine the energy costs for each building scenario over the study period, general procedures for energy modeling were followed (SWA 2006). The first step was to calculate energy consumption of a prototype post office facility and other scenarios using the eQUEST energy modeling tool. One of the concerns related to energy modeling is that it must be performed using the same energy modeling tool, the same operating conditions, the same weather data and the same purchased energy rates (State of Washington 2005). These concerns were addressed in this study by using an energy modeling tool, eQUEST and (TMY2\VA_Sterling-Washington) weather file. The next step was to calculate a typical annual energy cost for each scenario by multiplying the annual energy consumption by the price of energy. This annual energy cost would then be incorporated as part of the life cycle cost model developed in subsequent parts of the study.

The validity of outcomes from energy modeling is one of the key issues related to the success of energy modeling. Thus, this study employed two approaches to increase the reliability and validity of energy modeling. The first approach was to validate the developed energy model through detailed review by two experts, Dr. James R. Jones and Dr. Georg Reichard at Virginia Tech. The second approach was to compare the outcomes of the energy model with actual energy consumption from the utility bills of the prototype post office facility chosen for this study.

Additional details of energy modeling including input and output data and the operating costs with the result of energy consumption are discussed in Chapter 7.

4.5.2 Maintenance, Repair and Replacement Costs

Defining all the future maintenance, and repair and replacement cost of GBSTs is also very important. Maintenance costs are defined as scheduled costs associated with the upkeep of the facility asset (Fuller and Petersen 1995; State of Washington 2005; USDOE 2003b). An example of a maintenance cost is the cost of an annual HVAC inspection. This task is a scheduled event that is intended to continue the facility and its systems in good condition. Repair costs are defined as unanticipated expenditures that are required to prolong the life of a building system without replacing the system (ASTM 2007; DOE 2004; Fuller and Petersen 1995; Petersen 1995; USDOE 2003b). An example is the repair of a broken HVAC system or a broken light switch. Replacement costs are defined as anticipated expenditures to major building system components that are required to maintain the operation of a facility (Fuller and Petersen 1995; Kirk and Dell'Isola 1995; State of Washington 2005). There are two procedures for estimating annual total maintenance costs and repair and replacement costs, including the use of R.S. Means Facility Maintenance and Repair Cost Data and the calculation of annual maintenance costs, repair and replacement costs using USPS’s own standard practices of maintenance. In this study, the R.S. Means Facility Maintenance and Repair Cost Data was selected because it provided realistic details about the cost and repair frequencies of work items and it eliminated the need for collecting maintenance, repair, and replacement costs directly from the USPS. Furthermore, this approach also could eliminate the risks associated with unreliable and inaccurate facility data. This study assumed that R.S. Means Facility Maintenance and Repair Cost Data was reliable cost data without the validation process. The full procedure and results of developing maintenance, repair and replacement costs are discussed in Chapter 7.

4.5.3 Residual Values and Other Costs

One of the other costs of LCC is the residual value, which is the net worth of a building or building system at the end of the life period or at the time it is replaced during the study period (ASTM 2007; Fuller 2008; Fuller and Petersen 1995; Petersen 1995; USDOE 2003b). Residual values can be based on the value in place, resale value, salvage value, scrap value, net of any selling, conversion, or disposal costs (Fuller 2008; Fuller and Petersen 1995). As this is similar to the straight-line depreciation method of the building which is also the simplest and most commonly used depreciation method (Stickney et al. 2009), this study adopts this approach. Thus, the residual value of a system with remaining useful life in place can be calculated by linearly prorating its first costs. For example, for a system with an expected useful life of 15 years, which was installed 5 years before the end of the study period, the residual value would be approximately 2/3 (=(15-5)/15) of its first cost. This study only considered the residual values for specific components which were replaced within the study period and which varied from scenario to scenario. Components consistent across all scenarios were not considered.

In addition to residual values, there are other potential costs associated with developing and maintaining facilities such as non-monetary benefits and costs, health and well-being, finance charges, etc. One of the examples of the non-monetary benefits and costs is productivity gain or loss associated with thermal, air quality, lighting and ventilation (Fuller 2008; Fuller and Petersen 1995; Hedge and Sims 1995; Heerwagen 2000; Leaman 1999; Petersen 1995; Wyon 1996). Even though several studies have measured productivity losses and gains on the basis of implementing GBSTs (Brager and deDear 1998; Menzies et al. 1997), it is still very hard to accurately measure productivity and to convert it to monetary value (Heerwagen 2000). Thus, this study does not consider quantifying other costs and potential benefits by implementing GBST. Instead, the value of non-monetary benefits and costs will be considered part of further study.

4.6 Development of LCC

This Previous sections described and defined all costs in the facility life cycle related to LCC, which was a dependent variable of this study. In this section, Life Cycle Cost Analysis (LCCA) and its terms are expressed because a LCCA approach was adopted in this study. The LCCA formula is summarized for calculating LCC in this study, and all methods to calculate selected costs are clearly described. LCC can be defined as “The total discounted dollar costs of owning, operating, maintaining, and disposing of a building or building system over the appropriate study period.” (Fuller and Petersen 1995). International Organization for Standardization (ISO) 15686

(2004) defines LCC in Part I, §3.7.5 as the “total cost of a building or its parts through its life, including the costs of planning, design, acquisition, operations, maintenance and disposal, less any residual value”.

The American National Bureau of Standard (ASTM) defines LCCA in the *Life Cycle Costing Manual for the Federal Energy Program* as “… an economic method of project evaluation in which all costs arising from owning, operating, maintaining, and ultimately disposing of a project are considered to be potentially important to the decision.” (Fuller and Petersen 1995). However, LCC has to be distinguished from Life Cycle Assessment (LCA), defined in ISO 14040 (ISO 14040 2006). LCA address only ecological aspects with no connection to the economy (Pelzeter 2007). The following subsections describe all costs considered in LCCA and the methods and approaches taken for LCCA in this study.

4.6.1 All Costs in LCC

As previously defined, LCC is the sum of costs expressed as present values of investments, capital, installation, energy, operating, maintenance, and disposal costs over the life-time of the project (Figure 4.3 & 4.4) (adopted from ASTM 2007; DOE 2003c; Fuller 2008; Fuller and Petersen 1995; The President 1999). The method of calculating LCC is called Life Cycle Cost Analysis (LCCA) which can assess the LCC (Fuller 2008; Fuller and Petersen 1995; NRC 1990; 2004; 2008; Pelzeter 2007).

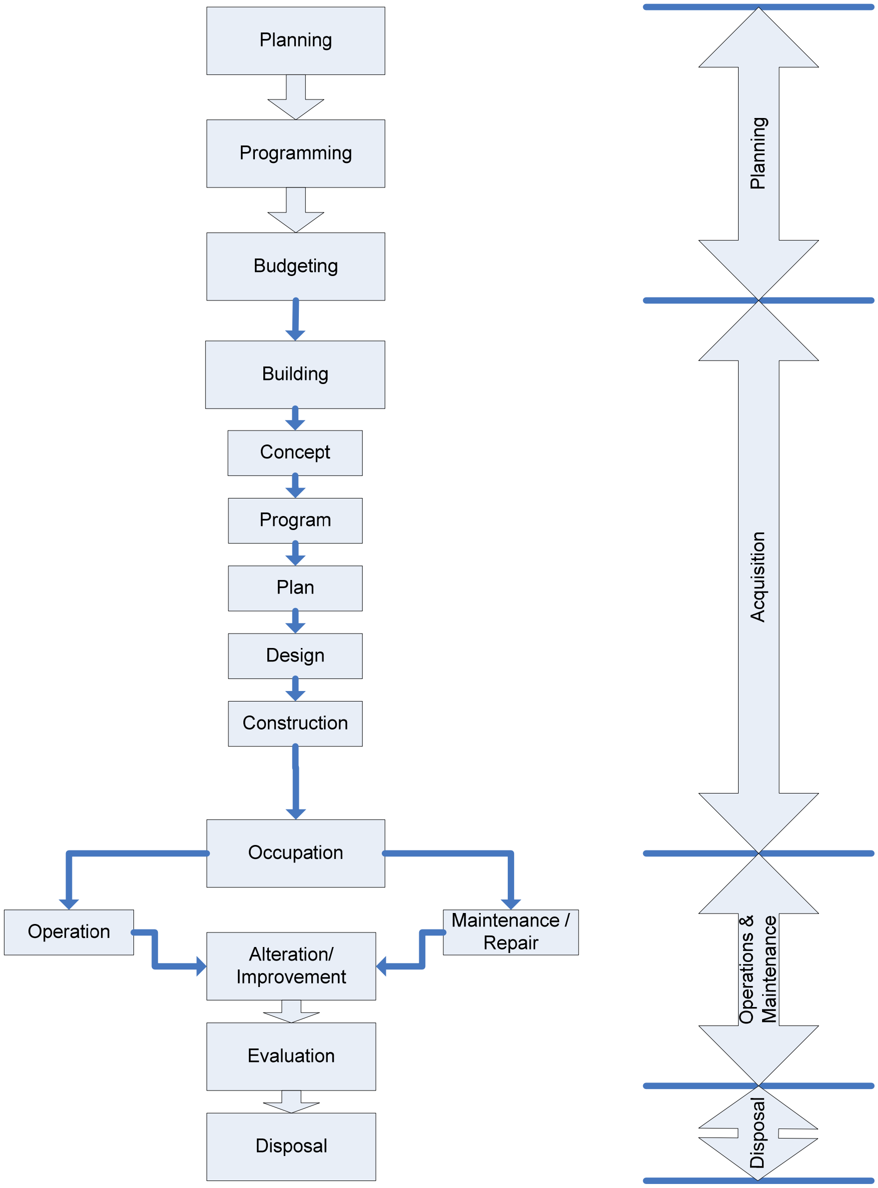

Figure 4.3 Life cycle phase of facility

4.6.2 Life Cycle Cost Analysis (LCCA)

The LCCA combines all costs (Figure 4.4) into net annual amounts, discounts them, usually to present value, and sums them to arrive at LCC (USDOE 2001).

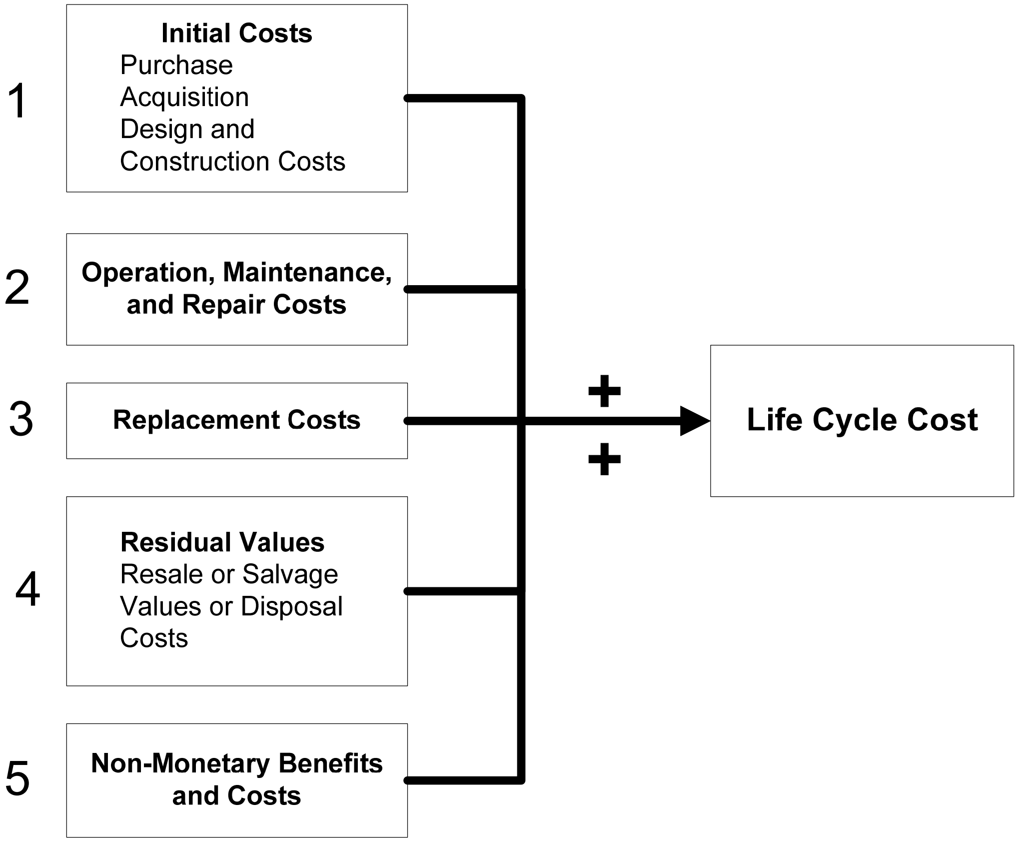

Figure 4.4 All costs in a LCC

The Net Present Value (NPV) in the LCCA can be defined as "the time-equivalent value of past, present or future cash flows as of the beginning of the base year." (ASTM 2007; DOE 2004; Fuller 2008; USDOE 2003b). Since base year means the fiscal year in which a LCCA is conducted, the first costs of facility assets in the public sector can be generally considered to be incurred at the base year (DOE 2004). Thus, there is no need to calculate the present value of the first costs at a LCCA. Future costs (2, 3 and 4 at Figure 4.4) can be broken down into two categories: one-time costs (non-recurring cost) and recurring costs (ASTM 2007; DOE 2004). Recurring costs are costs that occur every year or regular time period over the span of the study period (ASTM 2007; DOE 2004). Most operating costs and maintenance costs are recurring costs because they occur annually in the facility asset life cycle. One-time costs are the cost occurred one time during the study period such as most replacement costs and residual values for durable building components (ASTM 2007; DOE 2004; Fuller 2008). Recurring costs and one-time costs must be discounted into the present value on the basis of a discount rate (ASTM 2007;

DOE 2004; Fuller 2008; OMB 1992). In addition, the discount rate represents the opportunity cost of money or the minimum acceptable rate of return for a project (Fuller 2008; Fuller and Petersen 1995). The Office of Management and Budget in the United States defines discount rate as “the interest rate used in calculating the present value of expected yearly benefits and costs.” (OMB 1992).

4.6.3 LCCA Formula

The following is the general LCCA formula for the LCC present value model (Fuller 2008; NIST 2009b):

$$LCC = \sum_{t=0}^{n} \frac{C_t}{(1+d)^t} \qquad (4.1)$$

Where:

LCC = Total LCC in present-value dollars

Ct = Sum of all relevant costs, including first and future costs, less any positive cash flows

n = Number of years

d = Discount rate used to adjust cash flows to present value

The general LCC formula shown in Eq (4.1) requires that all costs be identified by year and by amount. This LCC formula requires extensive calculations, especially when the study period is more than a few years long and includes annually recurring amounts, for which future costs must first be calculated to include changes in prices (Fuller and Petersen 1995). The LCC formula in the building sector can be stated as follows:

$$LCC = I + Repl - Res + E + OM\&R \qquad (4.2)$$

Where:

LCC = Total LCC in present-value dollars of a give alternative

I = Present-value investment cost (generally just investment cost)
Repl = Present-value capital replacement costs
Res. = Present-value residual value less disposal costs
E = Present-value energy costs
OM&R= Present-value non-fuel operating, maintenance, and repair costs

The following formula depicts the present value of future one-time costs:

$$PV = \frac{F_t}{(1 + d)^t} \qquad (4.3)$$

Where:

PV = Present Value
Ft = Amount of one-time cost at a time t
d = Discount rate
t = Time (expressed as number of years)

To determine the present value of future recurring costs the following formula is used:

$$PV = A_0 \times \frac{(1 + d)^t - 1}{d \times (1 + d)^t} \qquad (4.4)$$

Where:

PV = Present Value
A0 = Amount of Recurring Costs
d = Discount Rate
t = Time (expressed as number of years)

From the several formulas above, LCCA requires extensive calculations if it considers all costs over the facility life. However, if certain categories of costs do not significantly influence the LCC, do not change from scenario to scenario, or are not relevant to a decision, it is possible to exclude those costs from the analysis (Fuller 2008). As a result, this study used those costs including first costs, operating and maintenance costs, and repair and replacement costs and omitted resale or salvage values, disposal costs, and non-monetary benefits and costs to reduce the complexity of LCCA for demonstration purposes. Such costs could be included as part of future research to increase the precision of the analysis.

4.6.4 Economic Analysis of LCCA

Due to the complexity of calculating a LCC, several LCCA tools are available to calculate LCC (Table 4.2). These LCCA tools were selected based on potential applicability to this study from many LCCA tools in the construction domain.

Table 4.2 LCCA tools

Name of LCCA Tool	Developer	Application	Strength
Building Life-Cycle Cost Program (BLLC) (NIST 2009b)	National Institute of Standards and Technology (USA)	Economic analysis, Federal buildings, Life-cycle costing	User friendly, ASTM economic analysis, and Detailed LCC analysis
Building for Environmental and Economic Sustainability (BEES) (NIST 2009a)	National Institute of Standards and Technology (USA)	Environmental performance, Life cycle assessment, Life-cycle cost	Combination among environmental science, decision science, and economics
LifeCycle (IES 2009)	IES, Ltd (UK)	Life-cycle cost, economics	Potential integration with other tools developed by IES
LCC Tool Using an Excel Spreadsheet on the Basis of ASTM Standard		Life-cycle cost, economics	Developed by a potential user

Based on these LCCA tools, this study developed a LCC tool using an excel spreadsheet on the basis of all standard requirements related to calculating LCC. This approach not only calculated precise LCC but also had the capacity to draw graphs and tables including breakeven graphs. This flexibility to meet the specific requirements of the analysis in this research made this approach more appropriate than the use of existing LCCA tools.

The next section describes how to collect cost data which is used for the LCCA in this study and it explains other important components in the LCCA such as discount rate and the duration of analysis period.

4.6.5 Additional Assumptions for LCCA

To calculate LCC, it is necessary to make several assumptions such as study period and discount rates. Thus, the following subsections explain and justify the study period and discount rates used in this study.

4.6.5.1 Study Period

The study period is the period of time over which ownership and operations expenses are to be evaluated (ASTM 2007; Fuller 2008; Fuller and Petersen 1995; Petersen 1995; State of Washington 2005; USDOE 2003b). There is no one correct study period, but it must be long enough to enable a correct assessment of long-run economic performance (Fuller 2002). The typical study period can range from twenty to forty years, depending on owner's preferences, the stability of the user's program, and the intended overall life of the facility (State of Alaska 1999). In addition, the study period can be divided into two phases: the planning/construction period and the service period (Fuller and Petersen 1995). The planning/construction period is the time period from the start of the study to the date the building becomes operational and the service period is the time period from date the building becomes operational to the end of the study (Fuller 2008; Fuller and Petersen 1995; Petersen 1995).

However, to simplify the LCCA, this study assumed that all first costs were incurred in the base year of the analysis. Thus, all first costs were entered into the LCCA at their full value. In regard to the service period, the USPS recommended 20 years for LCCA based on a discussion with Mr. McNiece, the director of the facilities energy program at the USPS. In addition, Executive Order 13423, "Strengthening Federal Environmental, Energy and Transportation Management" and 10 CFR 436 A, "Federal Energy Management and Planning Programs" require following the manual of *Life-Cycle Costing Manual for the Federal Energy Management Program*. This manual also requires that the study period of LCCA related to energy saving has to be twenty years. Thus, the study period used in this research is twenty years even though many of USPS's facilities would exist beyond this length of operation.

4.6.5.2 Discount Rate

The discount rate is “the rate of interest reflecting the investor’s time value of money.” (Kirk and Dell'Isola 1995). The discount rate used to adjust future costs and savings to present value is the rate of interest that makes the investor indifferent between cash amounts received or paid now or in the future (Fuller 2002; Fuller and Petersen 1995). In addition, the National Institute of Standards and Technology (NIST) takes the definition of discount rates a step further by separating them into two types: real discount rates and nominal discount rates (Fuller and Petersen 1995). The difference between the two is that the real discount rate excludes the rate of inflation and the nominal discount rate includes the rate of inflation (Fuller and Petersen 1995; Petersen 1995; State of Alaska 1999). Therefore, it is necessary to decide on the type of discount rate to use in LCCA. According to Fuller and Petersen (1995), for energy and water conservation and renewable resource project, the U.S. Department of Energy (USDOE) has legislative authority to establish the appropriate discount rate, using the procedure specified in 10 CFR 436. 10 CFR 436, “Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2009” specifies using a real discount rate with constant dollars (Rushing and Lippiatt 2009). Therefore, this study used a real discount rate and for fiscal year 2009, the real USDOE discount rate was 3.0 percent excluding general inflation.

4.6.5.3 Sensitivity Analysis

As sensitivity analysis can help in several ways to access the uncertainty of an LCCA and is a technique for determining what input values would make a crucial difference to the outcome of the analysis (Fuller and Petersen 1995). In addition, it can also calculate a range of outcomes to determine the lower and upper bounds of a project’s LCC (Fuller 2008; Fuller and Petersen 1995). Because of these advantages associated with sensitivity analysis, this study conducted two sensitivity analyses for three alternatives of future energy price indices and discount rates. Three scenarios of future energy price indices were predicted based on the future electricity data in the Energy Information Administration. In regard to the discount rates, this study considered three scenarios of the discount rates including 3% and 7% of the discount rates. The value of sensitivity analysis is to identify how the relationship between first cost premiums of GBSTs and LCC is varied along with changes in the key uncertainties including the discount rate and the future electricity price. The detail description of sensitivity analysis and outcomes is fully described in Chapter 8.

4.7 Life Cycle Cost Analysis and Relationship Framework

This section firstly describes the relationship framework for a LCCA including all cost components with uncertainties including the discount rate and the future electricity. In addition, this section also includes the explanation of a statistical approach employed in this study and independent and dependent variables in statistical analysis.

4.7.1 Relationship Framework

After cost data for all considered scenarios was developed by the previously described cost development procedures, various analyses were performed to identify the relationship between first costs related to GBSTs related to “Optimize energy performance” and LCC. In this study, LCC only included first costs, annual operating and maintenance costs, and repair costs and excluded the costs related to renovation or alternation and disposition of the facility. Given this information, the study identified the relationship between first cost related to alternatives in each GBST and their energy saving. By conducting this analysis, it was possible to identify the relationship between first cost of GBSTs and the magnitude of energy saving by incorporating GBSTs. In addition, this study identified how changing alternatives of GBSTs could affect a facility’s first costs, operating costs, maintenance and LCC. Second, this study conducted sensitivity analysis to identify how uncertainties including discount rates and the future electricity price indices could affect the relationships between first costs related to GBSTs and LCC. By varying future electricity price indices and the discount rates in a LCCA, it was possible to investigate relationship changes and also draw conclusions about the degree of uncertainty. Third, this study also identified how integrating alternatives of GBSTs can affect the relationships between first costs and LCC. From the identified relationships between first costs and LCC, this study developed a relationship framework which could help facility decision makers to make a green facility decision. Figure 4.5 shows the relationship framework which demonstrates the relationships between first costs related to GBSTs and LCC. For example, the different heat pump systems influence its first cost, operating cost, and repair and maintenance cost. Therefore, the different wall insulation levels also have an effect on LCC as an outcome of LCCA.

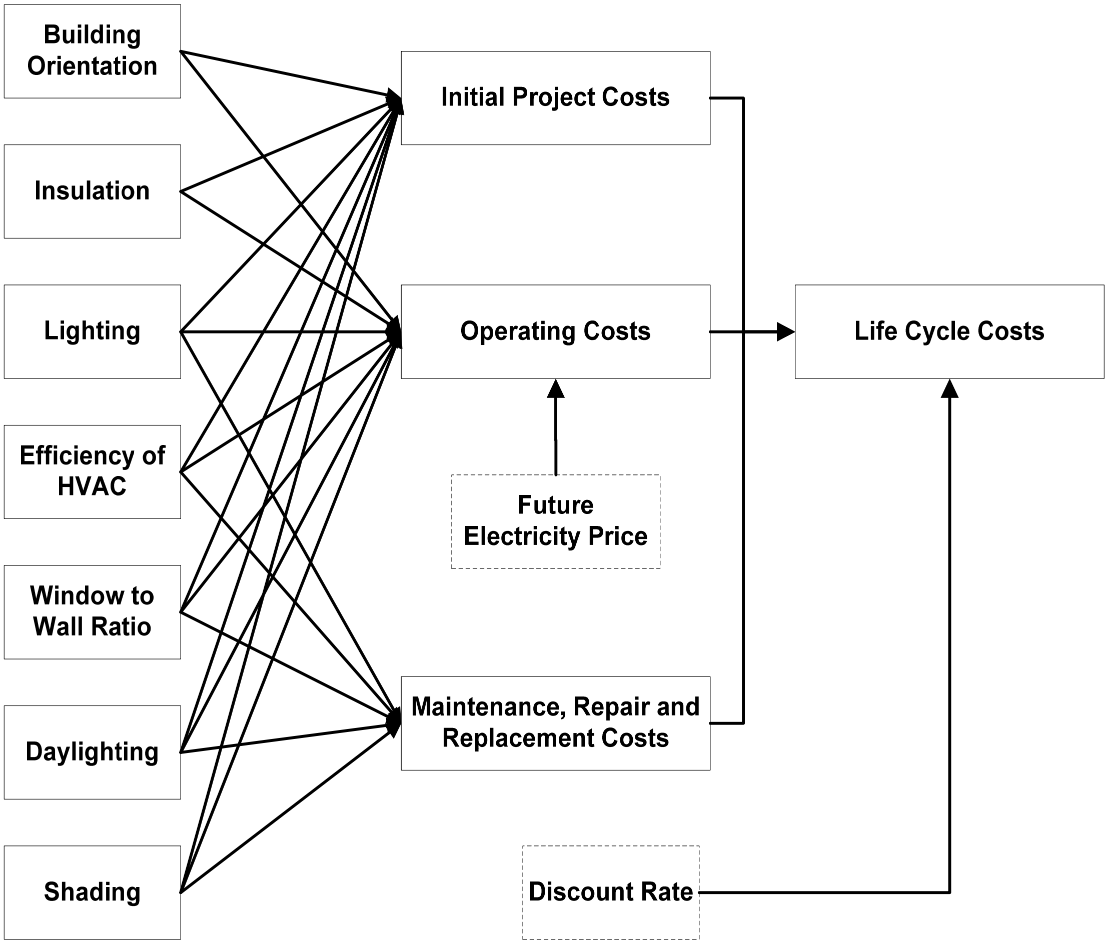

Figure 4.5 Relationships between first costs related to green building strategies and technologies and LCCs

4.7.2 Statistical Analysis (Regression Model)

In construction, several modeling techniques including GA, neural network, agent-based modeling, and regression analysis have been used to accurately forecast construction costs and indentify the relationship between first costs and LCC (Ashworth 1988; Bowerman and O'Connell 2003; Lowe et al. 2006). As previously discussed in Chapter 3, this study adopted categorical regression analysis as a modeling technique because it minimized the need to develop mathematical algorithms which would be required in other techniques including genetic algorithms. This approach also has advantages of speed, and a satisfactory degree of accuracy.

To conduct categorical regression analysis, it was necessary to collect data which divided into independent input variables and dependent output variables (Emsley et al. 2002). Once enough data was developed by the cost development procedures, it was necessary to divide these data into independent input variables and dependent output variables to identify relationships among variables. Table 4.3 shows input variables and dependent output variables in this study.

Table 4.3 Input and output variables

Input Variables	Output Variables
• Building orientation • Wall insulation level • Roof insulation level • HVAC system type • First costs • Operation costs • Maintenance costs • Repair and replacement costs • Window to wall ratio • Shading • Daylighting • Lighting	• Life Cycle Cost

As there were many input variables in this study, this study conducted multiple regression analyses. To conduct multiple regressions, this study used statistical analysis software of SPSS V. 17 among other analysis software including JMP and SAS. From multiple regressions, this study developed a regression model to identify the relationship between first costs GBSTs and LCC in public green facilities which were similar facility types and uses. In addition, this study could be efficient for many of those located in same region. The full description of procedures, regression analysis and results are described in Chapter 9.

4.8 Conclusion

As described in this chapter, this study firstly chose the USPS as a specific public agency to study, and selected a particular building prototype within the USPS. Second, this study identified specific GBSTs which could be employed to optimize energy performance of this post office facility type. After determining the subset of GBSTs on which to focus, the study developed first cost estimates for each scenario using incremental estimates, estimates of operating, maintenance, repair and replacement costs, and other costs for each scenario using building performance modeling and other sources. These cost estimates were used for the development of life cycle cost models for each scenario. Finally, this chapter described the analysis techniques including multiple regressions that were used to identify the relationships between first costs related to GBSTs and LCC. The next chapter discusses in detail how this study chose a public agency and building type in that agency.

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CHAPTER 5: CHOOSING AN AGENCY AND BUILDING TYPE

5.1 Introduction

The United State Postal Service (USPS) has been selected as a public agency in this study, to develop and demonstrate a framework which can identify the relationship between first costs related to GBSTs and LCC for public sector buildings. This chapter provides necessary background for this decision, including the history and the main business of the USPS, USPS facilities and its response to the green building movement, and the specific post office facility prototype selected to serve as the sample of the study.

5.2 USPS Business

The USPS has a clear mission as follows (USPS 2003):

> *"The USPS provides universal mail delivery service and access to postal services for all customers and all communities."*

Because of this mission, the USPS provides a variety of services to meet almost any mailing need. The major services of the USPS are (USPS 2007c):

- First class mail – Includes postcards, letters, or any other advertisement or merchandise up to 13 ounces.
- Priority mail – This 1-3 day nonguaranteed delivery service is typically used to send documents, gifts, and merchandise.
- Express mail – This overnight money-back guaranteed service includes tracing, proof of delivery, and insurance up to $100.
- Periodicals – Offered for newspaper, magazine, and newsletter distribution and requires prior authorization by the USPS
- Standard mail – Offered for any item, including advertisements and merchandise weighing less than 16 ounces.
- Package services – Offered for any merchandise or printed matter weighing up to 70 pounds.

- Special services – Offers a variety of enhancements that add value to mail service by providing added security, proof of delivery, or loss recovery.
- Money orders – Are offered as a safe, convenient, and economical alternative to sending cash through the mail.

The USPS currently delivers mail to 300 million people at 148 million homes, businesses, and post office boxes in every state, city and town in the United States and in Puerto Rico, Guam, the American Virgin Islands, and American Samoa (USPS 2008c). In addition, the USPS serves more than 7 million customers daily and delivers over 212 billion pieces of mail including letters, cards, ads, payments, and packages each year (Garris 2005; USPS 2008c). From these services, the USPS generated total revenues of over $70 billion along with a net loss of $5,142 million in 2008 (USPS 2007c). Furthermore, the USPS is the second largest employer in the United States with nearly 685,000 career employees (USPS 2008c).

Due to the massive business of the USPS, it is necessary to oversee approximately 34,175 facilities, totaling more than 325.5 million square feet, ranging from 60 square feet to 34 acres under one roof, to support retail, mail processing, maintenance, administrative, and support activities (USPS 2007c; 2008b). In addition, the USPS has a significant vehicle inventory of about 219,552 vehicles (the largest civilian vehicle fleet) (USPS 2007c). These vehicles drive more than 1.2 billion miles each year, and use nearly 121 million gallons of fuel (USPS 2008c). The following sections describe these facilities and their challenges to the USPS.

5.3 Facilities in the USPS

To support its main business, “universal mail delivery service and access to postal services for all customers and all communities”, the USPS has an inventory of over 34,000 facilities (Table 5.1) (USPS 2007c; 2008d).

Table 5.1 Facility inventory of the USPS (USPS 2007c; 2008d)

Facility Inventory	2008	2007	2006
Leased facilities	25,272	25,450	25,567
Owned facilities	8,546	8,437	8,437
GSA/Other government facilities	357	381	408
Total Facility Inventory	**34,175**	**34,318**	**34,412**
Annual rent paid to lessors (dollars in millions)	$1,011	$973	$1,002

Within the USPS facility inventory, facilities can be divided into retail and delivery facilities and processing facilities in as shown Table 5.2 & 5.3 Among the retail and delivery facilities, the majority are post offices, classified stations, classified branches and contact postal units (USPS 2007c). From the USPS statistical data, there are over 27,000 post offices, 1,493 classified branches, 3,358 classified stations, 658 carrier annexes, 3,148 contract postal units, and 834 community post offices (Table 5.2) used to provide mailing services to the public (USPS 2007c; 2008d). The main purposes of the retail and delivery facilities are to support the retail and delivery operations located in virtually every community across the United States (USPS 2008d). In addition, the processing facilities typically support mail processing operations, which process millions of pieces of mail on a daily basis and prepare them for transportation across the United States (USPS 2008d). Finally, the USPS has approximately 1,000 other facilities which include administrative, vehicle maintenance, and miscellaneous support facilities (USPS 2008d).

Table 5.2 Retail and delivery facilities (USPS 2007d; 2008d)

Retail and Delivery Facilities	2008	2007	2006
Post offices	27,232	27,276	27,318
Classified branches	1,493	1,508	1,522
Classified stations	3,358	3,379	3,457
Carrier annexes	658	532	578
Contact postal units	3,148	3,131	3,014
Community post offices	834	895	937
Total Retail and Delivery Facilities	**36,723**	**36,721**	**36,826**

Table 5.3 Processing facilities (USPS 2007d; 2008d)

Processing Facilities	**2008**	**2007**	**2006**
Processing and distribution centers	269	269	269
Customer service facilities	195	195	195
Bulk mail centers	21	21	21
Logistics and distribution centers	14	14	11
Annexes	64	66	66
Surface transfer centers	20	14	17
Airmail processing centers	20	29	77
Remote encoding centers	6	10	12
International service centers	5	5	5
Total Processing Facilities	**614**	**623**	**673**

Since the USPS has leased many facilities (Table 5.2), there are also significant total rental expenses. In 2008, the USPS spent over $1 billion for both $967 million of non-cancelable facilities including related taxes and $44 million of facilities leased from USGSA subject to 120-day cancellation (USPS 2008d).

In addition to annual rental expense for the leased facilities, the USPS invested over $548 million for facility improvements and $459 million for construction and facility purchase in the fiscal year of 2007 (USPS 2008d). Furthermore, the USPS also spent over $711 million for repairs and maintenance of facilities (USPS 2008d) during this period. This expense has significantly increased from $665 million in 2007 and $641 million in 2006 (USPS 2008d). This data shows that the USPS has to manage its facility inventory to not only support the USPS business mission but also to manage the USPS expenses related to facilities.

5.4 Challenges and Issues Associated with USPS Facilities

The USPS has experienced growing financial difficulties and has struggled to fulfill its primary mission of providing universal postal service at reasonable rates while remaining self-supporting from postal revenue (USGAO 2003b). Challenges and issues related to facilities in the USPS are as follows:

- High costs related to its nationwide facilities
- A freeze on capital spending for new facilities
- Vacant and underutilized facilities
- High energy consumption

- Constrained budgets that limit energy projects
- Measurement and data reliability issues.

The following subsections describe those challenges and issues that are related to facilities in the USPS.

5.4.1 High Costs Related to Its Nationwide Facilities

According to the U.S. Government Accountability Office (USGAO) report for the USPS, the important concerns are to control costs and improve productivity (USGAO 2003b). These two concerns are inevitably related to facilities because of the high costs of facilities and because the quality of the facilities significantly influences the occupants' productivity (USGAO 2003b). Due to its significant facility inventories, the USPS has many facility projects and activities as shown in Table 5.4.

Table 5.4 Facility projects and activities (USPS 2008b)

Projects	Completed in 2008	Ongoing
New construction, major renovations, and expansions less than $25 million	29	316
New construction, major renovations, and expansions greater than $25 million	2	8
Building purchase	23	99
New lease construction	9	181
Other lease actions (alternate quarters, new leases, and lease renewals)	4,491	4,049
Expense repair and alternation projects	3,471	2,178
Capital repair and alternation projects	5,170	22,211

Due to many activities related to facilities, the USPS spent about $3 billon for investing new facilities, paying rent to lessors, maintaining existing facilities, and paying significant amounts of energy bills as of 2008 (Table 5.5).

Table 5.6 Annual spending for facilities (USPS 2008b)

Items	Amount (Dollars in millions)
Annual rent paid to lessors (Operation and capital)	$1,011
New construction and expansion	$260
Repair and maintenance	$711
Energy expenses for facilities	$651
Other utilities	$277
Total	$2,910

5.4.2 Vacant and Underutilized Facilities

Another problem related to facilities held by the USPS is legal requirements and practical constraints that affect the number and size of its facilities, including a prohibition on closing small post offices solely to avoid operating at a deficit (USGAO 2003b). The USPS has a total of 114 vacant and underutilized facilities including a wide range of facility types – such as office buildings and post offices, and land located throughout the 50 states and in the District of Columbia and Puerto Rico (USGAO 2008a). According to the *High Risk Report on Federal Real Property,* disposal of unneeded facilities is a complicated issue influenced by various laws as well as budgetary limitations (USGAO 2003c). The USPS is specifically precluded from closing small post offices solely for economic reasons. In addition, the USPS is responsible for environmental cleanup of any hazardous substances associated with its facilities prior to disposal, such as asbestos and lead-based paint (USGAO 2003c).

5.4.3 Freezing of Capital Spending for New Facilities

The USPS has continued its freeze on capital spending primarily for new facilities and major renovations (USPS 2008b). Freezing capital spending may have detrimental financial and operational effects on the USPS. These delays may result in higher future capital costs, operational delays, deteriorating infrastructure, deferred maintenance costs and efficiency reductions, and difficulty in meeting demands for providing universal service (USGAO 2008a).

5.4.4 High Energy Consumption

The energy costs for USPS facilities were $651 million in 2008, which is a 6 percent increase over 2007 expenditures attributable to the rapidly rising cost of energy in 2008 (USPS 2008b).

Due to the significant energy consumption along with high energy cost, the USPS has implemented multiple efforts including energy audits, energy management programs, capital improvements of major building systems, and many low-cost and no-cost efforts to counteract and control the energy cost increase (Brown and Ansari 2001; USGAO 2007c; USPS 2008b). In addition, the USPS needs to follow a number of statutes and executive orders directing agencies to reduce energy consumption and greenhouse gas emissions such as carbon dioxide, which results from the combustion of fossil fuels. The statutes and executive orders also direct the USPS to increase the use of renewable energy (USGAO 2008a; USPS 2008b).

5.4.5 Constrained Budgets that Limit Energy Projects

Because of high energy costs and environmental issues, the USPS has implemented several efforts including an energy management plan, highly efficient design of facilities, and capital improvements. However, meeting energy goals and savings requires major capital investment, and such investments must compete with other budget priorities (USGAO 2008a). To overcome budget constraints, the USPS is increasingly turning to alternative financing mechanisms that primarily rely on third parties to fund projects with the promise that the agency will repay the third parties from energy savings (USGAO 2008a; USPS 2008b). In addition, the USPS implements high performance green design approaches to help facilities remain within constrained budget limits (USPS 2008b). The following section describes the problems associated with measurement and data reliability while managing their facilities.

5.4.6 Measurement and Data Reliability Issues

Reliable data is essential for making wise and reliable decisions. Currently, however, many GPAs including the USPS estimate energy use from monthly bills, handwritten ledgers, or other sources that may not be reliable (McNiece 2008; USGAO 2007b; 2008a). To address this challenge, the USPS has recently initiated a Utility Management System (UMS) pilot study to improve data reliability (USPS 2008b). In 2008, the current UMS was established to create a central utility bill verification and payment system that also streamlines and captures energy consumption and cost data for electricity, natural gas, steam, propane, and fuel oil (USPS 2008b). The USPS expects that the UMS will provide detailed utility consumption and cost profiles, bill payment, auditing, rate optimization, tax recoupment, and reporting (USPS 2008b). However, because the UMS is still in pilot study phase, there are still many issues such as missing data and inaccuracies related to data reliability and measurement, according to a discussion with a facilities energy analyst at the USPS, HQ Facilities Energy Management Program in Greensboro, NC (Schubert 2008). In addition, while the UMS will help to normalize energy data collected since its inception, it has not yet provided a way to catalogue or clean up historical data related to facility performance. Thus, accurate, trustworthy, and complete historical data is not widely available for USPS facilities to serve as a basis for effective decision making.

5.5 Green Building Movement

The USPS has been designing and building green buildings for almost 20 years, and it continues to adhere to the basic philosophy of working to balance the objectives of people, planet and expenses (USPS 2008b). Given the magnitude of its operations, the operational practices of the USPS inevitably bring negative environmental impacts. Because of the stated philosophy of the USPS and negative environment impacts from its facilities, the USPS is seeking to employ green building practices for its facilities. The following sections describe:

- History of green building movement and practices in the USPS
- Examples of green USPS facilities
- Current status of green building movement and practices in the USPS
- Emphasized GBSTs in the USPS

5.5.1 History of Green Building Practices in the USPS

The USPS began incorporating Green Building design features in its facilities during the 1990s. In March 1997, a green design addendum was developed as a supplement to the standard design criteria. Since that time, the USPS has completed a number of showcase projects to evaluate different green technologies and practices as described in the addendum (USEPA 2007; USPS 2007b). The following is a partial list of completed showcase facility projects:

- Fort Worth, TX Post Office (The first project, completed in 1998)
- Corrales, NM Post Office (Straw Bale construction)

- Anchorage, AK Distribution Center (five 200-kilowatt fuel-cell system, no longer operational, was the first national commercial application of its kind)
- Raleigh, NC Carrier Annex (compressed wheat straw Structural Integrated Panels (SIP) construction)
- West End, NC Post Office (small standard facility utilizing SIP construction).

After completing these facility projects, the USPS monitored and collected the effectiveness and applicability of GBST for their facilities. The most effective proven by systematic analysis were incorporated into the general design standards for all facility projects (USPS 2007b).

In addition to implementing GBST for building new facilities, the USPS has been governed by government legislation such as EPACT 2005 and EISA 2007 and has also voluntarily committed to follow the High Performance and Sustainable Buildings section of Executive Order 13423 – Strengthening Federal Environmental, Energy, and Transportation Management (USPS 2007b). One of the significant efforts related to EO 13423 requires that new construction and major renovation of facilities complies with Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (MOU) (USPS 2007b). To implement the MOU, the USPS is developing a High Performance and Sustainable Buildings Implementation Plan which will guide green building practices for new facilities and existing ones.

5.5.2 Examples of Green Building Facilities

This section describes GBST which have been implemented at previous USPS facility projects. The following facility projects incorporated many GBSTs. The first green building project was the Fort Worth post office project in Forth Worth, Texas.

5.5.2.1 Forth Worth Post Office

The Forth Worth post office project involved building a 26,000 square foot facility with a budget of $2.5 million in 1999. The post office was primarily constructed from recycled materials, used some of the most innovative energy-efficient systems available, and included features to improve indoor air quality (USEPA 2007). Some specific environmental strategies and technologies included in the post office were the installation of skylights and the use of organic (not chemical) fertilizer for the station's grounds. Additional environmental features of the Fort Worth Post Office are listed below:

- Indigenous landscaping
- 20 percent recycled-content content concrete (contains fly ash)
- Recycled-content gypsum board and ceiling tiles
- 90 percent post-consumer recycled-content steel
- Recycled-content dock bumpers and floor mats (contains recycled tires)
- Recycled-content plastic toilet partitions, tree grates, and workroom bumpers
- Heat-reflecting exterior ceramic coating system
- Energy-efficient low-emissivity glazing
- Natural lighting supplemented by energy-efficient fluorescent lighting with automatic dimming controls
- Full spectrum lighting
- Occupancy sensors installed in infrequently used rooms
- High-efficiency heating, ventilation, and air-conditioning (HVAC) system
- Rainwater harvesting system for irrigation
- Compressed straw exterior wall panels made from alternative agricultural products
- Compressed natural gas refueling station for fleet vehicles.

Based on the experience with this post office, the USPS found that it spent 10 percent more in the first costs for the additional GBSTs (USEPA 2007). The main rationale was that while the project met that 10 percent limit, the USPS expected that the long-term lifecycle cost savings should outweigh the higher first cost (USEPA 2007). From incorporating the mentioned GBSTs, the USPS anticipated to annually save $1,100 of electricity bill and $2,800 of water bill.

5.5.2.2 Corrales Post Office

Another showcase was the post office project in Corrales, NM, a suburb of Albuquerque. This post office project (8,000 sq.ft and $600,000) was designed and constructed to use 1,500 bales of harvested straw for the basic structure and insulation (Anonymous 2000; Garris 2005; USPS 2007b). According to Del Dixon, principal architect with Design Collaborative Southwest Architects of Albuquerque, straw-bale construction involved stacking straw bales in a staggered fashion on steel rebar pins, like giant shish kebabs (Anonymous 2000). Once straw bales were placed, the wall was covered with wire lath on both sides and finished with stucco on the exterior and plaster on the interior (Anonymous 2000). In addition to straw bale construction, this post office project incorporated other green design features such as recycled carpet and a rainwater collection system (Anonymous 2000).

5.5.2.3 Anchorage Distribution Center

The Anchorage distribution center project was the first to install a 1-MW (Five 200-kiowatt fuel-cell system) system of Phosphoric Acid Fuel Cells (PAFC) as a showcase project for the effectiveness of new fuel cell technology. The installed fuel cells generated electricity by converting chemical energy into electrical power with few moving parts (Gilbert 2000; USDOE 2001; Walsh and Wichert 2008). Power generation by means of fuel cells is a emerging technology that provides electricity with high efficiency and little noise (Gilbert 2000; PNAL 2009; Walsh and Wichert 2008). In addition, fuel cells produces no noxious gases that produce acid rain, no particulate pollutants that foul the air, no unburned hydrocarbons during normal operation, and proportionately less carbon dioxide than other, less efficient technologies (PNAL 2009). However, after testing the fuel cell system, the USPS decided to not operate the installed fuel cell system (USPS 2007b).

5.5.2.4 Raleigh Carrier Annex & West End Post Office

The Carrier Annex project involved developing a 50,000 square foot distribution facility project in South Raleigh, North Carolina. This project included a variety of green building materials and methods such as exterior compressed straw construction panels (USPS 2007b). The purpose of this project was to identify the applicability of Structural Integrated Panel (SIP) construction for USPS facilities. The West End post office project was similar to the Carrier Annex project in terms of implementing SIP construction for small standard facilities in the USPS (USPS 2007b).

From these five cases of incorporating GBSTs into facilities in the USPS, the USPS has had a chance to evaluate the applicability of a variety of GBSTs into its facilities. The following section describes the current status of green building activities in the USPS.

5.5.3 Current Status of Green Building Practices

Previous examples show that the USPS has implemented GBST for developing selected new facilities. As previously mentioned, the USPS has been complying with legislation such as EPACT 2005, EISA 2007, and the High Performance and Sustainable Building section of Executive Order 13423 – Strengthening Federal Environmental, Energy, and Transportation Management (USPS 2007b).

One of the first action items currently being undertaken is to integrate high performance and sustainable buildings requirements for all repair, alternation, and new construction projects with the USPS evaluating the implementation of additional sustainability requirements (USPS 2007b). In the high performance and sustainable buildings requirements, the USPS heavily emphasizes that all new construction is being designed to exceed the energy efficiency requirements of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 by 30 percent or the largest amount practicable (USPS 2007b). To achieve this goal of energy saving, the USPS is analyzing how to best adopt the Federal High Performance and Sustainable Buildings guidelines to integrate them into Postal Service construction programs and associated requirements (Pearce et al. 2008; USPS 2007b).

The USPS is also evaluating living roofs for possible installation at a test facility and continuing to evaluate renewable energy systems (USPS 2007b). In addition, the USPS is committed to a significant reduction in facility energy consumption (McNiece 2008; USPS 2007b; 2008b; d). The USPS has attempted to reduce energy costs and consumption by focusing first on the largest facilities, which are estimated to consume about 60% of the total facility energy load (McNiece 2008; USPS 2007d; 2008b). Following energy audits, these facilities receive energy upgrades that meet or exceed federally mandated requirements. The USPS is also making its utility expenses and consumption more visible with its new Utility Management System (UMS) (McNiece 2008; USPS 2007b). The system is being piloted in 600 facilities and provides detailed utility consumption and cost profiles, bill payment, auditing, rate optimization, and reporting. In addition, the USPS has started to develop the Enterprise Energy Management System (EEMS) (Figure 5.1) (McNiece 2008). This system is a tool to help reduce costs, increase efficiency and improve energy planning because it can (McNiece 2008):

- Consolidate all facility energy data
- Normalize and structure data to be useful
- Convert data to actionable information
- Measure and verify results of energy improvements
- Track performance of energy systems and identify anomalies (McNiece 2008).

Finally, the current USPS objective is to reduce energy consumption through strategies, including capital improvements, if it can get at least a 9% Return on Investment (ROI) (McNiece 2008; USPS 2007b).

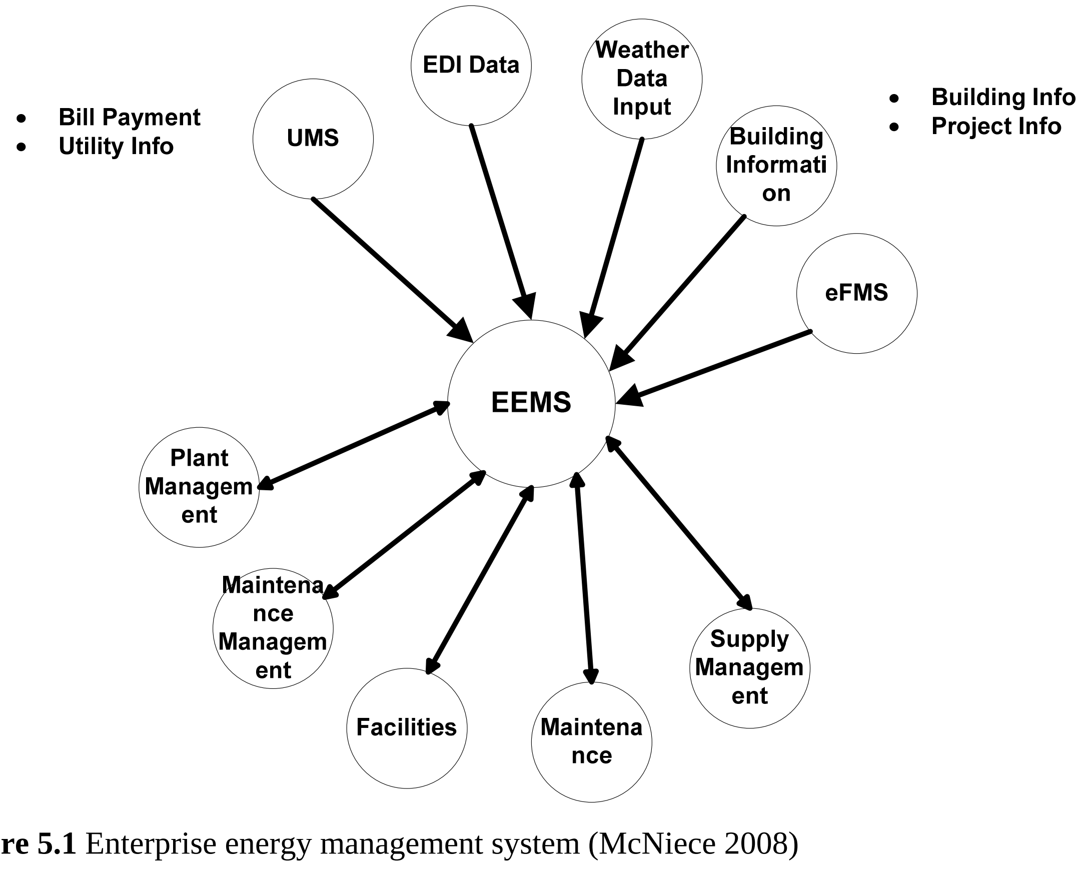


Figure 5.1 Enterprise energy management system (McNiece 2008)

In addition to energy issues for the facilities, the USPS has action plans to implement other aspects of High Performance and Sustainable Building Implementation Plan. The following table summarizes many of the implementation action items from that plan (Table 5.6) (USPS 2007b).

Table 5.6 High performance and sustainable building implementation plan

Action Items

Attain commitment for this plan from the Executive Order 13423 (Strengthening Federal Environmental, Energy, and Transportation Management) Senior Official.

1. Establish a sustainable building information page on the Postal Service Sustainability web page.
2. Determine the minimum standard to qualify a new Postal Service facility as “sustainable.”
3. Establish specific Postal Service targets and criteria for building new sustainable buildings and converting existing buildings to be sustainable.
4. Determine the minimum standard to qualify an existing Postal Service facility as “sustainable”.
5. Develop a draft revision to the Postal Service's standard design criteria for sustainable buildings to incorporate the MOU G*uiding Principles* and the requirements of Executive Order 13423 and its *Implementing Instructions* into new, renovated and existing buildings (owned and leased) that addresses the following topics:
    a) Postal Service policy for sustainable buildings.
    b) Identification of key players in the real estate project approval process and their responsibilities and functional relationships.
    c) Description and use of integrated teams at the earliest stages of project planning for all designated real property projects.
    d) Areas of expertise that the integrated team members should have, such as: sustainable design, energy, environment, commissioning, measurement and verification, water efficiency, facilities, building materials, ventilation and thermal comfort, moisture control, day lighting, indoor air quality, construction waste, and other green building qualifications for the design, construction, commissioning, and operation of the project. Team members may include both Postal and non-Postal contracted project team staff.
    e) Objectives for facility design and construction.
    f) Reporting procedures to demonstrate compliance.
    g) Requirements to enter completed major building projects into the High Performance Federal Buildings database (<www.eere.energy.gov/femp/highperformance/index.cfm>)
    h) Goal that 15% of existing Postal Service capital asset building inventory if practicable, as of the end of fiscal year 2015, incorporates the MOU Guiding Principles.

    The guidance should allow for and encourage continual improvement and include use of the Whole Building Design Guide, when appropriate. The guidance will address prioritization of existing buildings.
6. Issue approved guidance. Publish the guidance on the Postal Service Sustainability web page.
7. Establish guidance for measurement, verification and training to ensure continual improvement in the sustainable buildings program. Clearly define how the measurement and verification will be used.
8. Create procedures for tracking and reporting Postal Service performance targets for exceeding the minimum “sustainable” facility standards for new construction and major renovations.
9. Create a single source document or web page that consolidates or identifies all the current criteria for sustainable buildings including a library of specifications and other reference materials.
10. Develop annual system for reporting Postal Service progress towards addressing the *Guiding Principles* in all building life cycle stages.
11. Begin annual reporting of Postal Service progress toward incorporating the *Guiding Principles* in all building life cycle stages.

5.5.4 Green Building Strategies and Technologies

From the previous sections, the USPS has prepared to actively implement many GBSTs for its facilities in order to maximize potential social and economic benefits while minimizing environmental impacts. This section identifies GBSTs applicable to USPS facilities based on many considerations. They include several federal regulations including the EPACT 2005 and EISA 2007, the Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding, green building practices used by other competitors such as FedEx, UPS and DHL, and the USPS green building goals and polices.

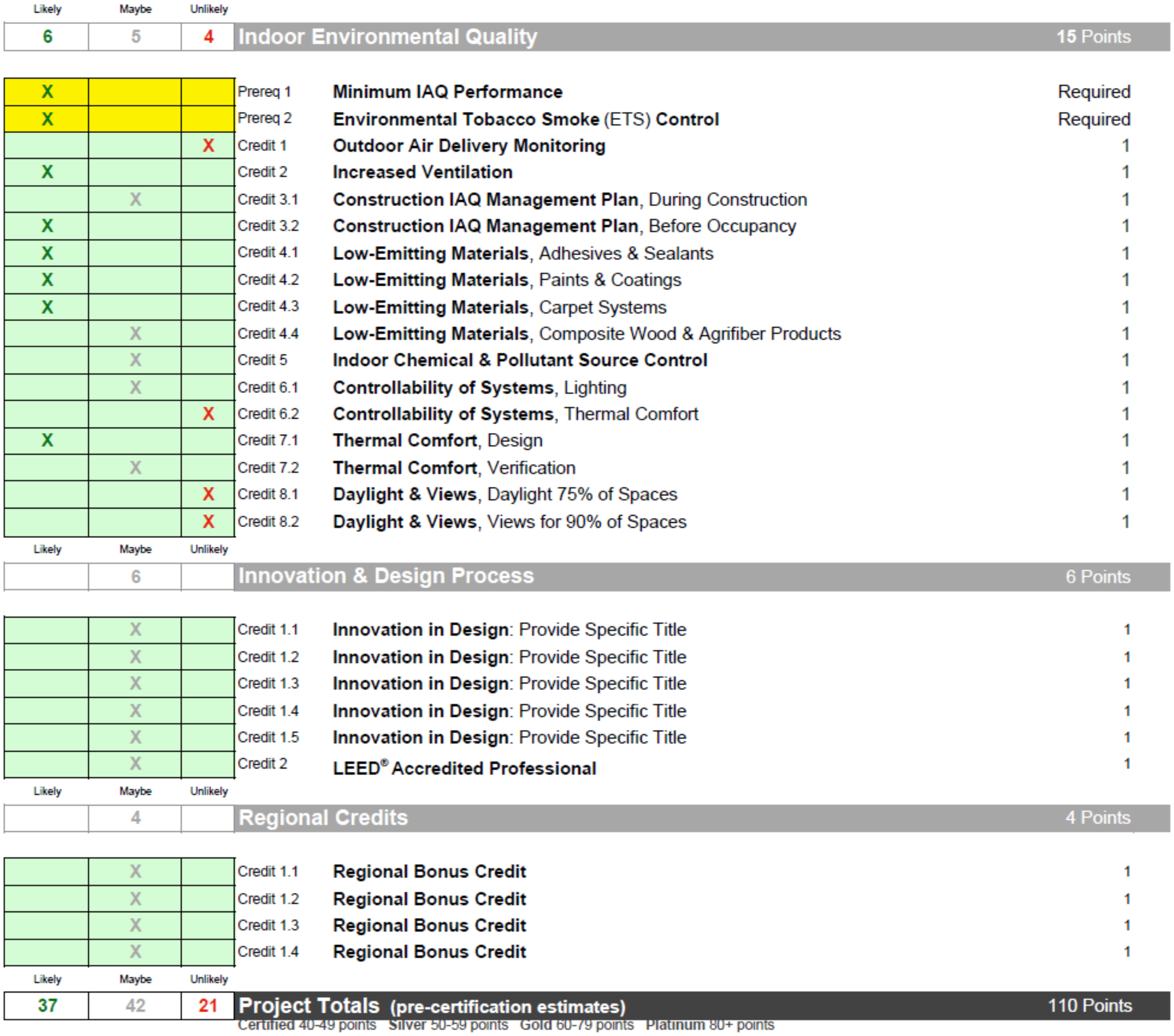
To identify the applicability of certain GBSTs for facilities in the USPS, this study directly quotes and builds on the “LEED Summary Worksheet for USPS Capital Projects” which has been developed by the Sustainable Facility Asset Management Research Team at Virginia Tech (Figure 3.2) (Pearce et al. 2008). The Virginia Tech study classifies each LEED credit into three categories such as “Likely”, “Maybe” and “Unlikely”. “Likely” indicates that the USPS already achieves the LEED credits by easily incorporating LEED suggested GBSTs. “Maybe” indicates that the USPS may achieve the “Maybe” LEED credits by incorporating LEED suggested GBSTs even though it depends on the specific facility. Finally, “Unlikely” indicates that GBSTs in those credits are unlikely matched with the nature of USPS green building considerations (Figure 5.2) (Pearce et al. 2008). Even though this Virginia Tech study does not list specific GBSTs in facilities in the USPS, it suggests what LEED credits are applicable to facilities in the USPS. Investigating GBSTs applicable to specific LEED credits can help to identify applicable GBSTs for the USPS.

Likely	Maybe	Unlikely			
15	10	1	**Sustainable Sites**		26 Points
X			Prereq 1	**Construction Activity Pollution Prevention**	Required
X			Credit 1	**Site Selection**	1
X			Credit 2	**Development Density & Community Connectivity**	5
	X		Credit 3	**Brownfield Redevelopment**	1
X			Credit 4.1	**Alternative Transportation**, Public Transportation Access	6
		X	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
	X		Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles	3
	X		Credit 4.4	**Alternative Transportation**, Parking Capacity	2
	X		Credit 5.1	**Site Development**, Protect or Restore Habitat	1
X			Credit 5.2	**Site Development**, Maximize Open Space	1
X			Credit 6.1	**Stormwater Design**, Quantity Control	1
	X		Credit 6.2	**Stormwater Design**, Quality Control	1
X			Credit 7.1	**Heat Island Effect**, Non-Roof	1
	X		Credit 7.2	**Heat Island Effect**, Roof	1
	X		Credit 8	**Light Pollution Reduction**	1

Likely	Maybe	Unlikely			
4	4	2	**Water Efficiency**		10 Points
X			Prereq 1	**Water Use Reduction: 20% Reduction**	Required
X			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	2
X			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	2
	X		Credit 2	**Innovative Wastewater Technologies**	2
	X		Credit 3.1	**Water Use Reduction**, 30% Reduction	2
		X	Credit 3.2	**Water Use Reduction**, 40% Reduction	2

Likely	Maybe	Unlikely			
9	12	14	**Energy & Atmosphere**		35 Points
X			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required
X			Prereq 2	**Minimum Energy Performance**	Required
X			Prereq 3	**Fundamental Refrigerant Management**	Required
9	10		Credit 1	**Optimize Energy Performance (at 30% using whole building simulation)**	1 to 19
		X	Credit 2	**On-Site Renewable Energy**	3 to 7
		X	Credit 3	**Enhanced Commissioning**	2
	X		Credit 4	**Enhanced Refrigerant Management**	2
		X	Credit 5	**Measurement & Verification**	3
		X	Credit 6	**Green Power**	2

Likely	Maybe	Unlikely			
3	11	0	**Materials & Resources**		14 Points
X			Prereq 1	**Storage & Collection of Recyclables**	Required
	X		Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	2
	X		Credit 1.2	**Building Reuse**, Maintain 95% of Existing Walls, Floors & Roof	1
	X		Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1
X			Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
X			Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
	X		Credit 3.1	**Materials Reuse**, 5%	1
	X		Credit 3.2	**Materials Reuse**,10%	1
X			Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)	1
	X		Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)	1
	X		Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regionally	1
	X		Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regionally	1
	X		Credit 6	**Rapidly Renewable Materials**	1
	X		Credit 7	**Certified Wood**	1



Likely	Maybe	Unlikely			
6	5	4	**Indoor Environmental Quality**		15 Points
X			Prereq 1	**Minimum IAQ Performance**	Required
X			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
		X	Credit 1	**Outdoor Air Delivery Monitoring**	1
X			Credit 2	**Increased Ventilation**	1
	X		Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
X			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
X			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
X			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
X			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
	X		Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
	X		Credit 5	**Indoor Chemical & Pollutant Source Control**	1
	X		Credit 6.1	**Controllability of Systems**, Lighting	1
		X	Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
X			Credit 7.1	**Thermal Comfort**, Design	1
	X		Credit 7.2	**Thermal Comfort**, Verification	1
		X	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
		X	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1
Likely	Maybe	Unlikely			
	6		**Innovation & Design Process**		6 Points
	X		Credit 1.1	**Innovation in Design**: Provide Specific Title	1
	X		Credit 1.2	**Innovation in Design**: Provide Specific Title	1
	X		Credit 1.3	**Innovation in Design**: Provide Specific Title	1
	X		Credit 1.4	**Innovation in Design**: Provide Specific Title	1
	X		Credit 1.5	**Innovation in Design**: Provide Specific Title	1
	X		Credit 2	**LEED® Accredited Professional**	1
Likely	Maybe	Unlikely			
	4		**Regional Credits**		4 Points
	X		Credit 1.1	**Regional Bonus Credit**	1
	X		Credit 1.2	**Regional Bonus Credit**	1
	X		Credit 1.3	**Regional Bonus Credit**	1
	X		Credit 1.4	**Regional Bonus Credit**	1
Likely	Maybe	Unlikely			
37	42	21	**Project Totals** (pre-certification estimates)		110 Points

Certified 40-49 points Silver 50-59 points Gold 60-79 points Platinum 80+ points

Figure 5.2 LEED credit summary Worksheet for USPS capital projects (Pearce et al. 2008).

5.6 Study Building Type

As post office facilities comprise a major portion of the total USPS portfolio (74.2%, Table 5.3), this study concentrates on the building type of post office facility. Among three major post office building types including Major Facilities (Majors), Medium Standard Building Design (MSBD) and Small Standard Building Design (SSBD), this study has selected a post office facility of SSBD after considering the applicability of the developed framework. In addition, the selection of the post office facility in the SSBD was also influenced by the recommendation of Mrs. Teresa Schubert, an energy analyst of HQ Facilities Energy Management Program in Greensboro, NC. The next step was then to identify the prototype post office which is going to be used in this study for the purposes of cost estimating and energy modeling. Based on consulting with Mrs. Schubert, the SSBD prototype post office was selected as the prototype post office facility in this study.

The selected prototype post office is located in the Washington Metropolitan Area (WMA) because the WMA has many post office facilities. To support this choice, this study involved collecting all supported drawings, specifications, and cost estimates of the prototype post office facility from the HQ Facility Energy Management Program in Greensboro, along with information for the contractor and estimator of the prototype post office facility. The size of the prototype post office facility is 6160 SF (Table 5.7). This prototype post office facility is composed of a workroom, lobby, service area, rent-a-box, rest rooms, mechanical room(s), office and a mail platform (Figure 5.3) to provide postal service to the public. Table 5.8 summarizes the general description of the prototype post office facility. In addition, Figure 5.3 and 5.4 present the floor plan and 3D view of the prototype post office facility. This prototype post office was designed and constructed based on the SSBD design guidelines and its specification of the USPS facility design criteria. This selected prototype post office facility provides the fundamental facility data employed in this study.

Table 5.7 General description of the prototype post office facility

Features	Post Office
Location	WMA
Size (SF)	6,160
Number of Floors	1
Weather File	VA_Sterling
Floor Heights	10ft
Roof Type	Pitched roof
Roof Frame Type	Metal frame, 24 in
Roof Material	Asphalt Shingle Roofing
Roof Insulation	R - 30 Batt Insulation
Wall Frame Type	Wood frame, 16 in
Wall Finishes	Face Brick (4”)
Wall Insulation	R – 15 Batt Insulation
Ground Type	4 in. concrete
Windows	7.5 % of gross wall area
Window Type	Aluminum window with Thermal Break
Glazing Type	Double Low E glass
HVAC System	Two Heat Pumps with Air Handling Unit (AHU) Electrical baseboard heating system Electrical resistance system

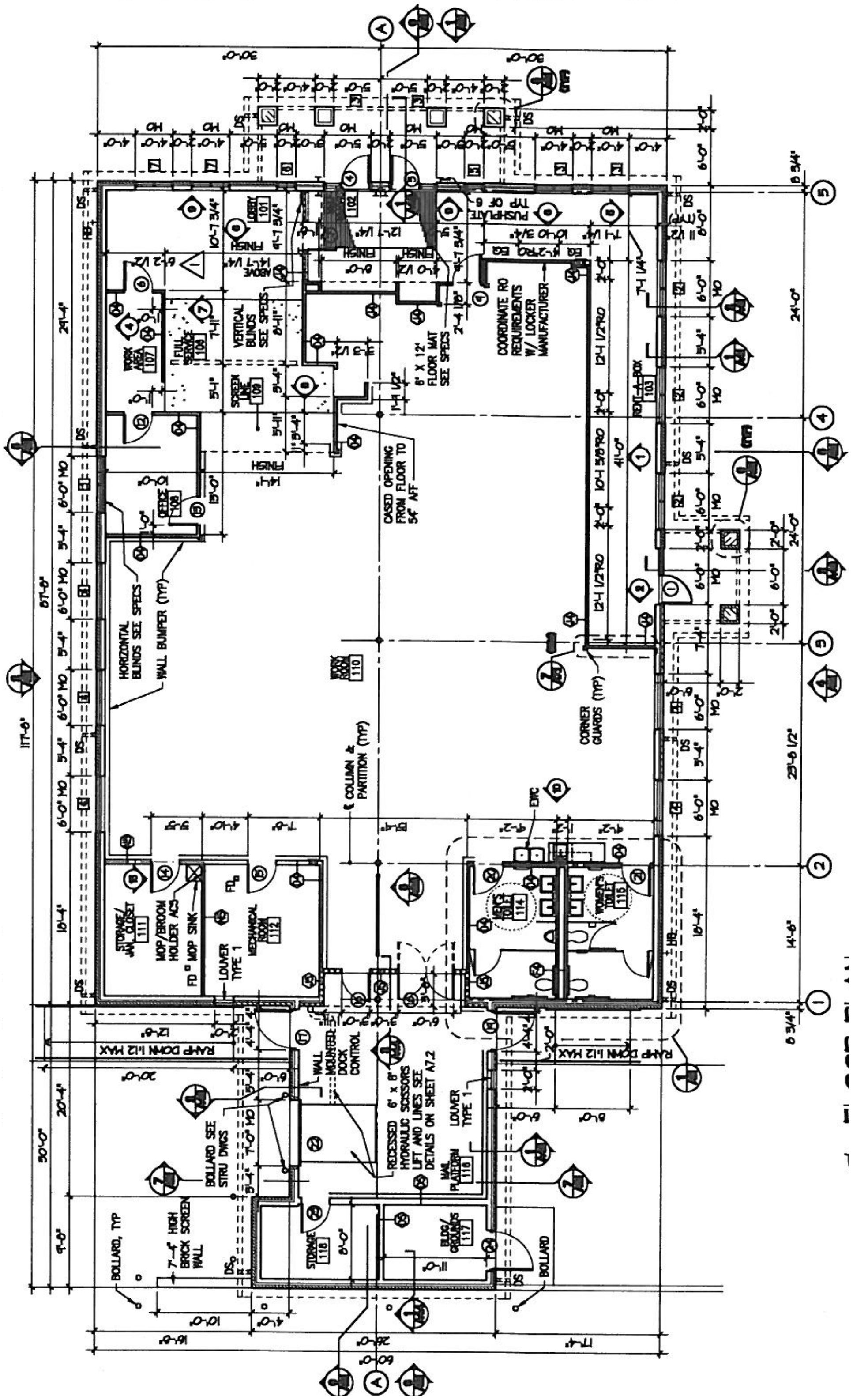


Figure 5.3 Floor plan of the prototype post office (Used with permission of Gauthier, Alvrado & Associates, M. Genovese, 2010)

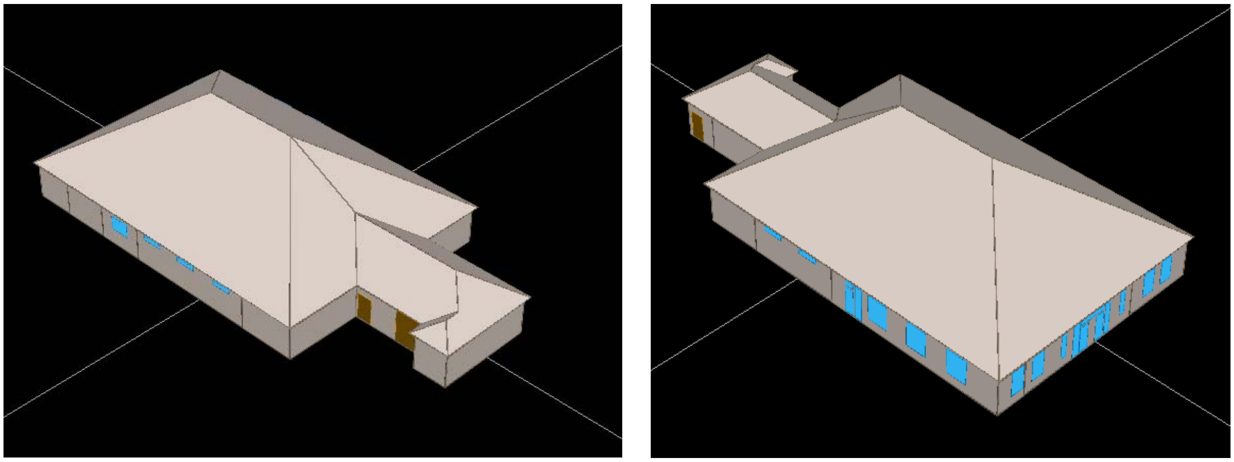


Figure 5.4 3D view of the prototype post office facility

5.7 Conclusion

This chapter described the rationale of why this study has selected the USPS as a public agency among many public agencies. After justifying this choice, the study reviewed and examined the history of the USPS, the business characteristics of the USPS, the relationship between facilities and its business, and the features and characteristics of its facilities. Based on this information, the study identified the current status of USPS facilities and identified challenges and issues related to facilities, including high costs related to its nationwide facilities, a freeze on capital spending for new facilities, vacant and underutilized facilities, high energy consumption of facilities, budget constraints that limit energy projects, and measurement and data reliability issues. In addition, this chapter described the green building movement and challenges associated with implementing green building in the USPS. Finally, this chapter describes the process and rationale for selecting a prototype post office facility which provides baseline data for cost estimating and energy modeling. Given the prototype selected in this chapter, the next chapter focuses on choosing a subset of GBSTs to be used in this study to demonstrate the methodology developed here.

CHAPTER 6: CHOOSING A SUBSET OF GBSTS

6.1 Introduction

The scope of what constitutes “green building” is very large and uncertain, and consists of a large variety of GBSTs. In addition, clear distinction between GBSTs and conventional strategies and technologies are also complicated and project-specific, and different stakeholders in construction also have slightly different understanding of and beliefs about GBSTs. To make the scope of this research manageable and demonstrate the methodology and framework developed here, this study chose a subset of GBSTs which had an effect on first cost related to GBSTs and LCC over the facility life. To accomplish this selection, this study firstly identified and listed many GBSTs in construction by reviewing credits in green building rating systems such as LEED and Green Globes, green building design guides, green building legislation, policies and regulations, and many case studies of green buildings. Based on many GBSTs which have been implemented in construction, this study developed selection criteria to narrow down a subset of GBSTs. By completing the defined selection process, this study identified specific GBSTs which could optimize energy performance in facilities. Thus, this chapter starts with identifying and listing of GBSTs in construction.

6.2 Choosing a Subset of GBSTs

Several studies have identified the relationship between LEED credits and their first cost and LCC impact, summarized in Table 3.1 & 3.2. However, there is a difference between a LEED credit and a GBST. A LEED credit is a performance-based requirement that specifies a level of performance a building must achieve in a particular area, for instance with regard to amount of water consumption or energy use. A GBST, on the other hand, is a type of strategy or technology employed to achieve the performance requirement, such as a low-flow faucet or an energy-efficient light fixture. Thus, this study started with a large list of GBSTs and then narrowed that list by identifying high priority credits, then choosing GBSTs that specifically contribute to those credits.

6.2.1 Identifying Green Building Strategies and Technologies

GBSTs have been identified and developed to achieve multiple objectives of sustainability in the built environment. These objectives includes the minimization of environmental deterioration, and the maximization of social and economic benefits, by diminishing water, energy, material, and resource consumption, reducing air, water, and soil pollution, and improving indoor environmental quality. To identify and collect GBSTs in construction, this study began with a list of over 200 GBSTs (Best Available Technologies and Strategies (BATS)) to achieve LEED NC credits identified by the Sustainable Facility Asset Management (SFAM) research team at Virginia Tech (Appendix D) (Pearce et al. 2009). Among many GBSTs in construction, this study narrowed down a subset of GBSTs which could influence not only first cost but also LCC. The following subsection descries the selection criteria to choose a subset of GBSTs in this study.

6.2.2 Identifying Selection Criteria

Once the possible population of GBSTs is identified (Appendix D), this study chose a subset of GBSTs. To do this, this study identified and developed the selection criteria for choosing specific GBSTs shown in Figure 6.1 and Table 6.1. As the LEED NC rating system has LEED credits and points with different weightings depends on their ability to impact different environmental and human health concerns (USGBC 2009d), the first step in this study was to examine the number of points in thirty six credits and eight prerequisites of the LEED NC 3.0 green building rating system. As the LEED NC v.3.0 rating system has been designed to guide and distinguish high-performance commercial and institutional facility projects, including office buildings, high-rise residential buildings, government buildings, recreational facilities, and laboratories, it was applicable to the criteria of this study (USGBC 2009e). The main assumption of the first criterion was that the number of points in each credit indicated the relative importance of the credit because the level of LEED certification (the level of green building activities) was based on the number of points earned. In the LEED NC V. 3.0 rating system, system developers significantly reallocated point weightings to better align credits with the relative importance of the environmental problems they purported to address (USGBC 2009e).

Previous green building cost studies suggested that additional costs associated with incorporating GBSTs were one of the most significant barriers of implementing green building in both the public and private sector (Ahn and Pearce 2007; OFEE 2003; Sterner 2002). Due to this circumstance, this study also considered the first cost premiums and potential LCC savings as major selection criteria (Second and Third Criterion) for choosing appropriate LEED credits (Figure 6.1).

The fourth criterion of narrowing down GBSTs was to identify specific LEED credits which potentially required high first cost premiums and also have significantly impact on LCC savings. This relationship between first cost and LCC indicated that if a decision maker invests additional resources into those specific credits, it consequently has the potential to reduce operation and maintenance costs of facilities during a specified operation phase of facilities. The fifth criterion was to investigate current status of public agencies and the feasibility of implementing each LEED credit by public agencies, especially the USPS. Through five selection criteria, this study selected a specific LEED NC credit which encompassed the essential GBSTs while developing new facilities.

For the specific LEED NC credit selected, this study reviewed applicable government legislation, rules, policies, regulations, and incentives. The main reason was that these policies, legislation, and regulations significantly affected public green facilities in the public sector. Through this process, it was possible to fully support the importance of the selected LEED NC credit as a way to choose from among the many possible GBSTs that could be analyzed. The outcome of this selection process was a set of independent variables in this study to identify the relationship between first cost premiums related to GBSTs and LCC savings. Once the specific criteria were identified and developed, this study pursed the process of selecting a subset of GBSTs.

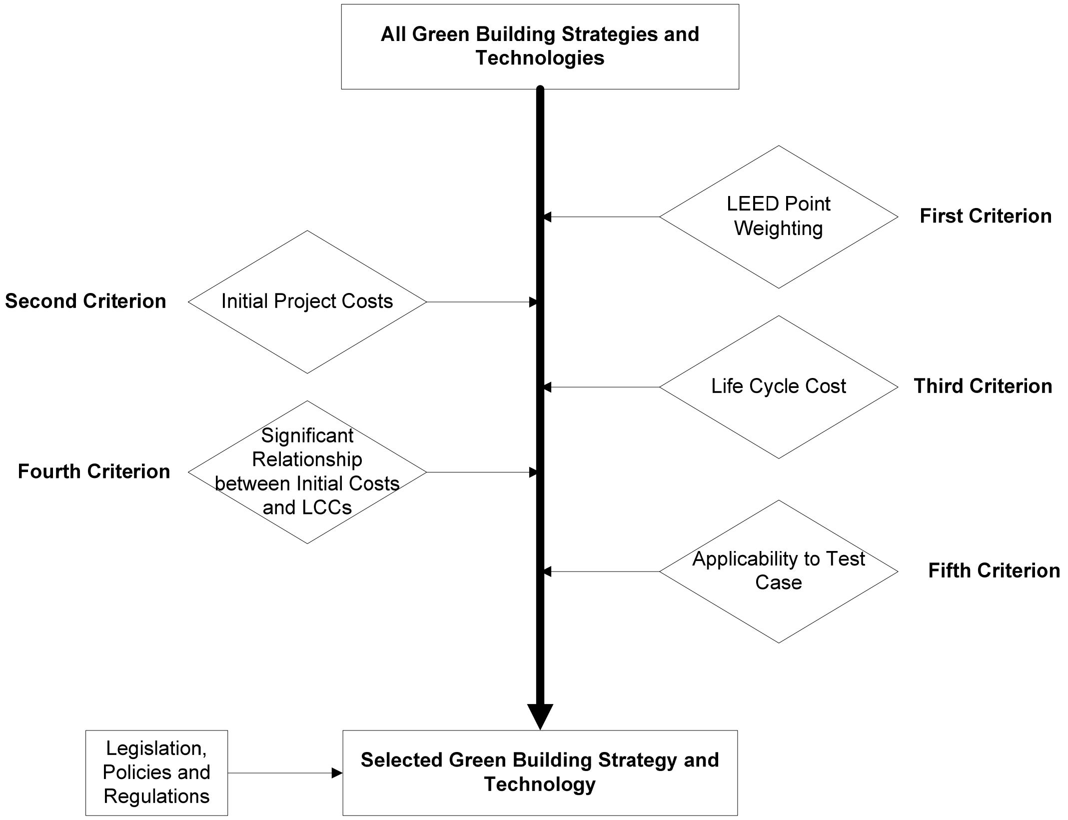


Figure 6.1 Five criteria with one consideration to narrow down green building strategy and technology

6.2.3 Choosing a Subset of GBSTs

Since After establishing the selection criteria for choosing a subset of GBSTs, the following subsections describe these criteria in greater detail and describe their application to select a subset of GBSTs for use in this study.

6.2.3.1 Number of Points in the LEED NC Rating System

The current version of the LEED-NC is version 3.0 which has been used since June 2009, before which LEED NC v2.2 was utilized until June 2009 (USGBC 2007; 2009e). Due to the transition period, this research considers both LEED-NC v2.2 and v3.0 as the first criterion of choosing a subset of GBSTs. From the LEED NC v.2.2, there are sixty-nine points in thirty-two credits with seven prerequisites (Appendix A) (USGBC 2007). Two credits within the energy and atmosphere category - “Optimize energy performance” and “On-site renewable energy” - have more than one point. The credit of “optimize energy performance” has a total of 10 points and the credit of “on-site renewable energy” has three points (USGBC 2007). In the LEED NC v. 3.0 (Appendix A), the rating system has been dramatically changed from the LEED NC v.2.2 in terms of number of points in the credits. The LEED NC v.3.0 emphasizes credits in the areas of development density and community connectivity, public transportation, water efficiency, and energy and atmosphere, and also introduces regional bonus credits. From the LEED NC v.3.0, the most strongly emphasized credits are as follows:

- Optimize energy performance (19 points)
- On-site renewable energy (7 points)
- Alternative transportation: public transportation access, low-emitting & fuel efficient vehicles, and parking capacity (10 points)
- Development density & community connectivity (5 points)
- Measurement & verification (3 points)
- Water efficient landscaping, reduce by 50%, and no potable use or irrigation (4 points)
- Innovative wastewater technologies (2 points)
- Water use reduction, 30% reduction and 40% reduction (4 points)
- Enhanced commissioning (2 points)
- Enhanced refrigerant management (2 points)
- Green power (2 points)
- Building reuse, maintain 75% of existing walls, floors & roof (2 points).

6.2.3.2 LEED Credits with High and Medium First Cost Premium

Identifying specific LEED credits for this criterion was mainly based on two LEED cost studies for public facilities conducted by the U.S. General Services Administration (USGSA) and the U.S. Department of Health and Human Services (USDHHS) (USDHHS 2006; USGSA 2004). Other LEED cost studies supported the selected LEED credit and increased the validity of selection process. The purpose of the two LEED cost studies was to evaluate the potential cost impacts for implementing a LEED rating system. The USGSA study examined prototype examples (courthouse and office building modernizing) and the DHHS’s study examined one prototype example (health care facility).

Identifying the first cost premium of LEED credits was very critical for implementing green building because many public agencies consider it as one of the most important decision criteria for facility asset investments (Office of Federal Environmental Executive 2003). Based on two cost studies, it was possible to identify moderate and high first cost premiums for LEED credits, which are summarized in Table 6.1.

Table 6.1 Selected LEED points with high and medium cost premium

DHHS High Cost Premium	**GSA High Cost Premium**
• Stormwater design: quantity and quality control • Optimize energy performance • On-site renewable energy	• Optimize energy performance • On-site renewable energy • Certified wood • Low-emitting materials (Composite wood)
DHHS Medium Cost Premium	**GSA Medium Cost Premium**
• Brownfield redevelopment • Heat island effect: Non-roof • Innovative wastewater technologies • Low-emitting materials (Composite wood)	• Water use reduction: 30% reduction • Measurement & verification • Recycled content • Regional materials • Carbon dioxide monitoring

6.2.3.3 LEED Credits with Life Cycle Cost Impacts

In addition to first cost premiums related to GBSTs, the next criterion was to identify GBSTs which significantly influenced the LCC of a project. Identifying LCC impacts had strong relationships with several factors such as location, facility type, facility use pattern, etc. Therefore, this study examined one of the LEED cost studies conducted by the U.S. Department of Health and Human Service and selected five LEED credits which had considerable LCC impacts in that study (USDHHS 2006). The selected five LEED credits were (USDHHS 2006):

- Alternative transportation, low-emission & fuel efficient vehicles
- Heat island effect, non-roof & roof
- Water efficient landscaping
- Optimize energy performance
- On-site renewable energy

Through the first cost premium and LCC impact caused by LEED credits, it was possible to narrow down the population to two LEED credits, “Optimize energy performance” and “On-site renewable energy” which both required high first cost premiums AND provided significant LCC saving opportunities. These two credits also had an inherent relationship because lowering the overall energy use of the facility reduced the amount of renewable power needed to achieve this credit (GSA 2004).

6.2.3.4 Green Building Strategies and Technologies in the Public Agency

Since this study selected one of the public agencies as a baseline for this study, it was necessary to identify the applicability of the selected LEED Credit(s) for the specific agency. As this study has selected the USPS as a public agency, this section identifies the most applicable LEED credit(s) in the USPS. The detailed reason of selecting the USPS as a public agency was discussed in Chapter 5. As mentioned earlier, the USPS oversees 34,175 building facilities nationwide, totaling more than 323.8 million square feet, spent over $2.35 billion for energy ($1.74 billion for transportation and $0.61 billion for utilities including energy) in 2007, and annually invests approximately $150 million to reduce energy consumption (USPS 2007a). In addition, the USPS has attempted to develop a customized green building rating system based on the LEED rating systems which encompasses Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding, EPACT of 2005, EISA of 2007 and additional GBSTs (Pearce et al. 2008). In all GBSTs, the USPS heavily emphasized issues related to energy consumption of post office facilities because of the number of facilities and magnitude of operating costs for their energy (Brown and Ansari 2001; Garris 2005; USPS 2007b). In addition, Mr. McNiece, the director of the facilities energy program at the USPS indicated that “energy issues” were one of the most important areas for developing new facilities and managing existing ones. Finally, the USPS has already an explicitly stated energy and environmental vision for its facilities: “USPS facilities use less energy and have less impact on the environment.” (USPS 2007b). Given all these factors, optimizing energy performance is arguably one of the most significant green building objectives presently being considered by the USPS.

6.2.3.5 Government Legislation, Policies and Regulations

This section reviews government legislation, polices, rules and regulations such as the Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (MOU), Executive Orders, Energy Policy Act of 2005, and Energy Independence Security Act of 2007. Many public agencies including the USPS, especially at the federal level, are governed by legislation, policies, and regulations when developing new facilities and managing existing ones (Memorandum of Understanding 2006; NAVFAC 2009; The President 2007; U.S. Congress 2005b; 2007). The specific sections of public requirements related to “Optimizing energy performance” are in Table 6.2, Table 6.3 and Table 6.4. These government policies, legislation, and regulations also supported the selection of “Optimize energy performance” in this study.

Table 6.2 MOU and Executive Orders related to “Optimizing energy performance”

Name of Regulation	Content
Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (MOU)	Establish a whole building performance target that takes into account the intended use, occupancy, operations, plug loads, other energy demands, and design to earn the Energy Star® targets for new construction and major renovation where applicable. For new construction, reduce the energy cost budget by 30 percent compared to the baseline building performance rating per the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Illuminating Engineering Society of North America (IESNA) Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential. For major renovations, reduce the energy cost budget by 20 percent below pre-renovation 2003 baseline.
Executive Order 13423 (Section A)	Each Federal agency shall improve energy efficiency and reduce greenhouse gas emissions of the agency through reduction of energy intensity by (i) 3 percent annually through the end of fiscal year 2015, or (ii) 30 percent by the end of fiscal year 2015, relative to the baseline of the agency’s energy use in fiscal year 2003.
Executive Order 13123 (Section 202)	Energy Efficiency Improvement Goals: Through life-cycle cost-effective measures, each agency shall reduce energy consumption per gross square foot of its facilities by 30 percent by 2005 and 35 percent by 2010 relative to 1985.

Table 6.3 Energy Policy Act of 2005

Section	Provisions
102. Energy management goals	• Annual energy incremental reduction goal of 2% from FY 2006 - FY 2015 • Reporting baseline changed from 1985 to 2003 • In 180 days, DOE issues guidelines • Retention of energy and water savings by agencies • DOE reports annually on progress to the President and Congress • DOE recommends new requirements for FY 2016 – FY 2025 by 2014
103. Energy use measurement and accounting	• Energy/electric metering required in federal buildings by 2012 • In 180 days, DOE consults and issues guidelines • Agencies report to DOE 6 months after guidelines issued
104. Procurement of energy efficient products	• Energy Star and Federal Energy Management Program (FEMP) recommended products procurement requirement • Exception when not cost-effective or does not meet agency functional requirements
104 (C). Energy efficient products in Federal categories	• Requires listing of Energy Star and FEMP-recommended products by GSA and Defense Logistics Agency
109. Federal building performance standards	• Buildings to be designed to 30% below ASHRAE standard or International Energy Code if life-cycle cost-effective • Application of sustainable design principles • Agencies must identify new buildings in their budget request and identify those that meet or exceed the standard • DOE must include the agency budget information in the annual report • DOE must determine cost-effectiveness of subsequent standard revisions within one year
111. Enhancing efficiency in management of federal lands	• Energy efficiency technologies in public and administrative buildings to the extent practical • Energy efficient vehicles on public lands managed by the secretaries

Table 6.4 Energy Independence and Security Act (EISA) of 2007

<table>
<tr><th>Section</th><th>Provisions</th></tr>
<tr><td>Section 323</td><td>

In the construction, alteration, or acquisition of a building or leased space by GSA – an estimate of the future performance is to be conducted along with a specific description of the use of energy efficient or renewable energy measures, including Photovoltaics (PV)
Same requirement for energy efficient lighting fixtures and bulbs – also addresses maintenance, EnergyStar®, additional energy efficient lighting designations, GSA guidelines, etc.

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<tr><td>Section 431</td><td>

Establish new energy reduction goals for facilities

<table>
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<tr><td>2</td><td>2006</td><td>18</td><td>2011</td></tr>
<tr><td>4</td><td>2007</td><td>21</td><td>2012</td></tr>
<tr><td>9</td><td>2008</td><td>24</td><td>2013</td></tr>
<tr><td>12</td><td>2009</td><td>27</td><td>2014</td></tr>
<tr><td>15</td><td>2010</td><td>30</td><td>2015</td></tr>
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<tr><td>Section 433</td><td>

Directs DOE to issue revised Federal building energy efficiency performance standards within one year of enactment of Act
For new buildings or building undergoing major renovations requiring a GSA prospectus to Congress or at least $2.5 million, fossil fuels use to be reduced as compared to a similar building's use in FY 2003; percentages may be adjusted downward and sustainable design principles shall be applied.

<table>
<tr><th>Percent</th><th>Year</th><th>Percent</th><th>Year</th></tr>
<tr><td>55</td><td>2010</td><td>90</td><td>2025</td></tr>
<tr><td>65</td><td>2015</td><td>100</td><td>2030</td></tr>
<tr><td>80</td><td>2020</td><td></td><td></td></tr>
</table>

Directs the Federal Acquisition Regulatory Council to consult with the Federal (GSA) and Commercial (DOE) Directors of Federal High-Performance Green Buildings to revise Federal Acquisition Regulation (FAR) within 2 years of enactment of the Act to require Federal officers and employees to comply with the Act's provisions regarding acquisition, construction, or major renovations. Office of Federal Procurement Policy (OFPP) to issue new guidance to all Federal agencies regarding the design of proposed facilities and major renovations.

</td></tr>
<tr><td>Section 434</td><td>

Requires that each Federal agency ensure that major replacements of installed equipment (such as heating and cooling systems) or renovation or expansion of existing space employ the most energy-efficient designs, systems, equipment, and controls that are life-cycle cost effective. Each Federal agency shall:

Develop a process for reviewing each decision made on a large capital energy investment to ensure that the requirements are met
Report to the Director of the Office of Management and Budget on the process established.

</td></tr>
</table>

Section	Provisions
Section 522	- Prohibits, except under certain circumstances, the purchase of incandescent light bulbs.
Section 524	- Encourages Federal agencies to minimize standby energy use in purchases of energy-using equipment.
Section 525	- Federal procurement to focus on ENERGY STAR[2] and Federal Energy Management Program (FEMP)-designated products.

Considering the five selection criteria, government legislation, policies, and regulations, and the status of the selected agency, this study chose a single credit in the LEED NC rating system, “optimize energy performance,” because it has been identified as an important area of achieving the goal of sustainability based on all criteria considered in this study (Table 6.5).

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[2] ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy helping us all save money and protect the environment through energy efficient products and practices Energy Star. (2010). "Energy Star." <http://www.energystar.gov/index.cfm?c=about.ab_index> (January 30, 2010).

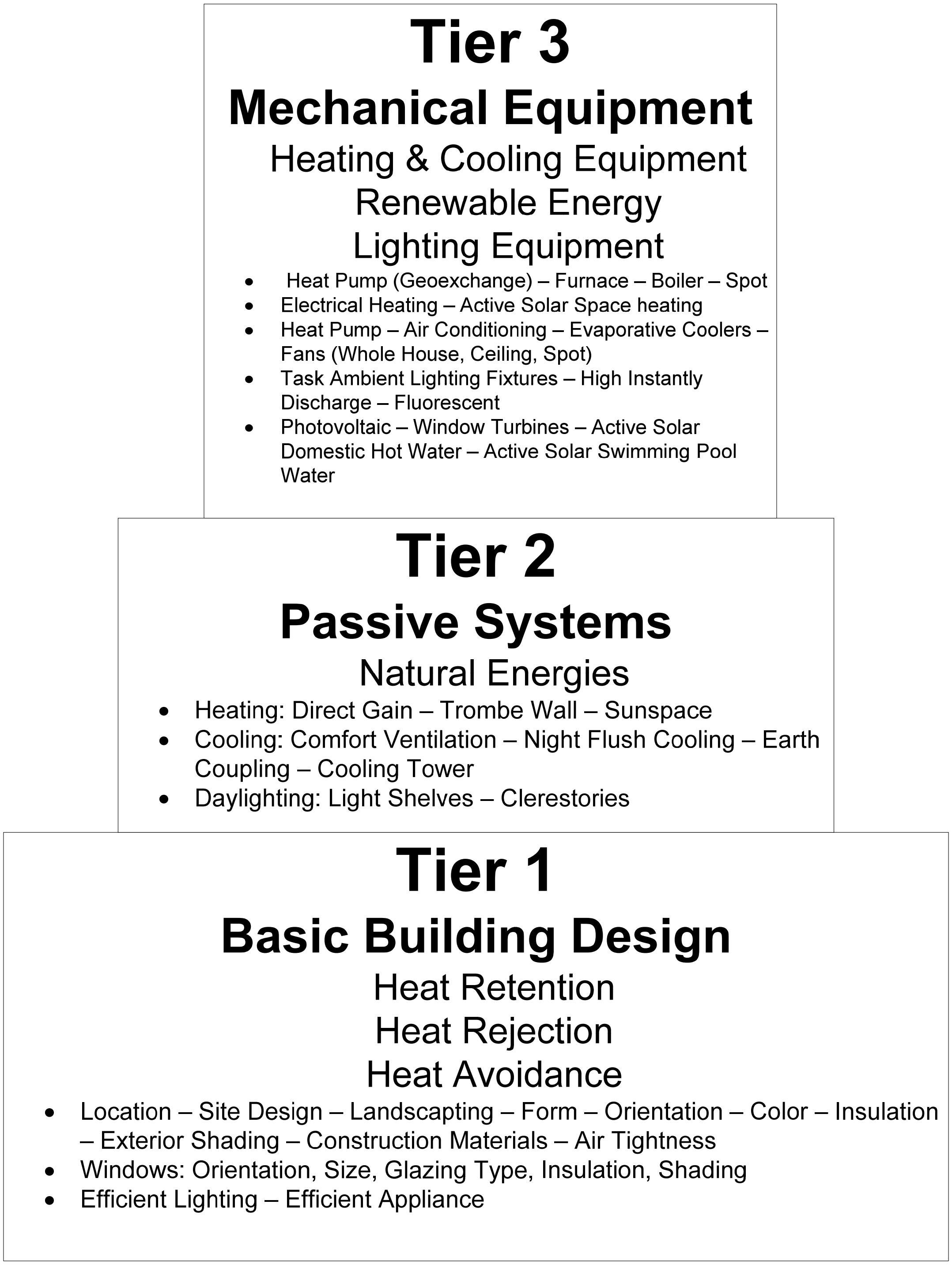
Table 6.5 Selected green building credits from six sources

Sources	Green Building Strategies and Technologies
LEED V. 2.2 (Criteria 1)	• **Optimize energy performance** • Onsite renewable energy
LEED V. 3.0 (Criteria 1)	• **Optimize energy performance** • Onsite renewable energy • Alternative transportation, public transportation Access • Development density & community connectivity
DDHS Cost Study (Criteria 2)	• Stormwater design: quantity and quality control • **Optimize energy performance** • On-site renewable energy
GSA Cost Study (Criteria 2)	• **Optimize energy performance** • On-site renewable energy • Certified wood • Low-emitting materials (Composite wood)
DDHS Life Cycle Cost Study (Criteria 3 & 4)	• Alternative transportation, low-emission & fuel efficient vehicles • Heat island effect, non-roof & roof • Water efficient landscaping • **Optimize energy performance** • On-site renewable energy
USPS (Criteria 5)	• **Optimize energy performance** • Water efficiency

Thus, this study focused on GBSTs to achieve the LEED credit of "optimizing energy performance" while developing new facilities.

6.2.4 Green Building Strategies and Technologies Affecting "Optimize Energy Performance"

Many GBSTs are available to optimize energy performance in a given facility. One of the most prominent studies is the three-tier approach to the design of heating, cooling, and lighting systems for green building by Norbert Lechner (Figure 6.2) (Lechner 2001). The first, highest priority tier is the architectural design of the building itself to minimize heat loss in the winter, to minimize heat gain in the summer, and to use light efficiently. The second tier involves the use of natural energies through such methods as passive heating, cooling, and daylighting systems. The third tier consists of designing and installing energy efficient mechanical equipment using mostly nonrenewable energy sources to handle the heating and cooling loads (Lechner 2001; 2009). This tiering prioritizes potential GBSTs based on the order in which they should be implemented in a project to maximize their effect. Additional specific GBSTs to optimize energy performance in built facilities were summarized in Table 6.6 based on the three tier approach suggested by Norbert Lechner.



Tier 3

Mechanical Equipment

Heating & Cooling Equipment
Renewable Energy
Lighting Equipment

- Heat Pump (Geoexchange) – Furnace – Boiler – Spot
- Electrical Heating – Active Solar Space heating
- Heat Pump – Air Conditioning – Evaporative Coolers – Fans (Whole House, Ceiling, Spot)
- Task Ambient Lighting Fixtures – High Instantly Discharge – Fluorescent
- Photovoltaic – Window Turbines – Active Solar Domestic Hot Water – Active Solar Swimming Pool Water

Tier 2

Passive Systems

Natural Energies

- Heating: Direct Gain – Trombe Wall – Sunspace
- Cooling: Comfort Ventilation – Night Flush Cooling – Earth Coupling – Cooling Tower
- Daylighting: Light Shelves – Clerestories

Tier 1

Basic Building Design

Heat Retention
Heat Rejection
Heat Avoidance

- Location – Site Design – Landscapting – Form – Orientation – Color – Insulation – Exterior Shading – Construction Materials – Air Tightness
- Windows: Orientation, Size, Glazing Type, Insulation, Shading
- Efficient Lighting – Efficient Appliance

Figure 6.2 Three-tier approach to the design of heating, cooling, and lighting (Lechner 2001; 2009) (Used with permission of Norbert Lechner)

Table 6.6 Three-tier design approach (Lechner 2001; 2009) (Used with permission of Norbert Lechner)

Three Tiers	Heating	Cooling	Lighting
Tier 1 Basic Building Design	Conservation • Surface-to-volume ratio • Insulation • Infiltration	Heat avoidance • Shading • Exterior colors • Insulation	Daylighting • Windows • Glazing type • Interior finishes
Tier 2 Natural Energies and Passive Techniques	Passive solar • Direct gain • Trombe wall • Sunspace	Passive cooling • Evaporative cooling • Convective cooling • Radiant cooling	Daylighting • Skylights • Clerestories • Light shelves
Tier 3 Mechanical and Electrical Equipment	Heating equipment • Furnace • Ducts • Fuels	Cooling equipment • Refrigeration • Ducts • Diffusers	Electric light • Lamps • Fixtures • Location of fixtures

In addition to the three tier approach, this study reviewed literature and public government polices to identify current practice of GBSTs to optimize energy performance for built facilities. This study classified GBSTs into two strategies including “Building Design and Passive Techniques” and “Mechanical and Electrical Equipment” and listed various GBSTs related to operating energy performance in Table 6.7 to identify what GBSTs have been prevalently accepted in public facility development.

Table 6.7 Green strategies and technologies for optimizing energy performance

Green Building Design Strategies and Technologies	1	2	3	4	5	6	7	8	9	10	11	Freq. Of Mention
Building Design and Passive Techniques												
Glazing Type (Efficient window)	X		X	X	X	X	X	X	X	X		**9**
Wall to window ratio	X	X	X	X	X	X	X					**7**
Insulation	X		X	X	X		X		X			**6**
Envelope type		X		X	X	X	X	X				**6**
Building orientation		X		X		X	X	X				**5**
Daylighting	X	X	X	X								**4**
Lighting type and intensity	X		X	X								**3**
Roof type						X	X				X	**3**
Shape of building						X						**1**
Natural ventilation cooling		X										**1**
Solar heating and power		X										**1**
Ventilation type					X							**1**
Mechanical and Electrical Equipment												
HVAC systems	X	X	X	X				X				**5**
Water heating type				X	X			X				**3**
Daylighting dimming system	X		X									**2**
Heat recovery system					X				X			**2**
Occupancy sensor (control for lighting)	X											**1**
Economizer			X									**1**
Duct systems			X									**1**

Reference of articles in Table 6.7

Number	Reference	Number	Reference	Number	Reference	Number	Reference
1	(USGSA 2004)	2	(USGBC 2007)	3	(USDOE 2003a)	4	(USDOE 2001)
5	(Verbeeck and Hens 2007b)	6	(Wang et al. 2005a)	7	(Wang et al. 2005b)	8	(Charron and Athienitis 2006)
9	(Hassan et al. 2007)	10	(Migliaccio et al. 2006)	11	(Wong et al. 2003)		

Through Based on frequency of mention as documented in the matrix of Table 6.7, this study selected a specific subset of GBSTs related to optimizing energy performance. Selected GBSTs included:

- Glazing type
- Window to wall ratio
- Insulation
- Envelope type
- Building orientation
- Daylighting
- Lighting type
- HVAC system
- Daylighting dimming system.

Based on selected GBSTs related to optimizing energy performance, the envelope type option was dropped because of issues related to security of the post office facility and prescriptive requirements for envelope type specified by USPS. In addition, the overall strategy of daylighting and a daylighting dimming system were combined into a single category: daylighting. Finally, glazing type was reworded to be included as part of a broader strategy of shading. Thus, this study selected six GBSTs to identify the relationship between first cost related to their first cost premiums and their LCC impact. The six GBSTs include:

- Building orientation
- Insulation
- Shading
- Window and wall ratio
- Lighting type
- Efficiency of HVAC systems

Based on six GBSTs in this study, each of these GBSTs has considerable variation depending on how it is applied in a specific design or construction situation. The following section describes alternatives within each GBST selected for further consideration.

6.3 Alternatives in the GBST

Each selected GBST has variations. For example, in the wall insulation, there are many types of wall insulation including loose-fill insulation, batt and blanket insulation, rigid board insulation, etc., and different levels of available R-value, a measure of thermal resistance. Each of these variations of the GBST are called alternatives in this study. Thus, this section describes the alternatives of each GBST selected for consideration in this study.

6.3.1 Orientation

One of the design considerations for minimizing "Optimize Energy Performance" (OEP) is the orientation of a built facility. According to Balcomb (1992), orientation is about 80 percent of passive solar design. One of the simplest approaches is that solar glazing shall be oriented to the south because in most cases, this orientation gives the best results for both winter heating, summer shading, and daylighting[3] (Grumman 2003; Lechner 2009; Leffers 2009). Figure 6.3 illustrates that south-facing glazing can transmit the maximum solar radiation in the winter while remaining sun can be controlled in the summer (Balcomb and Jones 1998; Efficient Windows 2009). However, east and west window are difficult to shade and should be avoided (Efficient Windows 2009; Lechner 2009). Possibly the greatest advantage of south-facing orientation of the building is that it usually results in a more pleasant and comfortable indoor environment because it is possible to get natural daylighting through windows (Lechner 2009). Based on various productivity studies, daylighting can increase worker's productivity and comfort in office spaces, foster higher student achievement, and decrease energy consumption (Heschong Mahone Group 1999; 2003; Kats 2006).

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[3] All discussion pertains only to the Northern hemisphere.

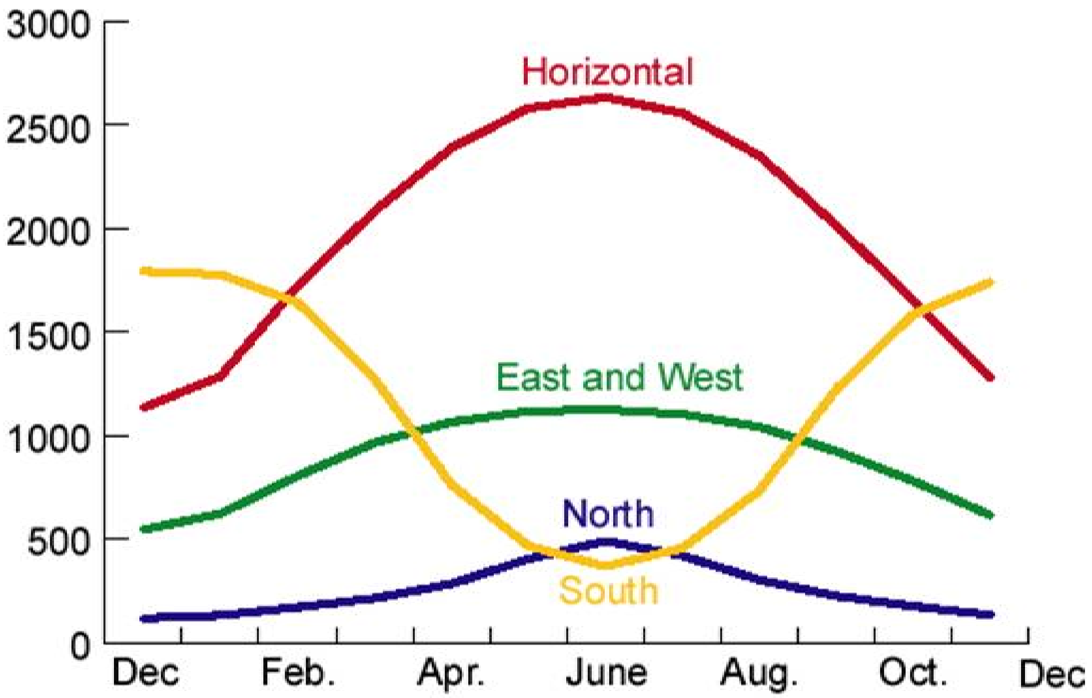

Figure 6.3 Solar transmissions for south glazing at various orientations[4]

Since the building orientation can have significant influence on not only energy consumption but also on the function and appearance of the facility, it is necessary to consider several alternatives for the orientation of the prototype post office facility. Therefore, four different alternatives of the building orientation for the post office facility were investigated in this study. The four alternatives consist of the front of the post office facility being faced toward:

- South
- North
- West
- East

6.3.2 Insulation

Insulation is used in almost every building in the United States to reduce energy consumption and increase thermal comfort. It is relatively inexpensive, durable, and much easier to install

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[4] http://www.nrel.gov/docs/fy02osti/29105.pdf

during first construction than to retrofit later in most cases. The key considerations are which material and how much (Lechner 2009). There is typically a limit to how much insulation should be used, due to the law of diminishing returns (Lechner 2009). The thickness of insulation has to be considered with first cost premiums of thick insulation and LCC saving by reducing annual energy consumption.

In addition to cost issues, large amounts of insulation can contribute to a building's passive survivability. For example, if there is a power failure in the winter in super-insulated building, the indoor temperature will drop more slowly and less far than in a conventional building. Furthermore, the building is less vulnerable from the standpoint of future energy supply and cost uncertainties. Insulation can also save a nation's limited energy resources as well as making the indoor environment more comfortable by helping to maintain a uniform temperature through the building and by making walls, ceilings, and floors warmer in the winter and cooler in the summer (USDOE 2008b).

Due to many important functions associated with insulation, there are various insulating materials which have their own thermal resistance. Table 5.1 describes each insulation material in terms of physical format, resistance, and comments (Lechner 2009; USDOE 2009e). Most insulation materials used in buildings fit into one of the following five categories: blankets, loose fill, foamed-in-place, boards, and radiant barriers (Lechner 2009; USDOE 2008b). In practice, insulation is rated in terms of thermal resistance, called R-value, which indicates the resistance to heat flow (USDOE 2008b). To achieve the desired R-value, the thermal resistance per inch of thickness (Table 6.8) should be divided into the desired R-value to get the required thickness of the insulation material. Even though insulation is not only the contributor to R-value of wall or ceiling assemblies, insulation is a major portion of the R-value of those assemblies.

Table 6.8 Insulating materials and their physical format, resistance and comments (Lechner 2009; USDOE 2009e) (Used with permission of Norbert Lechner)

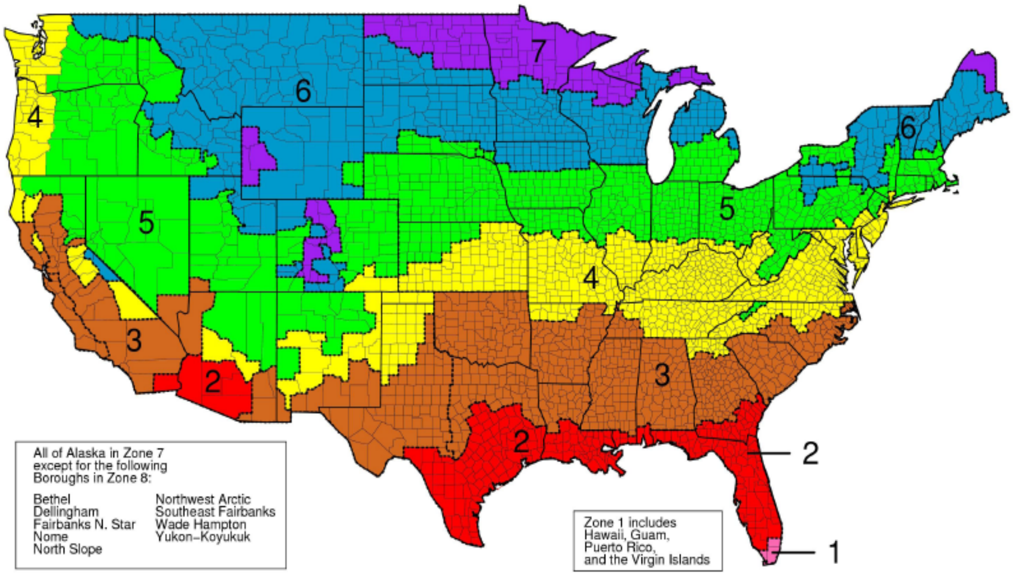
Material	Physical Format	Resistance R (I-P)	Resistance R (SI)	Comments
Fiberglass and Rockwool	• Batts	3 – 4	21 – 28	Good fire resistance
	• Loose fill	2.2 – 3	15 – 21	Hard to completely fill air spaces
	• Boards	3 – 4	21 – 28	Moisture reduces R-values Health danger to installers Use formaldehyde-free types
Perlite	• Loose fill	2.5 – 3.3	17 – 23	Very inert volcanic rock Some dust Very fire resistant
Cellulose	• Loose fill or sprayed	3.2 – 3.7	21 – 26	Made from recycled newspaper treated with borates Easy to fully fill air space Must be kept dry
Cotton	• Batts	3.0 – 3.7	21 – 26	Made from cotton and polyester mill scraps
Kynene	• Spray-in	3.6	25	Plastic foam using water as foaming agent No off gassing Provides air sealing
Air-krete	• Spray-in	3.9	27	All-mineral content Inert Very fire resistant Remains friable
Extruded polystyrene (EPS)	• Boards	3.6 – 4.2	25 – 29	Plastic foam Water resistant Must be protected from fire
Expanded polystyrene (XPS)	• Boards	4.5 – 5	31 – 35	Plastic foam Very water resistant Must be protected from fire Can be used below grade
Polyiso-cyanurate	• Board	5.6 – 6.3	39 – 44	Plastic foam Must be protected from water and fire Some off-gassing Very good sheeting material
Polyiso-cyanurate with foil facing	• Boards	7	49	Like regular polysocyanurate, but has a higher R-value

Material	Physical Format	Resistance		Comments
		R (I-P)	R (SI)	
Urethane	• Spray-in • Spray-on	3.6 – 6.8	25 - 47	Plastic foam R-value is a function of density Must be protected from fire Provides air sealing Forms a skin that is water resistant
Phenolic foam	• Boards	8.2	57	Plastic foam Fire and water resistant Very low off-gassing Good structural strength
Radiant barrier	• Metal film • Reflective foil • Reflective laminated roof sheathing	4 – 12	30 – 80	Radiant barrier must face an air space R-value is a function of air space orientation and direction of heat flow Best for preventing heat gain through the roof
Vacuum	• Panel	15-50	100 – 350	Because most heat flow is through the edges, larger panels are better Quality is most important to prevent loss of vacuum

While designing and constructing a building, designers and contractors have to consider installing insulation into ceilings, walls, floors, and slab edges (Lechner 2009). Due to importance of the level of insulation, the USPS requires meeting the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1-2004 insulation wall and roof requirements for walls (Table 6.9) for each of climate zones (Figure 6.4) (USPS 2008a). ASHRAE 90.1-2004 (specifies the minimum level of insulation for wall and roof (USPS 2008a). In addition, the USPS’ Standard Design Criteria of 2008 also specifies that “If the high level of insulation meets the energy conservation requirements, it is possible to provide higher R-value than those listed in ASHRAE 90.1-2004 standard.” (ibid). In addition, small standard building design (SSBD) drawings and manuals recommend that it is appropriate to use R-15 for the level of wall insulation and R-30 for the level of roof insulation. This study considered the level of wall and roof insulation because insulation in roof and wall were the most important sections in the post office facility. Thus, this study included three different alternatives for roof and wall insulation. In roof insulation, there were three levels of insulation (R-30, R-49, and R-60) with metal frame structure (Table 6.10). In wall insulation, this study considered three alternatives (R-15, R-21, and R-30) with wood frame structure (Table 6.10).

Table 6.9 ASHRAE 90.1 R-value requirements for wall and roof (ASHRAE 2004; 2007)

Climate	Wall		Roof	
Zone	ASH. 90.1-2004	ASH. 90.1-2007	ASH. 90.1-2004	ASH. 90.1-2007
1	R-13	R-13	R-30	R-30
2	R-13	R-13	R-30	R-38
3	R-13	R-13	R-30	R-38
4	R-13	R-13	R-30	R-38
5	R-13	R-13+3.8	R-30	R-38
6	R-13	R-13+7.5	R-38	R-38
7	R-13	R-13+7.5	R-38	R-38
8	R-13+7.5	R-13+1.6	R-38	R-49



All of Alaska in Zone 7
except for the following
Boroughs in Zone 8:

Bethel
Dellingham
Fairbanks N. Star
Nome
North Slope

Northwest Arctic
Southeast Fairbanks
Wade Hampton
Yukon–Koyukuk

Zone 1 includes
Hawaii, Guam,
Puerto Rico,
and the Virgin Islands

Figure 6.4 Energy code climate zones (Building Energy Codes 2009)

Table 6.10 Insulation alternatives for wall and roof

Alternatives	Wall Insulation	Roof Insulation
Alternative 1	R – 15	R – 30
Alternative 2	R – 21	R – 49
Alternative 3	R – 30	R – 60

6.3.3 Lighting

Lighting is the lumens from a light source which illuminate a surface (Lechner 2009). Lighting is very important for peoples' daily life and health because without proper lighting, people are unable to perform visual tasks and can also suffer from Seasonal Affective Disorder (SAD) (ibid). Lighting can be divided into two types: artificial lighting and daylighting. The following subsection describes these two different lighting types.

6.3.3.1 Artificial Lighting

Lighting represents a significant portion of energy consumption. According to the U.S. Department of Energy (USDOE) (2001), in the U.S. commercial buildings, lighting accounts for twenty three percent of total energy consumption and forty six percent of total electricity consumption. Hawken et al. (1999) also state that in homes and offices from 20 to 50 percent of total energy consumed is due to lighting. Executive Order 13123 and FAR section 23.704 specify that federal agencies have to purchase products in the upper twenty five percent of energy efficiency, including all models that qualify for the EPA/DOE Energy Star product labeling program (USDOE 2000). This includes lighting.

Due to this condition related to energy consumption, the selection of artificial lighting including incandescent, fluorescent, metal halide, high pressure sodium, Light Emitting Diode (LED), and others is one of the key green building approaches to optimize energy performance. In the USPS post office design and construction, the vast majority of interior lighting is designed and constructed with linear fluorescent fixtures (USPS 2008a). Because of this circumstance of the USPS post office, this study only considers interior lighting of fluorescent fixtures. Because there have been significant improvements in fluorescent lighting technologies in recent years, the selection of fluorescent fixture and lamps is important for energy efficiency. Therefore, this study compares two different alternatives of different lighting fixtures including high performance lighting (T5 lighting fixture and lamps) and standard lighting (T8 lighting fixture and lamps). Table 6.11 describes characteristics of two different lighting fixtures and lamps.

Table 6.11 Lighting fixtures with different lamps

Technical Data	**High Performance Lighting (T5)**	**Standard Lighting (T8)**
Luminaire Type	Lithonia SP 28 W T5	Lithonia 2SP 32W T8
Size of Luminaire	2’ X 4’	2’ X 4’
Lamp	Three 28 Watt T5	Four 32 Watt T8
Lamp Output	Rated Lumens: 3050	Rated Lumens: 2850
Ballast	QTP1x28T5UNV PSN/2x28T5UNV PSN	Magnetek Triad OCTIC T8
Ballast Factor	1	0.9

In addition to the types of lighting fixtures, many additional factors affect the number of lighting fixtures in space of the post office facility. These factors include (Janis and Tao 2005):

- Ballast factor
- Voltage factor
- Lamp lumen depreciation factor
- Luminaire dirt depreciation factor
- Reflectance of ceiling, wall, and floor, etc.

With respect to these factors, the factors of voltage and reflectance of ceiling, wall, and floor were held constant and the factors of ballast and lamp lumen deprecation were considered in the selection of types of lighting fixtures. However, luminaire dirt depreciation was independent so that this study considered it because it can significantly affect not only the number of lighting fixtures in the space but also the maintenance cost of lighting fixtures. Therefore, this study considers two different alternatives related to luminaire dirt depreciation. Two alternatives include the cleaning of lighting fixtures for every year vs. every two years.

6.3.3.2 Daylighting

A significant portion of all the lighting energy used by facilities could be saved through daylighting. Daylighting is the controlled admission of natural light into a space through windows, clerestories, or skylights (Ander 2008; Lechner 2009). In addition to the potential opportunity to save energy, daylighting is also strongly related to heating and cooling loads and the performance of occupants inside the facility (Heerwagen 2000; Heerwagen et al. 1997; Heerwagen and Orians 1986; James and Walker 2006; Kats 2003b; 2006; Lee et al. 2006). Furthermore, since daylighting is plentiful on a hot summer afternoon, it is possible to minimize the demand of lighting for electrical power when electricity is most expensive. Therefore, daylight can significantly reduce the cost of electricity because of both the reduced energy use and the reduced “demand charge” (Lechner 2009).

Even though daylighting offers many opportunities to optimize energy performance of the facility, the effectiveness of daylighting in the post office facility is minimal because of the restriction of glazing spaces in the post office facility. These considerations include (USPS 2008a):

- Windows in the administrative offices and related support areas should not exceed 30 percent of the exterior wall area
- If windows are located such that the sill is lower than 7’-0” above grade or above any surface which can provide access from the exterior, all windows on the non-public side of the security wall require security film
- The USPS does not usually install operable windows
- Baseline facility security discourages placing windows in storage rooms, equipment rooms, toilet rooms, locker rooms, or utility rooms.

Because of the comparatively small portion of glazing for the post office facility, this study has not included the daylighting alternative. Therefore, there were four alternatives in lighting in Table 6.12.

Table 6.12 Alternatives of Lighting

Alternatives	Features of Lighting Alternatives
Alternative 1	High Performance Lighting (T5): Annual Lighting Fixture and Lamp Cleaning
Alternative 2	High Performance Lighting (T5): Biannual Lighting Fixture and Lamp Cleaning
Alternative 3	Standard Lighting (T8): Annual Lighting Fixture and Lamp Cleaning
Alternative 4	Standard Lighting (T8): Biannual Lighting fixture and Lamp Cleaning

6.3.4 Window to Wall Ratio

As the thermal resistance of walls and windows is different, window to wall ratio has considerable impacts on operating and maintaining costs, thermal comfort, and occupant performance (Lechner 2009). Furthermore, window to wall ratio also influences the admission of natural daylight into a space which can reduce electric lighting and thereby improve LCCs, increase user productivity and satisfaction, improve user health and well-being, reduce user work stresses and reduce emissions (Ander 2008; Heerwagen 2000; Heerwagen and Orians 1986; Leather et al. 1998; Wilkins et al. 1989). Although there is an opportunity to identify the relationship between first costs associated with window to wall ratio and LCC savings, as previously mentioned in daylighting, the USPS has restrictions on the ratio of windows to walls in post office facilities because of security issues. Thus, window to wall ratio alternatives are not compatible with post office facilities and are not considered in this study.

6.3.5 Shading

Solar heating systems work better in the summer than the winter because there is much more sun in the summer along with high outdoor temperature. Therefore, shading is required to prevent solar heating in the summer and is a key strategy for achieving thermal comfort and minimizing cooling loads (Lechner 2009; Prowler 2008). Even though shading of the whole building is beneficial in summer, shading of the windows is crucial (Lechner 2009). However, shading in the post office facility is minimal because the restriction for the amount of glazing in the building envelope. Therefore, this study does not consider including shading as a GBST to optimize energy performance in the post office facility.

6.3.6 Efficiency of HVAC System

Heating, ventilating, and air-conditioning (HVAC) systems can be the largest energy consumers in built facilities. HVAC systems provide heating, cooling, humidity control, filtration, fresh air makeup, building pressure control and comfort control while requiring minimal interaction between the occupants and the system (Graham 2008; USDOE 2001). It is possible to accomplish significant energy savings by installing and utilizing high-performance HVAC systems, and by improving control of HVAC operations (Boecker et al. 2009; Bolin 2007; Graham 2008). As a heat pump system is the suggested HVAC system for the standard small USPS facility, this study has considered the efficiency of heating and cooling. The Coefficient of Performance (COP) of the heat pump is the ratio of the change in heat at the “output” to the supplied input which represents the heating efficiency of the heat pump. Based on the current heat pump models, this study considered the range between COP of 2.5 to 2.8 after discussion with a HVAC engineer, Jim Keefer, who works for New River Heating and Air located in Blacksburg VA. The Energy Efficient Ratio (EER) is the ratio of output cooling and the input power which represents the cooling efficiency of the heat pump systems. This study also considered the EER range of 12 to 16.15. Therefore, this study considered two alternatives of the HVAC system. The first alternative is the high performance heat pump system with COP of 2.8 and EER of 16.15, and the second is a heat pump system with COP of 2.5 and EER of 12 (Table 6.13).

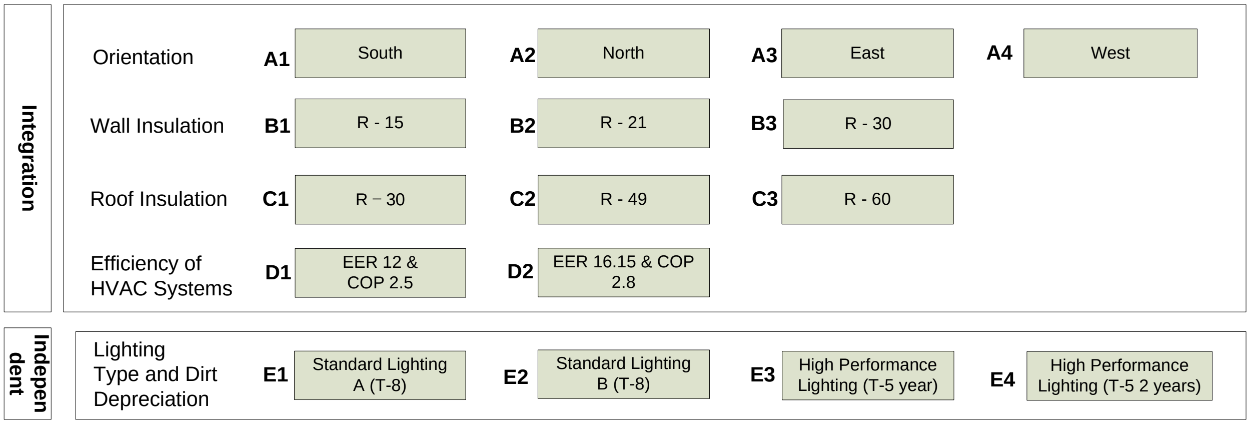
Table 6.13 Alternatives of heat pump systems

Alternatives	Features of HVAC system Alternatives
Alternative 1	Heat pump system with COP of 2.5 and EER of 12
Alternative 2	High performance heat pump system with COP of 2.8 and EER 16.15

Once Having identified and defined relevant alternatives for each GBST in this chapter, the next section describes the integration of those alternatives to optimize energy performance.

6.4 Integration of Alternatives of Green Building Strategies and Technologies

Combination of alternatives in GBSTs (Figure 6.5) is very important to optimize energy performance. However, it is even more important to correctly integrate alternatives of GBSTs to achieve the optimization of energy performance and to seek out design synergies in the building (Mendler and Odell 2000). Through this approach, it is possible to not only solve the problem of first cost premiums of GBSTs but also to achieve the benefits of LCC savings. However, the alternatives in lighting type and maintenance have a slight correlation with the other GBSTs. This indicates that the alternatives related to lighting are independent of the other GBSTs. Thus, this study has not included the lighting type and maintenance in the integration of GBSTs. In addition, daylighting, shading, and window to wall ratio were dropped from the list of integrated GBSTs because these strategies were not applicable to the USPS facility as previously discussed. Thus, this study included four GBSTs including orientation, wall insulation, roof insulation, and HVAC system and permutated alternatives in the GBSTs. Each combination of alternatives of GBSTs was called a “Scenario” in this study. Therefore, there would be 72 scenarios, each represented as “Scenario 1: A_i, B_j, C_k, and D_l”, where the subscript represents the specific alternative within each GBST incorporated into that scenario. These scenarios then serve as the study population for developing simulated cost data to be used in the remainder of the analysis.



Integration	Orientation	A1	South	A2	North	A3	East	A4	West
	Wall Insulation	B1	R - 15	B2	R - 21	B3	R - 30		
	Roof Insulation	C1	R – 30	C2	R - 49	C3	R - 60		
	Efficiency of HVAC Systems	D1	EER 12 & COP 2.5	D2	EER 16.15 & COP 2.8				
Indepen dent	Lighting Type and Dirt Depreciation	E1	Standard Lighting A (T-8)	E2	Standard Lighting B (T-8)	E3	High Performance Lighting (T-5 year)	E4	High Performance Lighting (T-5 2 years)

Figure 6.5 Finalized alternatives of selected GBSTs

6.5 Conclusion

This chapter started by describing the selection process of a subset of GBSTs to be considered in this study. This study systematically selected six GBSTs including building orientation, insulation, lighting, HVAC system, window to wall ratio, and shading to optimize energy performance. Based on those selected GBSTs, this study identified and defined alternatives of each GBST and evaluated the applicability of each in the context of post office facilities. Among seven GBSTs, this study dropped the GBSTs of window to wall ratio, daylighitng, and shading because the applicability of these GBSTs to the USPS facility is limited due to the limited size of glazing in the USPS facility. Based on selected GBSTs, this chapter identified alternatives of each GBST to compare different alternatives. Finally, this chapter permutated alternatives of GBSTs to develop scenarios which represented the integration of alternatives for GBSTs. These scenarios comprise the study population to be used in this study, the cost of which is described next.

CHAPTER 7: DEVELOPING COST ESTIMATES FOR LIFE CYCLE COST ANALYSIS

7.1 Introduction

To achieve the objectives of this study, it is necessary to identify costs of the facility over the life-time of the facility. These costs include first costs, operation and maintenance costs, and repair and replacement costs. In addition, these costs are the base costs of LCCA to calculate LCC of the facility over its life. Therefore, this chapter describes the development of estimates for first costs, operation and maintenance costs, and repair and replacement costs to calculate LCC. The chapter starts by describing the development of estimates for first cost resulting from implementing alternatives of GBSTs.

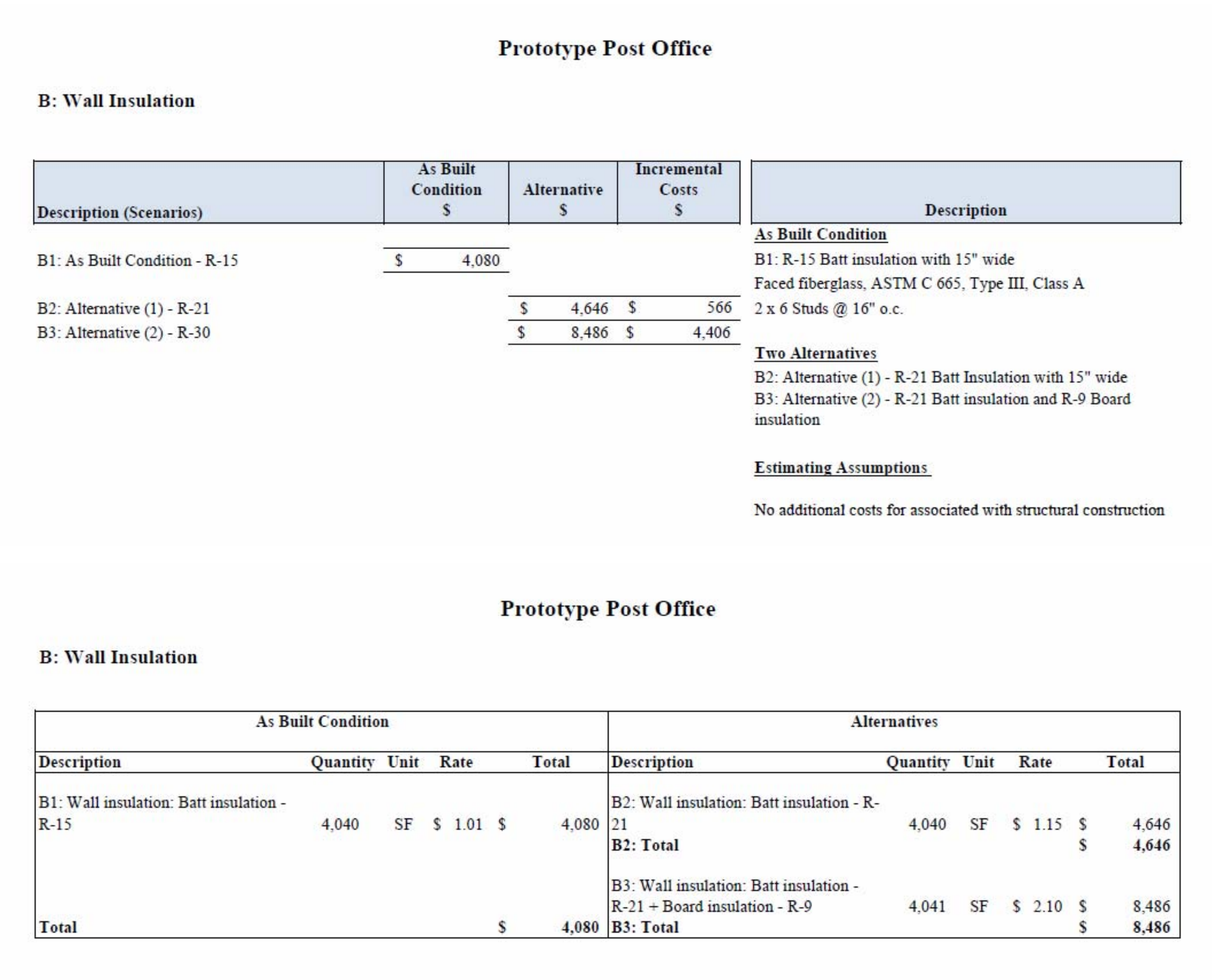
7.2 First Cost Estimates

The probable incremental first cost for first cost resulting from implementing each alternative of GBSTs for the design and construction of the facility in 2009 were identified for this study. The construction cost of the selected prototype post office was escalated to the study point of 2009 from the bid estimates in 2005. Incremental premiums of implementing alternatives of GBSTs were developed based on these construction costs. Thus, the incremental first costs could be added to the prototype estimates to cover the cost of constructing the various energy saving alternatives suggested in this study. The incremental costs of the alternatives of GBSTs were developed based on cost data provided by R. W. Brown & Associates located in Vienna, VA. R.W. Brown & Associates has over 30 years of estimating business experience in the Washington, DC, metropolitan area and has estimated more than 10 post office projects. For instances where R. W. Brown & Associated did not have construction cost data for specific items, this study used representative cost data from R.S. Means Cost Data and R.S. Means Green Cost Data (2009 edition) and material suppliers. The estimating procedures and cost items were also verified by Robert W. Brown, president of R. W. Brown & Associates, to increase the validity and reliability of first cost estimates.

7.2.1 Methodology of First Cost Estimates

The first cost analysis performed for this study applied formal value analysis methodology. This methodology is an appropriate way to capture the cost impact of alternative green building design and construction options by describing a current and proposed approach, costing each, and identifying the differential cost (SWA 2006). The construction estimates in this section reflect for first cost resulting from implementing GBSTs.

In order to measure the construction cost for each alternative of GBSTs, a detailed description of the prototype post office project was needed. Therefore, this study collected all necessary data, including drawings, specifications, and cost estimating data, from the USPS Eastern Facilities Service Office in Greensboro, NC. Estimates were prepared for both the selected design and the various alternatives considered in the base construction documents. A detailed estimate was prepared for each alternative that included both the cost of the as built condition and the range of possible improvements considered for inclusion in that alternative. The detailed estimates for each alternative are reported in terms of their direct construction costs (Figure 7.1 and Appendix E). This process made it possible to estimate each individual first project cost of the chosen alternatives for this study.



Prototype Post Office

B: Wall Insulation

Description (Scenarios)	**As Built Condition $**	**Alternative $**	**Incremental Costs $**
B1: As Built Condition - R-15	$ 4,080		
B2: Alternative (1) - R-21		$ 4,646	$ 566
B3: Alternative (2) - R-30		$ 8,486	$ 4,406

Description

As Built Condition

B1: R-15 Batt insulation with 15" wide
Faced fiberglass, ASTM C 665, Type III, Class A
2 x 6 Studs @ 16" o.c.

Two Alternatives

B2: Alternative (1) - R-21 Batt Insulation with 15" wide
B3: Alternative (2) - R-21 Batt insulation and R-9 Board insulation

Estimating Assumptions

No additional costs for associated with structural construction

Prototype Post Office

B: Wall Insulation

As Built Condition					**Alternatives**				
Description	**Quantity**	**Unit**	**Rate**	**Total**	**Description**	**Quantity**	**Unit**	**Rate**	**Total**
B1: Wall insulation: Batt insulation - R-15	4,040	SF	$ 1.01	$ 4,080	B2: Wall insulation: Batt insulation - R-21	4,040	SF	$ 1.15	$ 4,646
					B2: Total				$ **4,646**
					B3: Wall insulation: Batt insulation - R-21 + Board insulation - R-9	4,041	SF	$ 2.10	$ 8,486
Total				$ **4,080**	**B3: Total**				$ **8,486**

Figure 7.1 Estimates of the first cost premium for the level of wall insulation

The verification of the first incremental costs developed based on the developed green building scenarios was conducted by a highly experienced estimating consultant who had performed many previous estimating exercises for post office projects. In this study, all cost estimating verification was performed by Robert W. Brown, the president of R.W. Brown & Associates in Vienna, Virginia. In order to relate the costs of the prototype post office project to other similar projects, the total project costs were divided by the project area to yield a unit cost expressed in terms of the cost-per-gross-square-foot.

The first cost resulting from implementing GBSTs were estimated as part of the previously described process for each of the alternatives of GBSTs by adding this cost premium to the overall cost of the prototype post office project. To consider all the possible combinations, it was necessary to examine a total of 72 scenarios for this study (Appendix F). In addition, it was necessary to compare first cost premiums for lighting types and lighting maintenance.

7.2.2 First Cost of the Prototype Post Office

The prototype post office estimating data, along with other additional data such as drawing sets and their specifications, were obtained from the Eastern Facility Service Office (FSO) of the USPS. The prototype post office is located in the WMA and its size is about 6160 SF. The prototype post office was built at the end of 2005, so its cost estimates had to be escalated into January 2009 for this study. The escalation rate applied here was 21.7%, which was calculated based on the average rate of R.S. Means rate escalation and the Associated General Contractors escalation rate (Table 7.1). The estimated construction cost of the prototype post office was therefore $1,123,477, divided into 16 CSI master format divisions as shown Table 7.2.

Table 7.1 Construction cost escalation

	RS Means		**Associated General Contractors**	
Year	“Historical Cost Index”	Annual Percent Increase	“Historical Cost Index”	Annual Percent Increase
2002	128.7	2.9%	n/a	0.7%
2003	132.0	2.6%	n/a	2.4%
2004	143.7	8.9%	n/a	9.3%
2005	151.6	5.5%	n/a	7.4%
2006	162.0	6.9%	n/a	4.0%
2007	169.4	4.6%	n/a	4.6%
2008	177.4	4.7%	n/a	3.7%

Table 7.2 Cost estimates for the prototype post office (Used with permission of Gauthier, Alvarado & Associates, M. Genovese, 2010)

DIV	Items	Prototype Post Office	
		Building Costs	**Indirect Costs**
DIV 1	General Requirements		$130,996
DIV 1	General Requirements - Permits & Fees		$60,350
DIV 2	Site Work		$493,095
DIV 3	Concrete	$62,304	
DIV 4	Masonry	$144,463	
DIV 5	Metals	$17,540	
DIV 6	Wood & Plastics	$71,953	
DIV 7	Thermal & Moisture Protection	$69,503	
DIV 8	Doors & Windows	$86,739	
DIV 9	Finishes	$69,211	
DIV 10	Specialties	$15,263	
DIV 11	Equipment	$90,525	
DIV 12	Furnishings	$0	
DIV 13	Special Construction	$0	
DIV 14	Conveying	$8,570	
DIV 15	Plumbing	$53,279	
DIV 15	HVAC	$171,856	
DIV 15	Fire Protection	$0	
DIV 16	Electrical	$145,044	$77,750
	Subtotal	**$1,006,249**	**$762,190**
	General Contractor's OH&P @ 10%	$100,625	$76,219
	Subtotal	$1,106,874	$838,409
	Bond @ 1.5%	$16,603	$12,576
	Total	**$1,123,477**	**$850,985**
	Unit Cost / SF	$182	$138
	Gross Area	6,160	SF

7.2.3 First Cost Premium

Based on the proposed methods described in the above sections, it was possible to calculate the first cost premiums for each scenario. The developed first cost premiums for the scenarios for the GBSTs proposed shown in Table 7.3 and Appendix F. The developed first cost premiums were used in LCCA to calculate LCC and were one of the most important costs considered in this study.

Table 7.3 First cost premiums of the first 10 permutations

ID	Orientation	Wall Insulation	Roof Insulation	HVAC Efficiency	Incremental Costs	Incremental Unit Costs
1	A1	B1	C1	D1	$0	$0
2	A1	B1	C1	D2	$12,529	$2.03
3	A1	B1	C2	D1	$5,514	$0.90
4	A1	B1	C2	D2	$18,043	$2.93
5	A1	B1	C3	D1	$7,617	$1.24
6	A1	B1	C3	D2	$20,146	$3.27
7	A1	B2	C1	D1	$566	$0.09
8	A1	B2	C1	D2	$13,095	$2.13
9	A1	B2	C2	D1	$6,080	$0.99
10	A1	B2	C2	D2	$18,609	$3.02

Since given the first cost premiums of alternatives in GBSTs that have been calculated, the next section describes the calculation of operating costs.

7.3 Operation Cost Estimates

Operating costs are incurred during the operation phase of the post office facility. Therefore, these costs have to be calculated annually over the life-time of the post office facility. In addition, the operation cost of the post office facility is also dependent on the geometry of the post office facility, the behaviors of occupants, and operating schedule of the post office. As a result, the following subsections describe the description of post office geometry and operating schedules.

7.3.1 Description of Post Office Geometry and Operating Schedules

The prototype post office has been briefly described in the Chapter 5, and this section provides a more detailed description of its layout and internal load patterns of the prototype post office. These data are very important for accurately simulating annual operating costs, especially those related to energy consumption.

7.3.1.1 Description of the Post Office

The prototype post office considered in this study, which has a gross area of approximately 6,160 square feet, is considered a small post office. It includes a mechanical room, an electrical and storage room, a work room, a work area, an office, a rent-a-box room, a service area and a lobby.

This study assumes that the prototype post office is located in the Washington Metropolitan Area (WMA); the location was purposely selected on the basis of data availability. The Sterling, VA (TMY2\VA_Sterling-Washington) weather file was therefore used to provide hourly simulations of typical operations. The following subsection describes the internal load patterns anticipated for the prototype post office facility.

7.3.1.2 Internal Load Patterns

The USPS has many different types of facility assets in its portfolio, and building operation patterns differ based on the type, size, and location of each post office. This study must therefore consider internal load patterns, including schedules for occupancy and building operation, for the specific post office facility that is to be constructed. The following section describes how these patterns apply generally in post office facilities across the nation.

Building Occupancy Patterns

Heat gains resulting from the presence of people in the building must be included in the energy simulations. In addition, the number of occupants and their occupancy patterns affect the operation of the HVAC systems and lighting. Discussions with Deborah Crawford, a postmaster in the Blacksburg post office, Greg Stucky, a postmaster in the Beleaton post office, and Terry Schubert, Facilities Energy Analyst, United States Postal Service, HQ Facilities Energy Management Program allowed this study to build up a picture of the number of occupants and typical occupancy patterns, both throughout the day and over longer time scales, that was then used in the subsequent model.

Based on these conversations with USPS staff, the building can be divided into two portions, referred to as the service area and process area in this study. The service area includes the lobby and the self-service and rent-a-box areas. The service areas are open 24 hours a day, 7 days a week. The process area includes the work area, office, work room, storage, rest rooms, platform, and mechanical room. The process area is generally occupied between 7:00 am and 5:00 pm from Monday to Friday and 7:00 am to 1:00 pm on Saturday. The process area is closed during other hours as it is generally unoccupied. The process area is also closed on public holidays including:

- New Year’s Day
- Birthday of Martin Luther King, Jr.
- Presidents Day
- Memorial Day
- Independence Day
- Labor Day
- Columbus Day
- Veterans Day
- Thanksgiving Day
- Christmas Day.

The public holidays follow the same hourly schedules as Sundays. The following figures show the occupancy schedules anticipated for the prototype USPS post office. These occupancy patterns can be applied to calculate the design maximum occupancy (square foot / person) in each area. Eventually, the design maximum occupancy (sf/person) of each area becomes input data for the energy simulation model (Figure 7.2 to Figure 7.6).

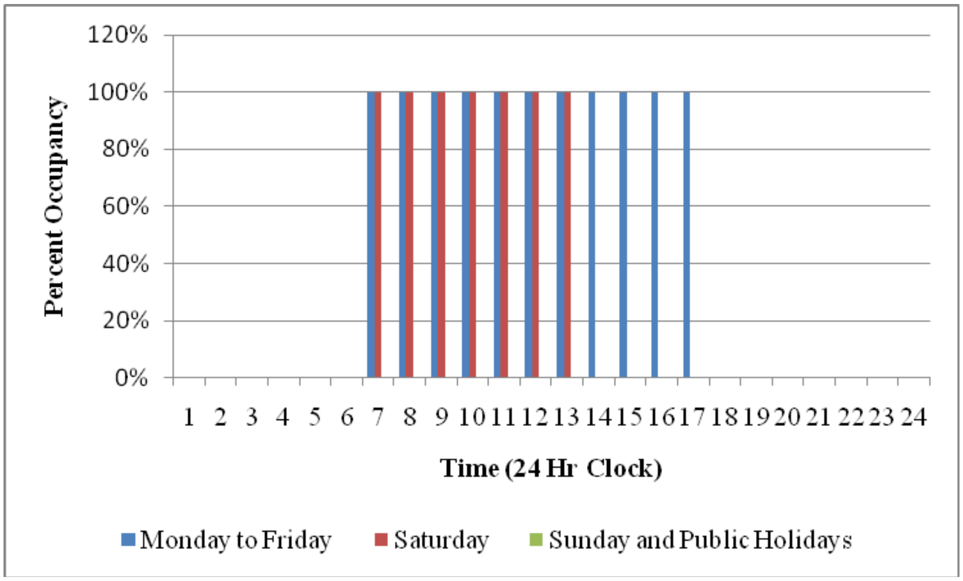


Figure 7.2 Office occupancy schedule

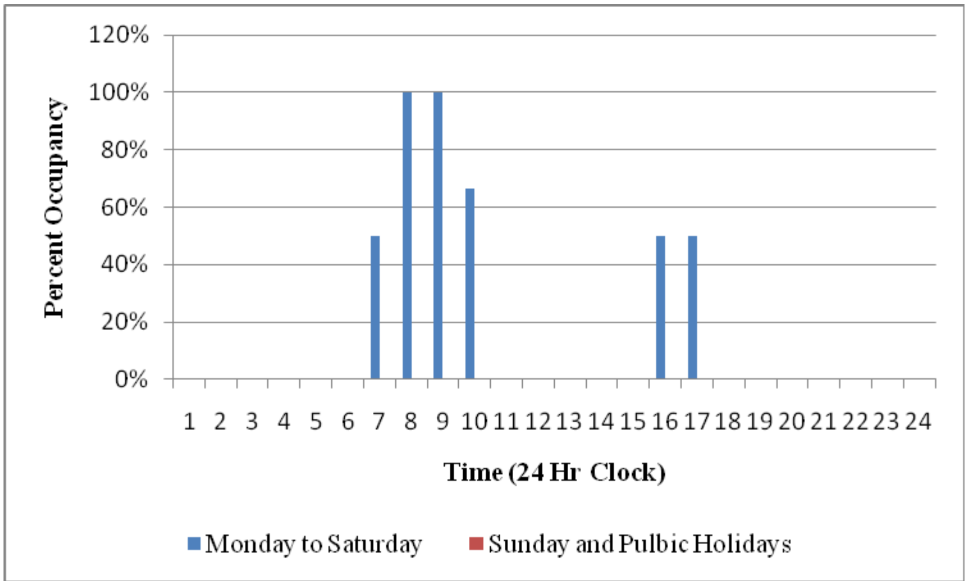


Figure 7.3 Workroom (processing area) occupancy schedule

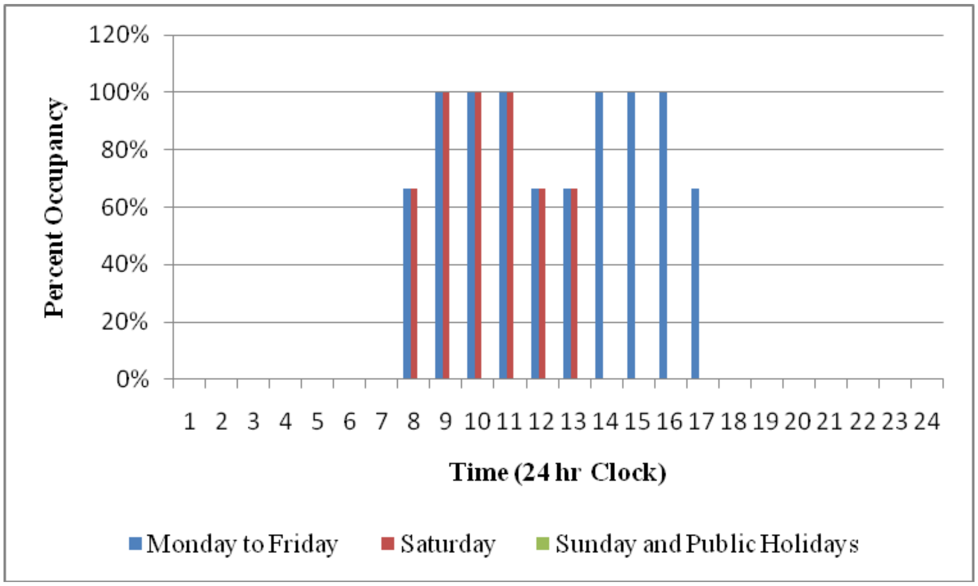


Figure 7.4 Service area occupancy schedule

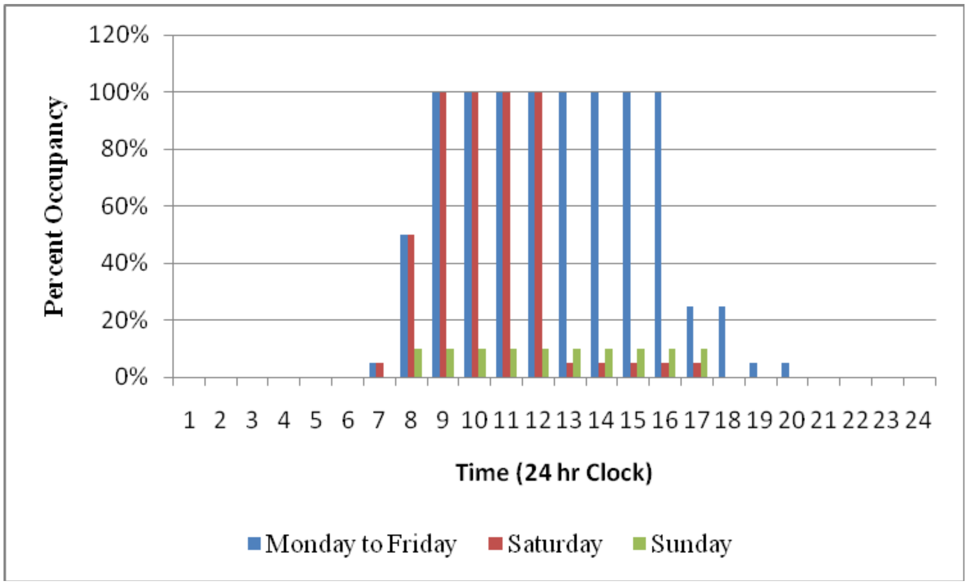


Figure 7.5 Post office users' occupancy schedule

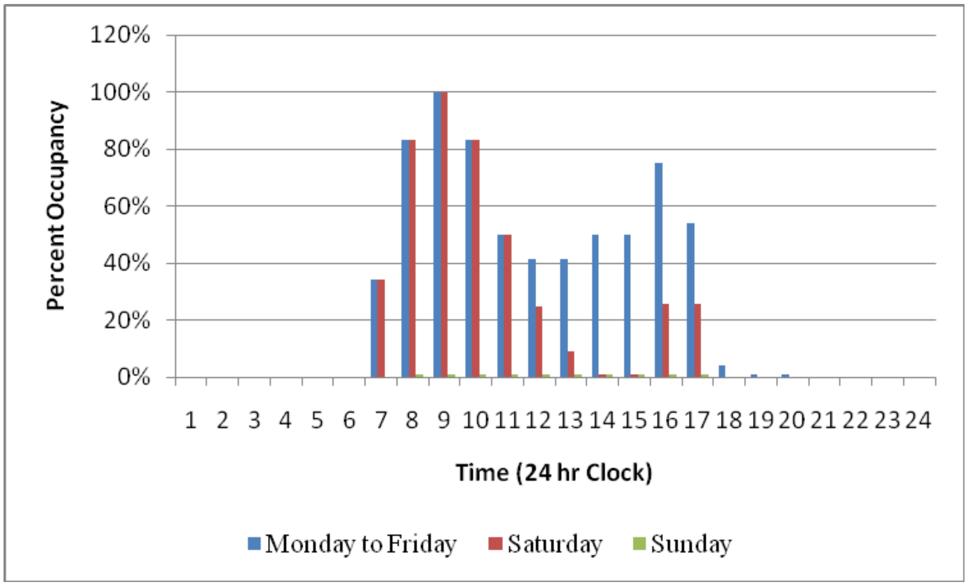


Figure 7.6 Total occupancy schedule

Building Lighting Usage Patterns and Lighting Power Density

Lighting represents a significant portion of energy consumption. According to U.S. Department of Energy (USDOE) (2001), lighting accounts for twenty three percent of total energy consumption and forty six percent of total electricity consumption in U.S. commercial buildings.

Hawken et al. (2000) also stated that in homes and offices from 20 to 50 percent of total energy consumed is due to lighting. Consequently, lighting usage patterns are also very important in this study. The lighting schedules used here are based on the occupancy schedules discussed above. The lighting design is taken to be that specified in the design documents and the selected alternatives are used as the basis of the model.

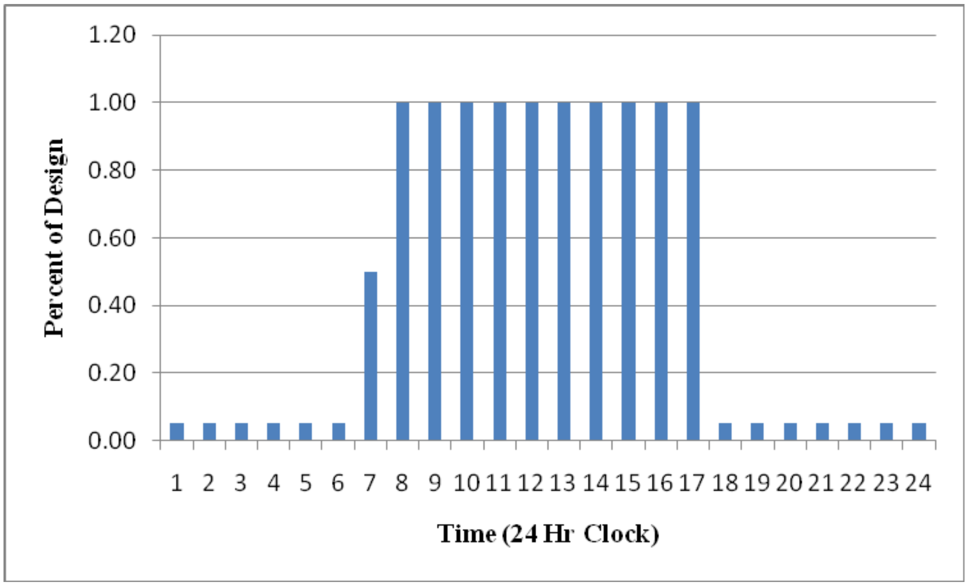


Figure 7.7 Weekday office lighting schedule

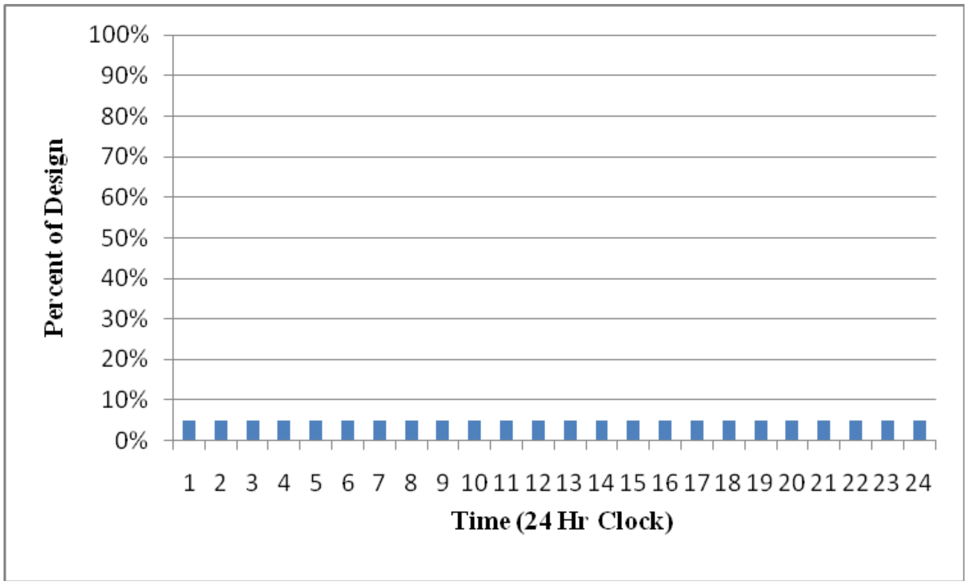


Figure 7.8 Weekend office lighting schedule

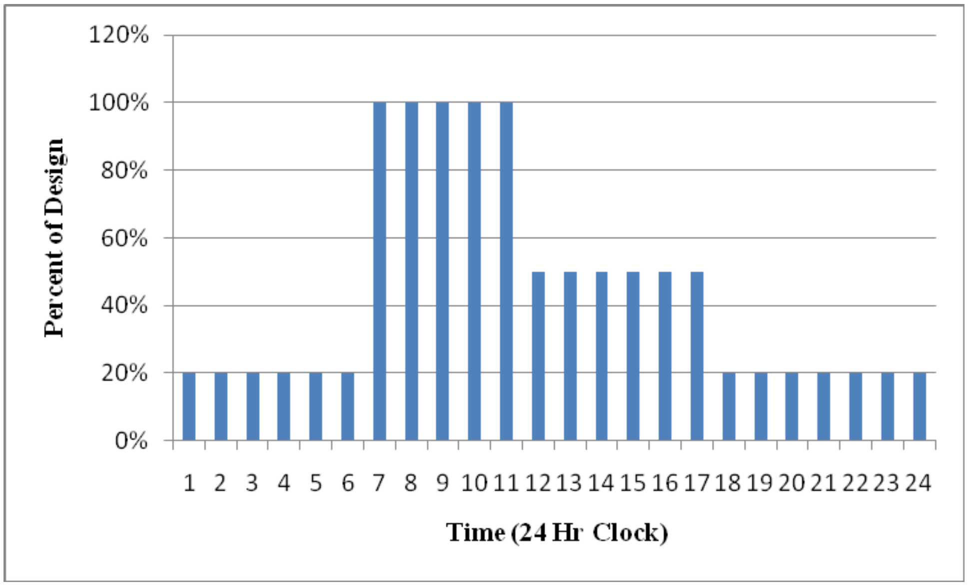


Figure 7.9 Weekday workroom lighting schedule

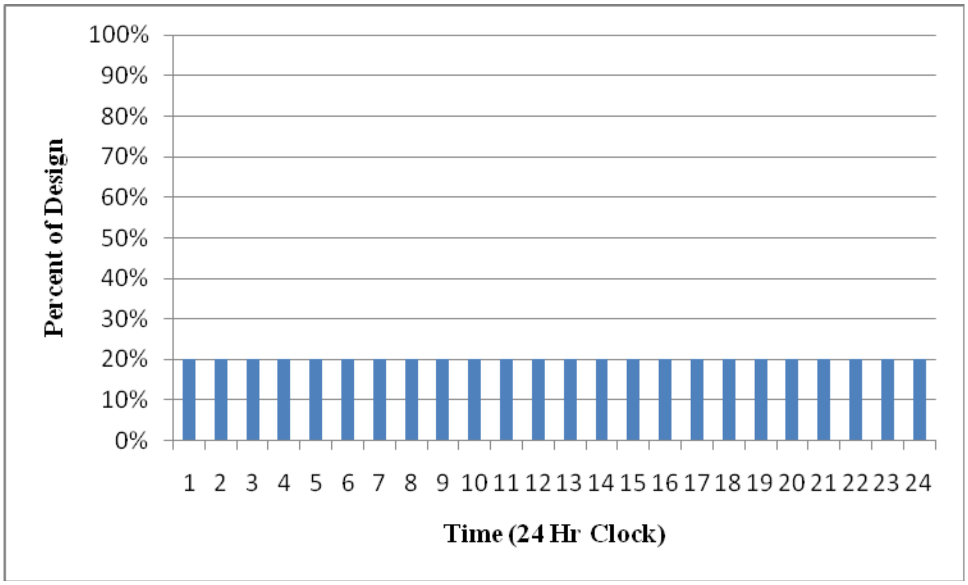


Figure 7.10 Weekend workroom lighting schedule

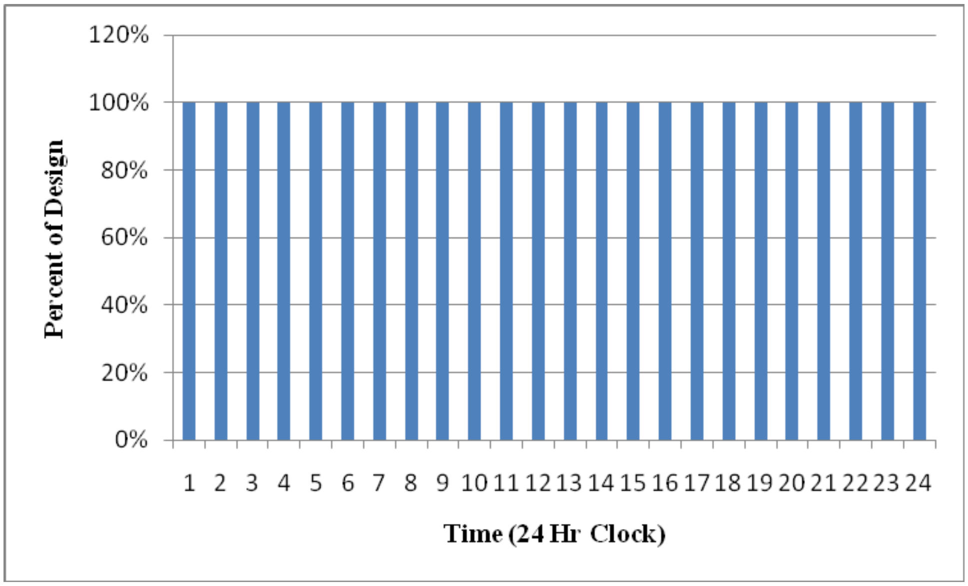


Figure 7.11 Front door and rent a box (service area) lighting schedule

Lighting power densities were also required to conduct an eQUEST energy simulation. There were basically two types of lighting: interior ambient lighting (T8 lighting fixtures) and interior task lighting (T8 lighting fixtures). Both lighting systems were used in the eQUEST energy simulation to calculate annual energy consumption. The power density of ambient lighting was calculated as follows. The first step was to identify the number and type of lighting fixtures and the number of lamps in each fixture. By multiplying the lamp wattage by the number of lamps, it was possible to calculate total wattage. Ambient power densities were then calculated by dividing the total wattage by the size of the area. Lighting power densities for the various spaces were listed in Table 7.4. Lighting power densities were used as input to eQUEST to calculate the electricity consumption for lighting.

In addition to area lighting, there were additional task lighting fixtures to provide additional lumens in the work area while sorting and handling mail. The power density of task lighting fixtures was also calculated in the same way as for the ambient lighting. The power density of task lighting fixtures is listed in Table 7.4.

Calculations of the power density of T5 lighting fixtures also required several steps. The light produced by the lighting fixtures was calculated using the zonal cavity method which was an application of Lumen’s Method (E = F/A, where E is Power Density, F is Lumens, and A was the area illuminated by the light source) to determine the horizontal luminance on a working plane in an interior space. Lumen’s Method took into account lighting loss factors such as the voltage factor, temperature factor, ballast factor, luminary surface depreciation factor, lamp lumen depreciation factor, luminary dirt depreciation factor, lamp burnout factor, and coefficient of utilization (Appendix G). The complete calculation is summarized in Appendix G. Knowing the number of lighting fixtures, the lighting power density was then calculated by dividing the total wattage by the size of the area. The power density of the lighting fixtures is shown in Tables 7.4, 7.5, 7.6 and 7.7 for two different cleaning schedule alternatives.

Table 7.4 Lighting power densities for the prototype lighting (Standard Lighting (T8))

Areas	**# Fixtu.**	**Lamps / Fixture**	**Input Wattage**	**Lamp Type**	**Total Watt**	**Size (SF)**	**W / SF**
Work Room	43	4	108	32W T8	4,644	3,394	1.37
Office	2	2	56	32W T8	112	130	0.86
Lobby	15	4	108	32W T8	1,620	1,092	1.48
Work Area	2	4	56	32WT8	112	91	1.23
Mechanical / Storage	4	2	56	32W T8	224	365	0.61
Rest Rooms	4	2	56	32W T8	224	296	0.76
Storage	4	2	56	32W T8	224	234	0.96
Platform	4	2	56	32W T8	224	462	0.49
Total	**78**						
Task Lighting	13	2	56	32W T8	728	3,394	0.21

Table 7.5 Lighting power densities for the prototype lighting (Standard lighting with recommended lighting system design by the USPS)

Areas	**# Fixtu.**	**Lamps / Fixture**	**Input Wattage**	**Lamp Type**	**Total Watt**	**Size (SF)**	**W / SF**
Work Room	16	4	108	32W T8	1,728	3,394	0.51
Office	1	4	108	32W T8	108	123	0.89
Lobby	12	4	108	32W T8	1,296	1,092	1.19
Work Area	2	4	56	32W T8	112	91	1.23
Mechanical / Storage	4	2	56	32W T8	256	365	0.61
Rest Rooms	4	2	56	32W T8	256	296	0.76
Storage	4	2	56	32W T8	256	234	0.96
Platform	4	2	56	32W T8	256	462	0.49
Total	**47**						
Task Lighting	13	2	56	32W T8	832	3,394	0.21

Table 7.6 Lighting power densities for high performance lighting (T5 Lighting fixtures being cleaned every year)

Areas	**# Fixtu.**	**Lamps / Fixture**	**Input Wattage**	**Lamp Type**	**Total Watt**	**Size (SF)**	**W / SF**
Work Room	14	3	96	28W T5	1,344	3,394	0.40
Office	1	3	96	28WT5	96	123	0.78
Lobby	13	3	96	28W T5	1,248	1,092	1.14
Work Area	1	3	96	28WT5	96	91	1.05
Mechanical / Storage	4	2	56	32W T8	256	365	0.61
Rest Rooms	4	2	56	32W T8	256	296	0.76
Storage	4	2	56	32W T8	256	234	0.96
Platform	4	2	56	32W T8	256	462	0.49
Total	**45**						
Task Lighting	13	2	56	32W T8	832	3,394	0.21

Table 7.7 Lighting power densities for high performance lighting (T5 Lighting fixtures being cleaned every two years)

Areas	**# Fixtu.**	**Lamps / Fixture**	**Input Wattage**	**Lamp Type**	**Total Watt**	**Size (SF)**	**W / SF**
Work Room	16	3	96	28W T5	1,536	3,394	0.45
Office	1	3	96	28WT5	96	123	0.78
Lobby	14	3	96	28W T5	1,344	1,092	1.23
Work Area	1	3	96	28WT5	96	91	1.05
Mechanical / Storage	4	2	56	32W T8	256	365	0.61
Rest Rooms	4	2	56	32W T8	256	296	0.76
Storage	4	2	56	32W T8	256	234	0.96
Platform	4	2	56	32W T8	256	462	0.49
Total	**48**						
Task Lighting	13	2	56	32W T8	832	3,394	0.21

Heating & Cooling Schedules and Building Equipment & Usage Patterns

The heating and cooling schedules of the post office building are also important as they are directly correlated with energy consumption. The schedule applied for this study is based on discussions with Greg Stucky, postmaster of Bealeton Post Office and Terry Schubert, the USPS HQ energy specialist. The prototype post office is assumed to set the thermostat temperatures for their heat pump as follows:

- Occupied spaces

    - Cool: 70.0 °F
    - Heat: 72.0 °F

- Unoccupied spaces
    - Cool: 82.0 °F
    - Heat: 64.0 °F

The thermostat temperature setting for unit heaters in the storage, mail platform, mechanical room, and storage areas is as follows:

- Storage, mail platform, mechanical room and storage - Heat: 69.0 °F

The prototype post office has a 40 gallon electric domestic water heater (4,632 KWh. per year) that provides hot water service to employees. According to the 1995 ASHRAE Applications Handbook (1995), domestic hot water loads designs are based on 1 gallon per occupant per day. Since there are expected to be 10 full time employees in the prototype post office facility, the daily consumption of hot water is around 10 gallons. In addition, since six of the ten full time employees spend only 4 hours in the post office facility each day, with the rest of their time being spent delivering mail, the hot water consumption is expected to be minimal. Furthermore, the amount of hot water consumed is the same in all scenarios, so this study does not consider any heat gains and electric consumption associated with the domestic hot water service.

Heat gains resulting from equipment located within the spaces were considered for inclusion in the model for this study. However, as there was no specific equipment in the small prototype post office that generates any significant amount of heat, apart from a few computers, the decision was made to also omit electric consumption associated with equipment and miscellaneous loads. The prototype post office expends energy on exterior lighting, but since exterior lighting energy consumption also has no effect on this study, which is designed to identify the relationships between first project costs related to GBSTs and LCCs and none of the considered alternatives involve exterior lighting-related GBSTs, this factor is also not considered here.

7.3.1.3 Utility Rates

Since electricity is the power source used in the prototype post office facility, this study only considers electricity rates. Other types of USPS facilities may employ natural gas or other types of fuel, but they are outside the scope of this analysis. As the electricity rate greatly affects post office operation costs, it is very important to consider them; here, the electricity rate applied is the average retail electricity price of the Commonwealth of Virginia, which is $0.1053/KWh as of October 2009. This electricity rate is the average retail electricity price for the residential sector, which is set by the Energy Information Administration (EIA 2009b). This method of assessing the electricity price to be used for this study was verified by Terry Schubert, a facilities energy analyst at the United States Postal Service, based at the company's HQ facility energy management program in Greensboro, NC. The following sections describe the procedure used to simulate operating costs and the simulated energy usage and operating costs.

7.3.2 Simulating Operating Costs

Operating costs consist of variable annual costs that include the cost of utilities. However, this study considered only the annual operating costs related to energy costs. Other such costs including insurance costs, water costs, cleaning cost, etc. were not expected to vary from scenario to scenario and thus were eliminated from the analysis. The operating costs related to energy use were calculated by multiplying the amount of electricity used as calculated by the eQUEST model by the utility rates. Since electricity is the only energy source to be used in the prototype SSBD post office facility, this study did not consider other energy sources such as gas. As previously described, this study utilized an energy simulation to calculate the facility's electricity consumption.

7.3.2.1 Simulation of Energy Usage

Energy consumption was simulated by eQUEST, an energy simulation tool. Figure 7.3 and Appendix F list all the scenarios tested for the energy simulation. To calculate the annual energy usage of each scenario, this study applied the eQUEST version 3.63 software package, which was a comprehensive eQUEST building energy simulation tool. eQUEST combined a building creation wizard, an energy efficiency measure (EEM) wizard, and graphical reporting with a simulation "engine" derived from the latest version of DOE-2, which is a widely used and accepted building energy analysis program that predicts the energy use and cost for all types of buildings (USDOE 2009c). According to an evaluation by Crawley et al. (2008), eQUEST is a building energy use analysis tool that provides high quality results on the basis of enhanced DOE-2.2.

The procedure used by this study to simulate annual energy usage was to create scenarios of the prototype post office based on data from actual post offices, then input different alternatives and simulate the annual energy consumption for each alternative (Figure 7.12).

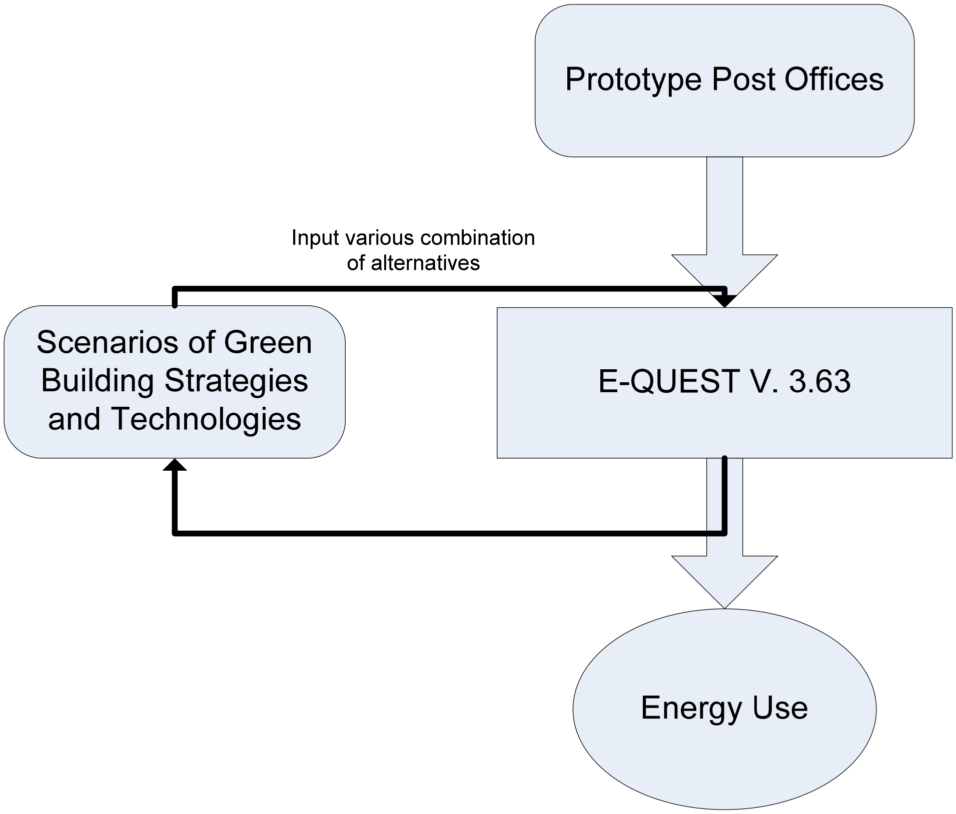


Figure 7.12 Simulation tool and procedures

7.3.2.2 Input Data for eQUEST Simulation Model

eQUEST is an energy simulation tool that is used to calculate the energy usage of a building. When performing these calculations, it is critical to input all the necessary data and ensure that this data is accurate in order to generate accurate energy use predictions. This section therefore discusses the input data that was screen-captured by the eQUEST simulation tool.

Building Envelope Construction

The exterior wall construction to be used in the facility is as follows (Figure 7.14):

- Wood frame, 2 X 6, 16 in. o.c.
- Brick and red masonry
- Batt insulation

The roof envelope construction is as follows (Figure 7.13 and Figure 7.15):

- Metal frame, 24 in. o.c.
- Roof, built-up (Medium, absorption rate of 0.6)
- Pitched roof at 33º, with 1 ft overhang (Figure 7.13)
- Lay-in acoustic tile for ceiling

The following layers make up the floor construction (Figure 7.14):

- 4 inch concrete slab
- 2” rigid perimeter insulation under slab
- Ceramic / Stone Tile

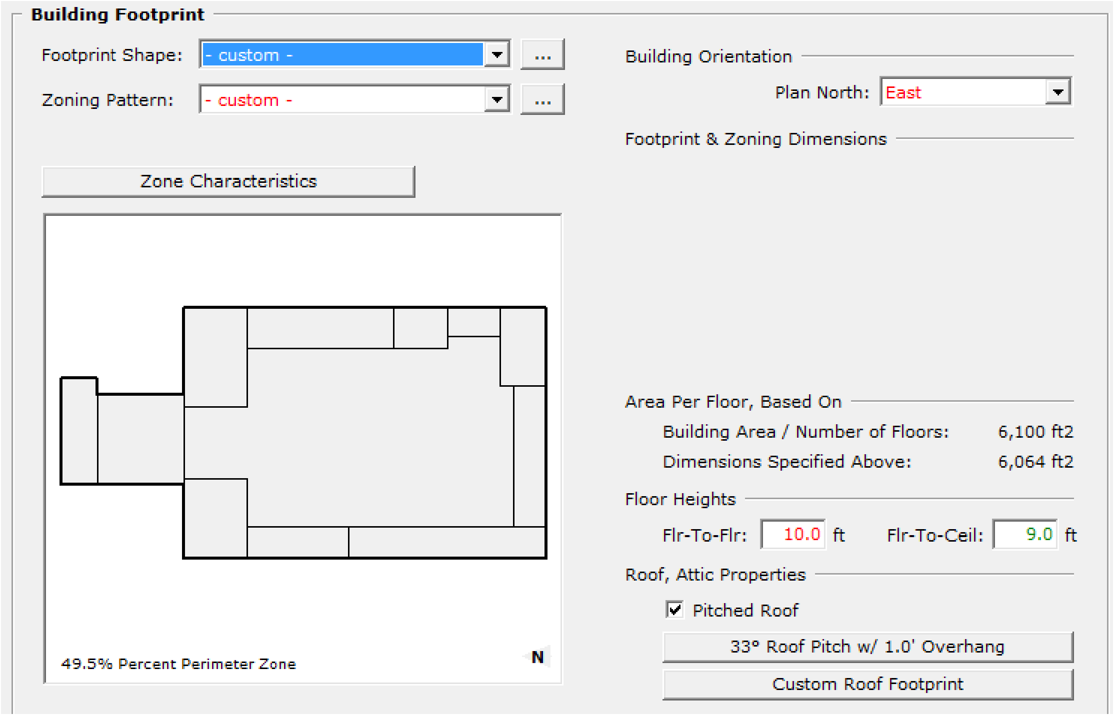
The vertical glazing is insulating low-e double glass with thermally broken aluminum frames and the following properties (Figure 7.16).

- Double low-e-glazing with a 0.1 emissivity coating of 0.1
- Solar reflectance (from the inside): 0.243
- Visible reflectance (from the inside): 0.201

The interior walls are typically constructed of wood frame without insulation (Figure 7.15). The infiltration (shell tightness) is as follows (Figure 7.14):

- Perimeter zone-1.3 air changes / hr

- Core zone-0.5 air changes / hr



Building Footprint

Footprint Shape: - custom -

Zoning Pattern: - custom -

Building Orientation

Plan North: East

Footprint & Zoning Dimensions

49.5% Percent Perimeter Zone

Area Per Floor, Based On

Building Area / Number of Floors: 6,100 ft2

Dimensions Specified Above: 6,064 ft2

Floor Heights

Flr-To-Flr: 10.0 ft

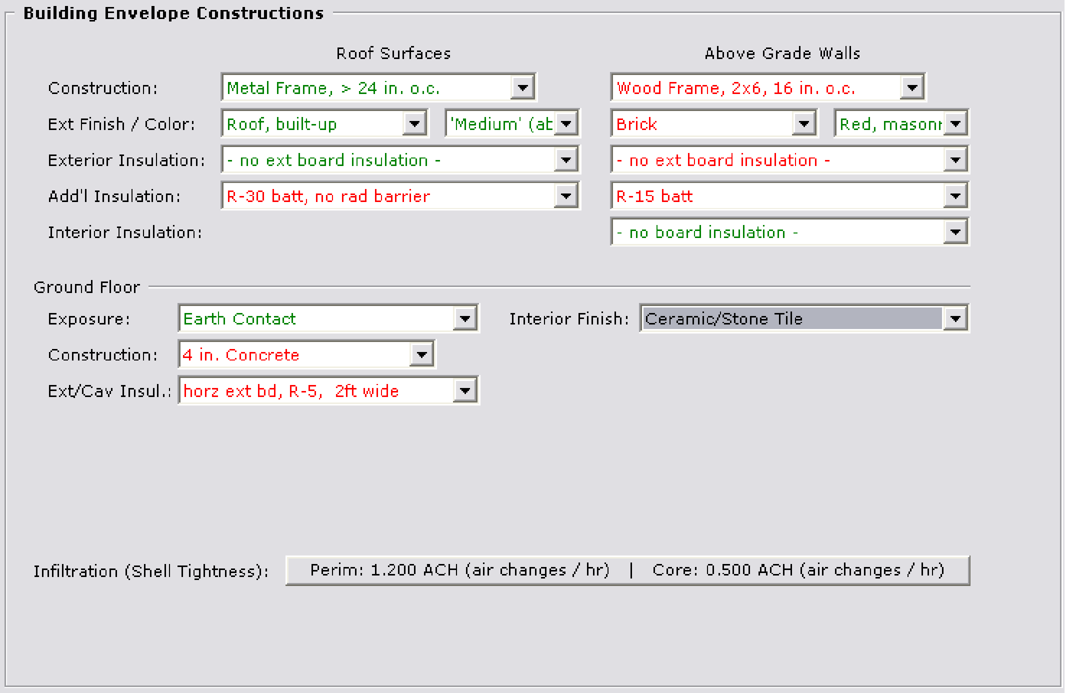
Flr-To-Ceil: 9.0 ft

Roof, Attic Properties

☑ Pitched Roof

33° Roof Pitch w/ 1.0' Overhang

Figure 7.13 Input wizards for shell components in the prototype post office



Building Envelope Constructions

	Roof Surfaces	Above Grade Walls
Construction:	Metal Frame, > 24 in. o.c.	Wood Frame, 2x6, 16 in. o.c.
Ext Finish / Color:	Roof, built-up 'Medium' (ab	Brick Red, masonr
Exterior Insulation:	- no ext board insulation -	- no ext board insulation -
Add'l Insulation:	R-30 batt, no rad barrier	R-15 batt
Interior Insulation:		- no board insulation -

Ground Floor

Exposure: Earth Contact

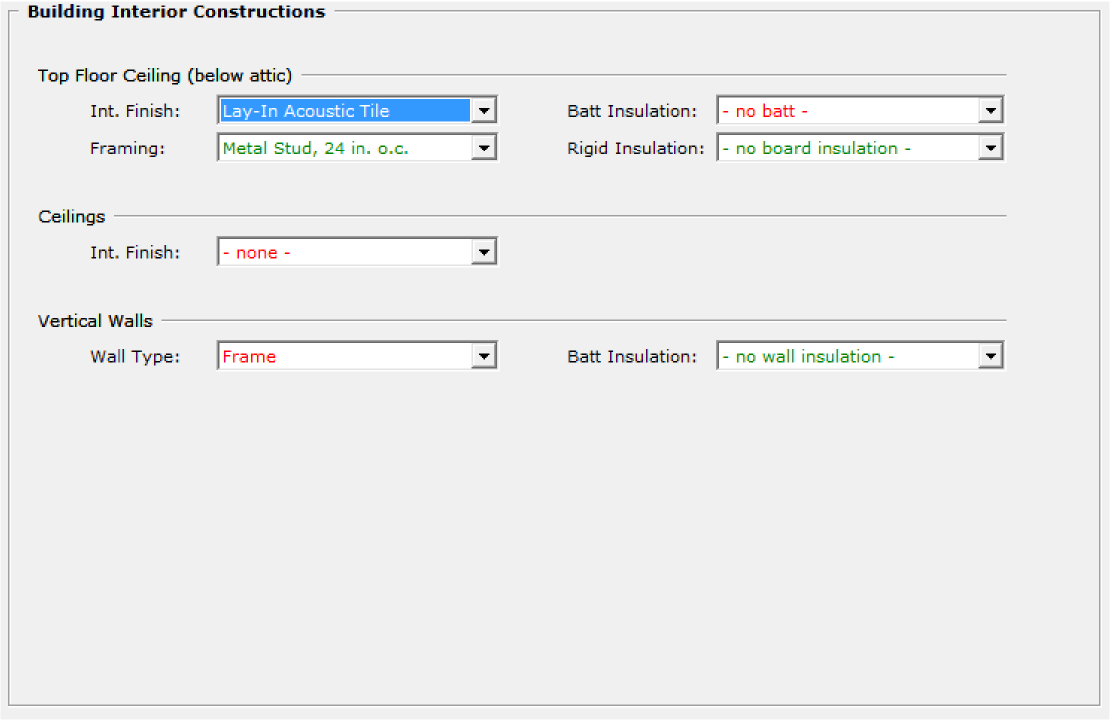
Interior Finish: Ceramic/Stone Tile

Construction: 4 in. Concrete

Ext/Cav Insul.: horz ext bd, R-5, 2ft wide

Infiltration (Shell Tightness): Perim: 1.200 ACH (air changes / hr) | Core: 0.500 ACH (air changes / hr)

Figure 7.14 Input wizards for the building envelope in the prototype post office



Building Interior Constructions

Top Floor Ceiling (below attic)

Int. Finish: Lay-In Acoustic Tile

Batt Insulation: - no batt -

Framing: Metal Stud, 24 in. o.c.

Rigid Insulation: - no board insulation -

Ceilings

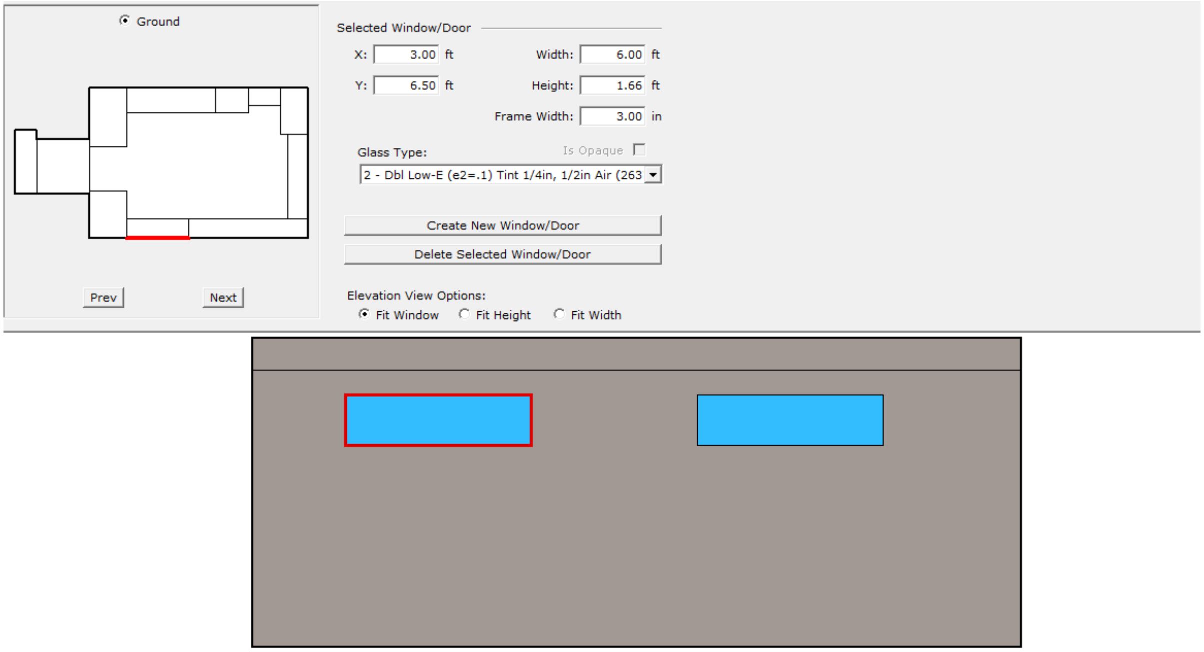
Int. Finish: - none -

Vertical Walls

Wall Type: Frame

Batt Insulation: - no wall insulation -

Figure 7.15 Input wizards for the building interior construction in the prototype post office



● Ground

Selected Window/Door

X: 3.00 ft Width: 6.00 ft

Y: 6.50 ft Height: 1.66 ft

Frame Width: 3.00 in

Glass Type: 2 - Dbl Low-E (e2=.1) Tint 1/4in, 1/2in Air (263

Is Opaque ☐

Elevation View Options: ● Fit Window ○ Fit Height ○ Fit Width

Figure 7.16 Input wizards for the windows and walls in the prototype post office

Mechanical Systems

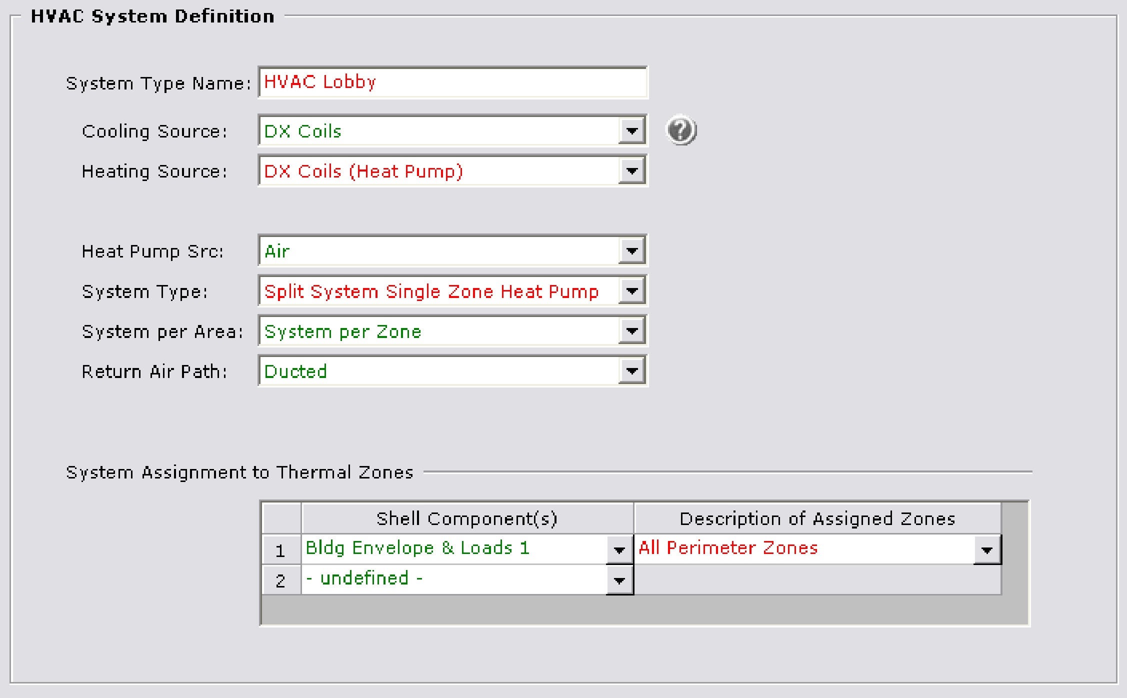
The prototype post office facility is served by two heat pumps, unit heaters, and baseboard wall heaters. The sizes of the two heat pumps are determined based on the outcomes of the DOE-2.2 energy analysis program. The following sections show the input data used to select the HVAC systems in this study (Figure 7.17 to 7.20).

- Heat Pump 1 (Service Area)
    - Cooling source: Direct Expansion (DX) Coils
    - Heating source: DX Coils (Heat pumps)
    - System type: Split system single zone heat pump
    - Heat pump source: air
    - Return air path: ducted
    - Minimum design flow: 1.30 cfm/ft^2
    - Cooling - Energy Efficiency Ratio (EER): 12
    - Heating – Coefficient of Performance (COP): 2.5
    - Fan schedules – 24 hours (continuous)
    - Enthalpy economizer (High limit 65.0 ºF)

- Heat Pump 2 (Workroom)
    - Cooling source: Direct Expansion (DX) Coils
    - Heating source: DX Coils (Heat pumps)
    - System type: Split system single zone heat pump
    - Heat pump source: air
    - Return air path: ducted
    - Minimum design flow: 1.20 cfm/ft²
    - Cooling - Energy Efficiency Ratio (EER): 12
    - Heating – Coefficient of Performance (COP): 2.5
    - Fan schedules –Monday to Sunday (continuous)
    - Baseboards – Electric (8KW)
    - Enthalpy economizer (High limit 65.0 ºF)

- Unit Heater 1 (Platform, Mechanical and storages)
    - Heating source: Electric resistance
    - System type: Air electric heaters with zone ventilation

- Unit Heater 1 (Building ground and storage areas)
    - Heating source: Electric resistance
    - System type: Air electric heaters with zone ventilation



HVAC System Definition

System Type Name: HVAC Lobby

Cooling Source: DX Coils

Heating Source: DX Coils (Heat Pump)

Heat Pump Src: Air

System Type: Split System Single Zone Heat Pump

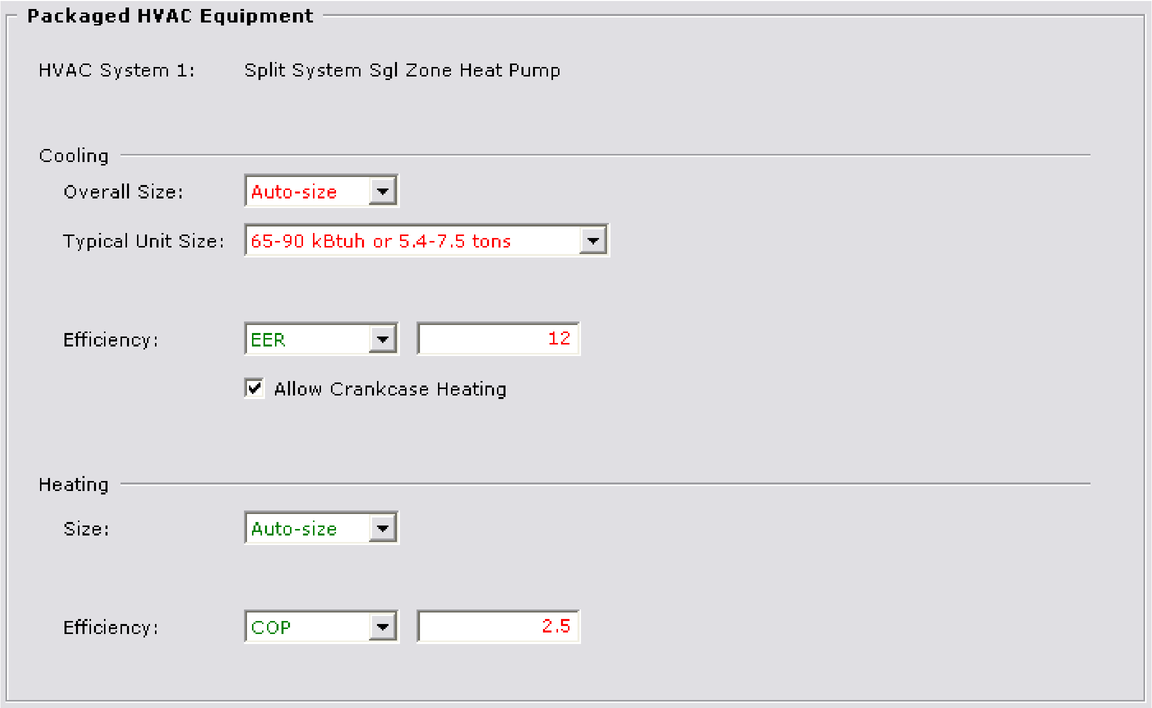
System per Area: System per Zone

Return Air Path: Ducted

System Assignment to Thermal Zones

	Shell Component(s)	Description of Assigned Zones
1	Bldg Envelope & Loads 1	All Perimeter Zones
2	- undefined -	

Figure 7.17 Input wizards for the HVAC system definition in the prototype post office



Packaged HVAC Equipment

HVAC System 1: Split System Sgl Zone Heat Pump

Cooling

Overall Size: Auto-size

Typical Unit Size: 65-90 kBtuh or 5.4-7.5 tons

Efficiency: EER 12

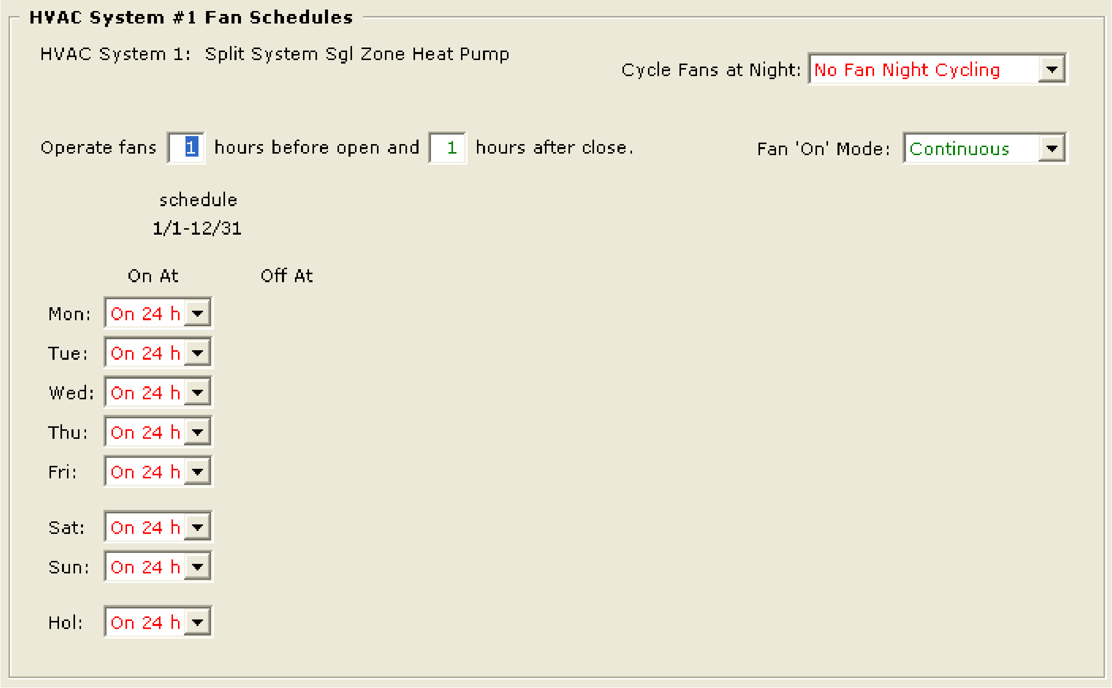
☑ Allow Crankcase Heating

Heating

Size: Auto-size

Efficiency: COP 2.5

Figure 7.18 Input wizards for the HVAC equipment in the prototype post office



HVAC System #1 Fan Schedules

HVAC System 1: Split System Sgl Zone Heat Pump

Cycle Fans at Night: No Fan Night Cycling

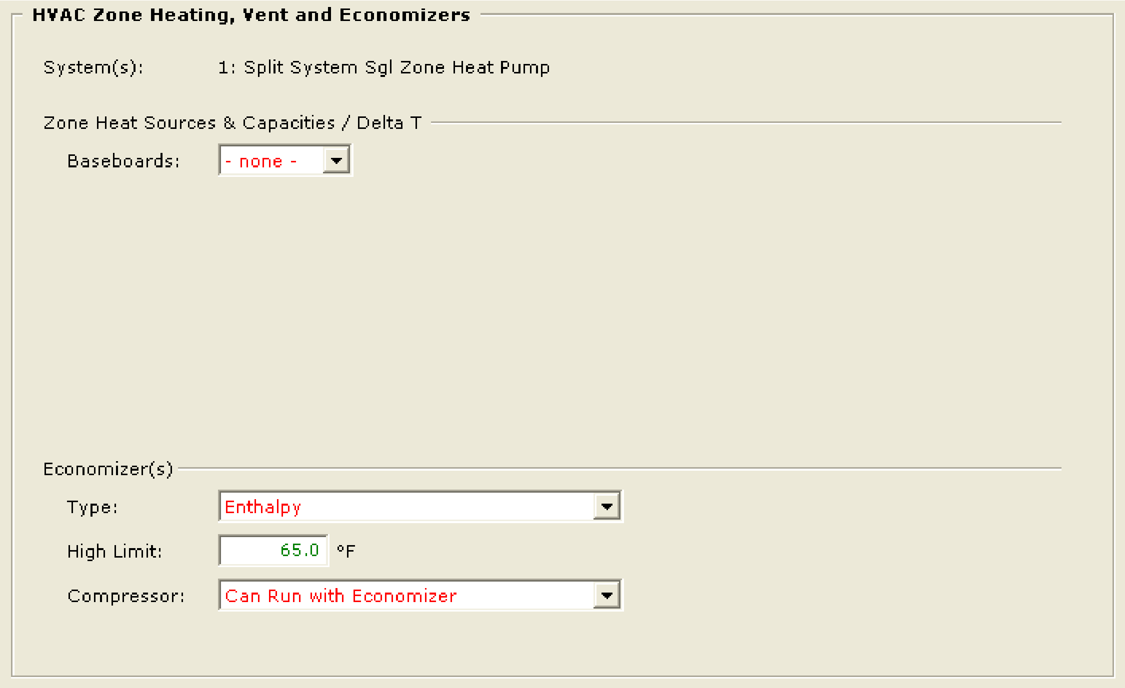
Operate fans 1 hours before open and 1 hours after close.

Fan 'On' Mode: Continuous

schedule
1/1-12/31

	On At	Off At
Mon:	On 24 h	
Tue:	On 24 h	
Wed:	On 24 h	
Thu:	On 24 h	
Fri:	On 24 h	
Sat:	On 24 h	
Sun:	On 24 h	
Hol:	On 24 h	

Figure 7.19 Input wizards for the fan schedules in the prototype post office



HVAC Zone Heating, Vent and Economizers

System(s): 1: Split System Sgl Zone Heat Pump

Zone Heat Sources & Capacities / Delta T

Baseboards: - none -

Economizer(s)

Type: Enthalpy

High Limit: 65.0 °F

Compressor: Can Run with Economizer

Figure 7.20 Input wizards for the HVAC zone heating, vent and economizers in the prototype post office

7.3.2.3 Energy Use and Operating Costs

Using the eQUEST energy simulation tool, this study identified the amount of energy that would be used for a wide range of scenarios. The simulated energy consumption was prorated to better model the likely real energy consumption based on data collected from the prototype post office due to discrepancies between the simulated energy consumption and real energy consumption. Table 7.8 and Appendix F described the prorated annual energy consumption (KWh) based on many scenarios. By multiplying the unit cost of energy by the energy use, it was possible to calculate the operating costs due to the facility's energy usage. Table 7.8 and Appendix F also depicted these operating costs for the scenarios tested.

Table 7.8 Incremental operating costs

ID	Annual Energy Use (KWh)	Annual Energy Costs ($)	Energy Saving ($)	Energy Saving Unit Cost ($/SF)
1	121,031	$13,313	$-	$-
2	114,610	$12,607	$706	$0.116
3	120,740	$13,281	$32	$0.005
4	114,310	$12,574	$739	$0.121
5	120,620	$13,268	$45	$0.007
6	114,190	$12,561	$752	$0.123
7	120,280	$13,231	$82	$0.014
8	113,870	$12,526	$788	$0.129
9	119,990	$13,199	$114	$0.019
10	113,570	$12,493	$821	$0.135

7.4 Maintenance, Repair and Replacement Costs

Estimating building life cycle costs is a process of identifying the building elements or components that may require regular maintenance, repair, and scheduled replacement. As a general building characteristic, the structural portion of the building normally does not incur maintenance, repair, and replacement costs during the operation phase of a building. However, many other components and parts of the building, such as the HVAC systems, internal finishes, windows and doors, furniture, etc. will require more frequent maintenance, repair, and replacement. To calculate such costs for building components, it is necessary to establish the life expectancy of components or materials in order to work out the number of times a building component will need to be replaced, maintained or repaired over the facility's life cycle.

This process is not straightforward, as the life expectancy of building components varies widely depending on the type of building and the level of maintenance and repair activities (Ding 2004; Kirk and Dell'Isola 1995; Langston 1994; 1996). According to Ding (2004), calculating the life expectancy of building components and their costs relies on appropriate, relevant and historical information and data. Because of the difficulty involved in accurately predicting the expectancy of building components, this study estimated the life expectancy of building components based on scenarios generated by *R.S. Means Facility Maintenance and Repair Cost Data*, discussions with product vendors[5], industry accepted equipment life estimates, and studies by Langston (1994), and Kirk and Dell’Isola (1995). Table 7.9 summarizes item descriptions, maintenance descriptions, life expectancy and percentage replacements for some of the facility building's elements that vary from scenario to scenario as with utility costs. In addition, as the USPS outsources the tasks of maintaining, repair and replacing building components, those costs include material and labor costs with associated profits and overheads[6].

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[5] Bulb: elightbulbs & Philips light
HVAC: New River Heating & Air & Virginia Train

[6] Discussion with

Table 7.9 Summary of maintenance, repair and replacement data

Item Description	Unit	Maintenance Description	Repair / Replacement Description	Life Expectancy (Year)	Percent Repla.
Orientation					
N/A	N/A	N/A	N/A	N/A	N/A
Roof Insulation					
Roof Insulation	SF	No maintenance	No Repair and replacement	Life of building	N/A
Wall Insulation					
Wall Insulation	SF	No maintenance	No Repair and replacement	Life of building	N/A
Lighting Type					
Lighting fixture	EA	Washing fixture lens, etc (10 minutes / year)	N/A	N/A	N/A
Lighting fixture	EA	Repair fixture (0.01 failures/yr) (1.67 MH/failure)	N/A	N/A	N/A
Lamp change	EA	Replace lamps - Remove fluor. lamps in fixture - Replace new fluor. lamps	N/A	T8 lamps: 24,000 hrs T5 lamps: 25,000 hrs	100
Lighting fixtures	EA	N/A	Replace lighting fixtures - Turn branch circuit off and on - Remove fluor. Lighting fixtures - Fluor. 2’*4’, recess mounted	20	100
Fluorescent ballast	EA	N/A	Replace fluor. ballast - Remove fluor. ballast - Replace new ballast	10	100

Item Description	Unit	Maintenance Description	Repair / Replacement Description	Life Expectancy (Year)	Percent Repla.
HVAC System					
Heat Pump	EA	Maintain heat pump systems	N/A	1	100
Heat Pump	EA	NA	Repair heat pump - Repair / replace controls - Remove / replace supply fan - Remove supply fan motor - Replace supply fan motor - Remove compressor - Replace compressor - Remove / replace condenser fan - Remove condenser fan motor - Replace condenser fan motor - Replace refrigerant - Remove / replace heater	10	100
Heat Pump	EA	NA	Replace heat pump, condensing unit only - Remove heat pump - Replace heat pump	20	100

7.4.1 Orientation

As the orientation of building is not expected to materially affect building components for this facility, it is reasonable to assume that there will be no cost differences for maintenance, repair, and replacement. Therefore, in this study, LCCA excluded maintenance, repair and replacement costs related to building orientation.

7.4.2 Insulation

As thermal insulation is generally installed in building envelope components to reduce the need for space heating and space cooling, insulation is an important part of a roofing and exterior wall system. The insulation materials in a roofing system have same the life expectancy as the roof structure. The roofing has a life expectancy of over 40 years (Table 7.9) with minimal maintenance, repair and replacement costs, so this study assumed that there was no maintenance, repair, and replacement costs differences associated with the three roof insulation alternatives (R-30, R-38, and R-49) since the study period was 20 years.

The exterior wall system also has a long life expectancy (75 years; Table 7.9). As wall insulation was an integral part of the wall structure, this study also assumed that there was no maintenance, repair and replacement cost differences among the different insulation alternatives, including R-19, and R-21. Therefore, the insulation in the wall and roof system has no impact on the maintenance, repair and replacement sections of LCCA.

7.4.3 Lighting Type

As the two types of lighting fixtures used in the facility, namely the T5 and T8 lamps, had different features (number of lamps in each fixture, life of lamp, and price of each lamp), this study took into account the cost differences for the annual maintenance, repair and replacement of the lighting fixtures and lamps. While the T5 lighting fixtures use three lamps instead of the four lamps in T8 lighting fixtures, it was possible to reduce labor costs associated with cleaning lighting fixtures and replacing lamps. From Table 7.10, the replacement costs associated with each type of lighting fixture are as follows:

- T8 lighting fixture: \$227
- T5 lighting fixture: \$265

In addition, it is necessary to occasionally replace the lamps in a lighting fixture. From Table 7.9, replacing an F32T8 lamp annually costs $ 41.08 and replacing an F28T5 lamp costs $ 61.01. Furthermore, it is necessary to replace the fluorescent ballast in a lighting fixture every 10 years. Replacement costs associated with ballasts in each T8 lighting fixture are $137 and replacement costs for each ballast in T5 lighting fixtures are $154.

Finally, it is necessary to wash the lighting fixtures to improve their performance. This also affects the Luminaire Dirt Depreciation (LDD) factor, which is one of the factors used to calculate the number of lighting fixtures that is required in the building. The cleaning costs of three different alternatives are summarized in Table 7.10.

Table 7.10 Maintenance, repair and replacement costs for lighting fixtures and lamps (RSMeans 2008)

Lighting Fixtures	**Prototype Lighting (T8)**	**Prototype Lighting (Recommended Design)**	**High Performance Lighting (T5: Cleaning fixture every year)**	**High Performance Lighting (T5:Cleaning fixtures every two years)**
Operation (hr/day)				
• Work room	• 18 hours / day	• 18 hours / day	• 18 hours / day	• 18 hours / day
• Lobby	• 24 hours / day	• 24 hours / day	• 24 hours / day	• 24 hours / day
Number of lighting fixtures (work room and lobby)	62	31	29	32
Life expectancy of lighting fixtures	20 years	20 years	20 years	20 years
Replace Fixtures				
• Labor	$ 94.86	$ 94.86	$94.86	$94.86
• Fixture costs	$ 94	$ 94	$ 126	$ 126
• Overhead	20%	20%	20%	20%
Replace fixture costs (per fixture)	$ 227	$ 227	$ 265	$ 265
Total fixture replacement costs	$14,074	$7,034	$7,685	$8,480

Lamp Type	**F32T8/TL735/ALTO (Philips)**	**F32T8/TL735/ALTO (Philips)**	**F28T5/835/ALTO (Philips)**	**F28T5/835/ALTO (Philips)**
Life of lamp (12 hours per start)	30,000 hrs	30,000 hrs	25,000 hrs	25,000 hrs
Life expectancy of lamps	About 3.42 years	About 3.42 years	About 2.85 years	About 2.85 years
Lamps per lighting fixture	4 lamps	4 lamps	3 lamps	3 lamps
Lamp cost	$ 2.99 (eLight bulb)	$ 2.99 (eLight bulb)	$ 12.99 (eLight bulb)	$ 12.99 (eLight bulb)
Maintenance cost				
• Material (lamps cost per fixture)	$ 11.96	$ 11.96	$ 38.97	$ 38.97
• Labor	$ 29.12	$ 29.12	$ 21.84	$ 21.84
Replacement cost of lamps (per fixture)	$ 41.08	$ 41.08	$ 60.81	$ 60.81
Total maintenance / replacement lamp costs (# Lamp fixtures * replacement lamps)	$ 2,547	$1,274	$ 1,764	$1,946
Annual Replacement Costs	$745	$372	$619	$683

Type of Ballast	**T8 Ballast**	**T8 Ballast**	**T5 Ballast**	**T5 Ballast**
Number of lighting fixtures	62 fixtures	31 fixtures	29 fixtures	32 fixtures
Life expectancy of ballast	10 years	10 years	10 years	10 years
Replacement cost				
• Labor	$ 48.01	$ 48.01	$ 48.01	$ 48.01
• Material	$ 32.99 *2 = $ 65.8 (eLight bulbs)	$ 32.99 *2 = $ 65.8 (eLight bulbs)	$ 39.99 * 2 = $ 79.98 (eLight bulb)	$ 39.99 * 2 = $ 79.98 (eLight bulb)
• Overhead	20%	20%	20%	20%
Replace ballasts	$ 137	$ 137	$ 154	$ 154
Total ballast replacement Cost	$ 8,494	$ 4,247	$ 4,466	$ 4,928

Annual Maintenance (Cleaning Fixture)	**T8 Fixtures**	**T8 Fixtures**	**T5 fixtures (Cleaning fixture every year)**	**T5 Fixtures (Cleaning fixtures every two years)**
Number of lighting fixtures	62 fixtures	31 fixtures	29 fixtures	32 fixtures
Cleaning Time	10 minutes per fixture	10 minutes per fixture	10 minutes per fixture	10 minutes per fixture
Hours	10.33 hours	5.17 hours	4.83 hours	5.33 hours every two years
Hourly Wage[7]	$47/hr	$47/hr	$47/hr	$47/hr
Annual Cleaning Cost	$485	$243	$227	$125

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[7] Bare cost of electrician (R.S. Means Facilities Maintenance and Repair Cost Data 2009)

7.4.4 Efficiency of Heat Pump System

The efficiency of a heat pump affects not only the costs of running the heat pump system in the building but also its maintenance, repair and replacement costs. From “RS Means Facility Maintenance & Repair Cost Data”, a heat pump system is expected to incur annual maintenance costs of $294 for heat pumps of up to 5 tons and $360 for heat pumps over 5 tons. Thus, Heat Pump A and Heat Pump B in the prototype facility require $654 to maintain both 5 ton and 10 ton heat pump systems. In addition, heat pump systems also require repairs every 10 years. According to *R.S. Means Facility Maintenance & Repair Cost Data*, Heat Pump A and B require expenditure amounting to $5,368 and $5,904, respectively, to repair controls and replace their supply fans, supply fan motors, compressors, condenser fans, condenser fan motors, refrigerant, and heaters. However, as the life expectancy of both heat pump systems is 20 years, it is not necessary to include replacement costs associated with the heat pump system. Table 7.11 shows the maintenance and repair costs associated with heat pump systems.

Table 7.11 Maintenance and repair costs associated with heat pump systems (RSMeans 2008)

	Heat Pump A (5 ton and 10 ton heat pumps)	**Heat Pump B (5 ton and 10 ton heat pumps)**
Efficiency	• EER – 12 • COP – 2.5	• EER – 16.15 • COP – 2.8
Total Annual Maintenance	$ 654	$ 654
• 5 ton annual Main.	$ 294	$ 294
• 10 ton annual Main.	$ 360	$ 360
Repair Heat Pump Systems (10 years)	$ 5,368	$ 5,904
• 5 ton annual Main.	$ 2,047	$ 2,226
• 10 ton annual Main.	$ 3,321	$ 3,678

7.5 Residual Value

As previously mentioned in Chapter 4, the residual value was only considered for specific building components that were likely to need replacing during the study period. As heat pump systems and lighting fixtures have the life expectancy of 20 years, they do not need to be considered to have a residual value in this study.

7.6 Conclusion

This chapter described the detailed method of developing first cost premiums for GBSTs and its results, the first cost premiums of GBSTs in this study. In addition, to first cost premiums, this chapter described the prototype post office's geometry, occupancy schedules, lighting schedules, and other key components, all of which were important input data for the development of an energy simulation model using eQUEST. The chapter included numerous screenshots showing the type of input data gathered for the prototype post office. In addition, this chapter illustrated the process of developing energy consumption simulations for a wide range of scenarios. Finally, this chapter defined the life expectancy of the building components and materials in order to work out how often a building component will need to be replaced, maintained, or repaired over the life cycle of the building. The final section of this chapter identified the repair, maintenance, and replacement costs that are major elements of LCCA. This data is essential for developing the LCCA for this study, described in the next chapter.

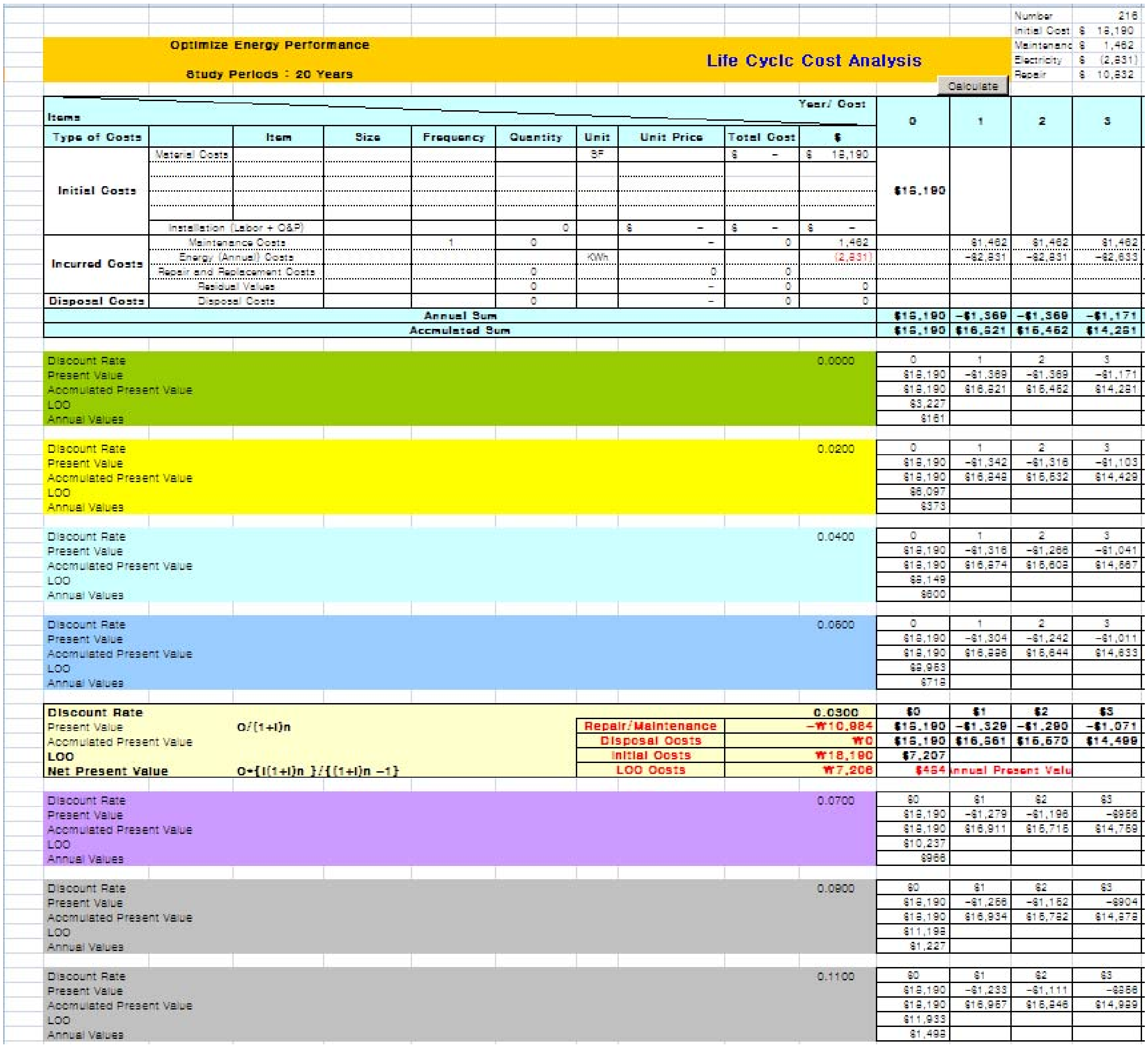
CHAPTER 8: DEVELOPMENT OF LIFE CYCLE COST

8.1 Introduction

Life cycle cost is a very important decision making criterion because it considers all the costs associated with a facility, from construction costs to operation, maintenance, repair, and replacement costs throughout the facility's life span. Thus, this chapter describes the approach used to estimate life cycle cost using cost inputs including first cost premiums, operating and maintenance costs, and repair and replacement costs. In addition, as the LCCA method escalates all amounts to their future year of occurrence and discounts them back to the base date to convert them to present values, there are several assumptions associated with LCCA. Thus, this chapter also describes various assumptions related to the method of LCCA. The chapter describes the procedure used for LCCA and the results of the LCCA, which is LCC. Finally, this chapter also describes how uncertainties, including the escalation rate of utility prices and discount rates, affect LCC. In the conclusion of this chapter, the LCC of each scenario is calculated to use as the basis for additional analysis in subsequent chapters.

8.2 Developing a Life Cycle Cost Tool

Since LCC is a summation of cost estimates from inception to disposal for projects as determined by an analytical study and estimate of the total costs experienced in annual time increments throughout the project's life, taking into account the time value of money, the calculation of LCC is complex and requires many steps. Thus, this study has developed the LCCA model using an Excel-based spreadsheet that utilizes the same financial principles as those employed for a discounted cash flow analysis. The Excel-based LCCA model was loaded with a comprehensive set of cost data, including first costs, maintenance costs, annual energy costs, and repair and replacement costs. It was then able to calculate the net present value of the cash flows. Figure 8.1 shows the Excel-based spreadsheet LCC model which is used to calculate LCC of each scenario of GBSTs. The following section describes the data input data into the LCCA model.



Number	216
Initial Cost	$ 18,190
Maintenanc	$ 1,462
Electricity	$ (2,831)
Repair	$ 10,832

Optimize Energy Performance

Study Periods : 20 Years

Life Cyclc Cost Analysis

Items									Year/ Cost	0	1	2	3
Type of Costs		Item	Size	Frequency	Quantity	Unit	Unit Price	Total Cost	$				
Initial Costs	Material Costs					SF		$ -	$ 18,190	$18,190			
	Installation (Labor + O&P)				0		$ -	$ -	$ -				
Incurred Costs	Maintenance Costs			1	0		-	0	1,462		$1,462	$1,462	$1,462
	Energy (Annual) Costs					KWh			(2,831)		-$2,831	-$2,831	-$2,633
	Repair and Replacement Costs				0		0	0					
	Residual Values				0		-	0	0				
Disposal Costs	Disposal Costs				0		-	0	0				
Annual Sum										$18,190	-$1,369	-$1,369	-$1,171
Accmulated Sum										$18,190	$16,821	$15,452	$14,281

Discount Rate	0.0000	0	1	2	3
Present Value		$18,190	-$1,369	-$1,369	-$1,171
Accmulated Present Value		$18,190	$16,821	$15,452	$14,281
LCC		$3,227			
Annual Values		$161			

Discount Rate	0.0200	0	1	2	3
Present Value		$18,190	-$1,342	-$1,316	-$1,103
Accmulated Present Value		$18,190	$16,848	$15,532	$14,429
LCC		$6,097			
Annual Values		$373			

Discount Rate	0.0400	0	1	2	3
Present Value		$18,190	-$1,316	-$1,266	-$1,041
Accmulated Present Value		$18,190	$16,874	$15,608	$14,567
LCC		$8,149			
Annual Values		$600			

Discount Rate	0.0600	0	1	2	3
Present Value		$18,190	-$1,304	-$1,242	-$1,011
Accmulated Present Value		$18,190	$16,886	$15,644	$14,633
LCC		$9,963			
Annual Values		$718			

Discount Rate			0.0300	$0	$1	$2	$3
Present Value	O/(1+I)n	Repair/Maintenance	-₩10,984	$18,190	-$1,329	-$1,290	-$1,071
Accmulated Present Value		Disposal Costs	₩0	$18,190	$16,861	$15,570	$14,499
LCC		Initial Costs	₩18,190	$7,207			
Net Present Value	O*{I(1+I)n }/{(1+I)n -1}	LCC Costs	₩7,208	$454	nnual Present Valu		

Discount Rate	0.0700	$0	$1	$2	$3
Present Value		$18,190	-$1,279	-$1,196	-$956
Accmulated Present Value		$18,190	$16,911	$15,715	$14,759
LCC		$10,237			
Annual Values		$966			

Discount Rate	0.0900	$0	$1	$2	$3
Present Value		$18,190	-$1,256	-$1,152	-$904
Accmulated Present Value		$18,190	$16,934	$15,782	$14,878
LCC		$11,198			
Annual Values		$1,227			

Discount Rate	0.1100	$0	$1	$2	$3
Present Value		$18,190	-$1,233	-$1,111	-$856
Accmulated Present Value		$18,190	$16,957	$15,846	$14,989
LCC		$11,933			
Annual Values		$1,498			

Figure 8.1 Excel-based spreadsheet LCC model

8.3 Life Cycle Cost Inputs

LCC represents the total cost over the lifetime incurred by a building, including first costs, operating costs, maintenance costs, and repair and replacement costs. Future operating, maintenance, repair and replacement costs were discounted to the based year of 2009 and summed over the study period. The following section describes these calculated costs, including first costs, operating costs, and maintenance, repair and replacement costs.

8.3.1 Inputs for First Costs

The input data used to calculate the first costs was a little different to the data generally used for first costs. In this study, the input for first cost was the cost of premiums compared to that for a standard prototype post office facility. Therefore the input for the first cost of each scenario was as follows:

Input for First Costs ($) = *First Cost of Scenario – First Cost of Baseline Prototype*

8.3.2 Operating Costs Inputs

The operating cost represents the costs incurred during the operation of the post office facility. As this study focused on “energy efficiency”, the annually incurred utility bills were the main operating costs of the post office facility. The specific inputs for operation costs are:

Input for Operating Costs ($) = *Operating Costs for Scenario*
– Operating Costs for Baseline Prototype

As utility prices would inevitably fluctuate over the life span of the post office facility, it was necessary to consider the likely trend of utility prices in the future. Since electricity was the only utility cost considered in this study, three scenarios for future electricity prices were selected that reflect the uncertainty of electricity prices over the forecast period. The Energy Information Administration (EIA) predicted three scenarios for electricity prices up to 2030, of which this study considered two scenarios referred to as real prediction and high prediction. In addition, this study also considered a third scenario in which the price of electricity increased in a linear fashion based on the average price growth from 1995 to 2007. The total growth of electricity price (Consumer Retail Price) increased from $0.084 / KWh to $0.1128 / KWh and the annual growth of electricity price was 1.82% over this period, which was assumed to continue for this scenario. Figure 8.2 and Table 8.1 show the predictions of the three scenarios for electricity prices up to 2030 (EIA 2009c). In the calculation of operation costs, three scenarios for electricity costs (annual energy usage * electricity price) were considered as a sensitivity analysis.

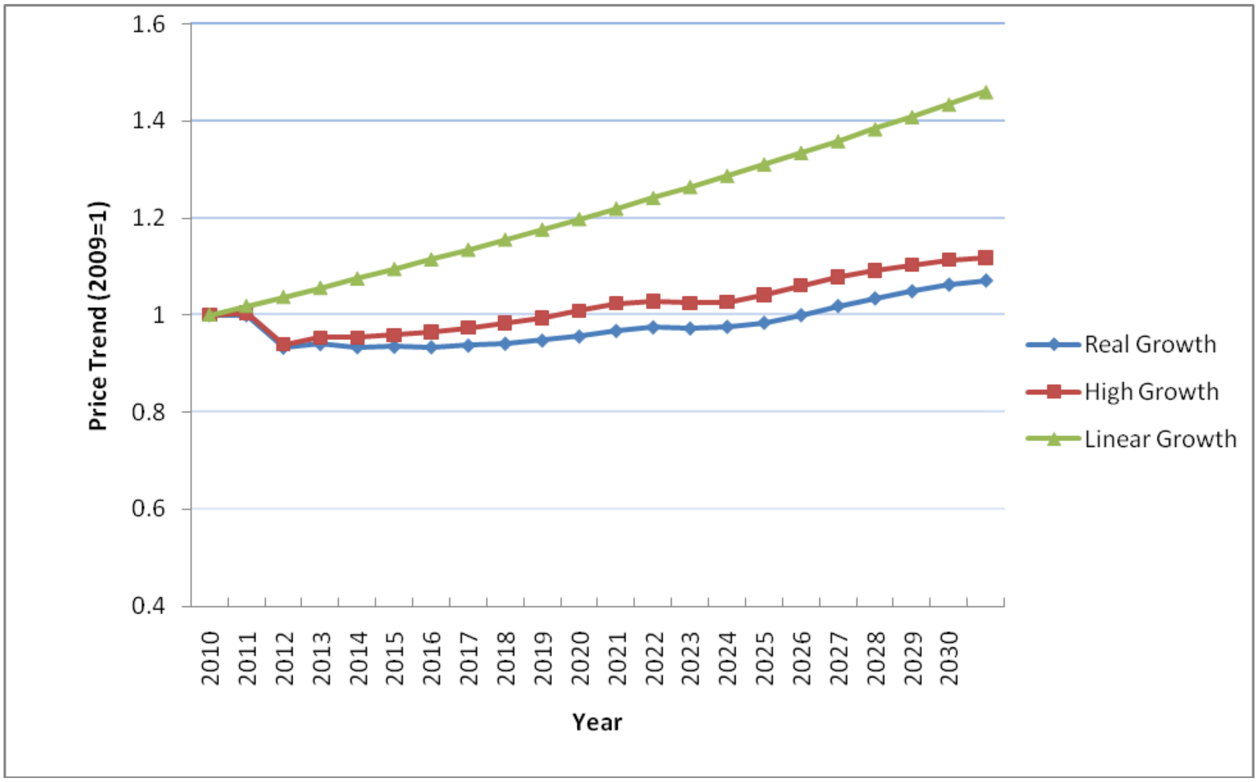


Figure 8.2 Predicted electricity price trends (EIA 2009a; c) (assembled the graph based on EIA data)

Table 8.1 Three scenarios for future electricity pricing (EIA 2009a; c)

Year	Real	High	Linear
2010	1.00	1.01	1.02
2011	0.93	0.94	1.04
2012	0.94	0.95	1.06
2013	0.93	0.95	1.07
2014	0.94	0.96	1.09
2015	0.93	0.96	1.11
2016	0.94	0.97	1.13
2017	0.94	0.98	1.16
2018	0.95	0.99	1.18
2019	0.96	1.01	1.20
2020	0.97	1.02	1.22
2021	0.98	1.03	1.24
2022	0.97	1.02	1.26
2023	0.98	1.03	1.29
2024	0.98	1.04	1.31
2025	1.00	1.06	1.33
2026	1.02	1.08	1.36
2027	1.03	1.09	1.38
2028	1.05	1.10	1.41
2029	1.06	1.11	1.43
2030	1.07	1.12	1.46

8.3.3 Maintenance, Repair and Replacement Costs Inputs

Once a post office facility goes into operation, it incurs additional costs associated with maintenance, repair, and replacement of the facility components. The maintenance cost of lighting systems and HVAC systems were considered in this study because other GBSTs incurred no significant maintenance cost over the life of the GBSTs or over the study period. Operating the post office facility also involved repairs to be performed periodically in order to return failed components into service. In addition, routine repair is also needed, which consists of actions taken to restore components, including lighting fixtures and lamps, to their original capacity, efficiency, or capability. For example, the replacement of a failed lamp with a new lamp would be a routine repair. In addition, there is a life expectancy for building components, and some components require replacement, including lighting fixtures, ballasts in lighting fixtures, and so on, at the end of their service life. Replacement costs included the labor and materials costs associated with replacing building components at the end of their life time; these were summarized in Chapter 7. Once components reach the end of their expected lifetimes, new components must be installed at the beginning of that year. The replacement costs, including material and labor costs with associated profits and overheads which the USPS outsources, are discounted back to the base year of the study period (2009). The maintenance, repair, and replacement costs are constant over the study period because this study has adopted a real discount rate.

8.4 Discount Rate

The discount rate is the rate at which the USPS discounts future expenditures in order to establish their present values. Thus, the higher the discount rate, the lower the present value of future expenditures. Due to the significant impact of LCC, it is necessary to use an appropriate discount rate in the LCCA. The first consideration when selecting a discount rate is real versus nominal discount rates. As previously explained in Chapter 4, this study used a real discount rate.

As the discount rate determines the present value of future project related costs, especially those related to operation, maintenance, repair and replacement, this study considered three different discount rates. Because the USPS is a quasi-public agency similar to conventional public agencies, the first rate considered was that given in the "Office of Management and Budget (OMB) Circular No. A-94 Appendix C revised December 2008". However, the discount rate specified in the circular is only valid for the calendar year 2009 and is subject to annual updates by the OMB (OMB 2009). According to OMB Circular No. A-94 Appendix C, real discount rates are as shown in Table 7.2.

Table 8.2 Real discount rate (OMB 2009)

3 – Year	5 – Year	7 – Year	10 – Year	20 – Year	30 – Year
0.9	1.6	1.9	2.4	2.9	2.7

The second scenario considered for discount rates is the U.S. Department of Energy (USDOE)'s discount rate for projects connected with energy conservation. The USDOE's real discount rate for 2009 is 3.0% (Rushing and Lippiatt 2009). This discount rate is specified in the annual report of "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis –

2009" by the National Institute of Standard and Technology in the U.S. Department of Commerce.

The third discount rate considered was the prevailing discount rate in the private sector. Since U.S. treasury interest rates are below interest rates in the private sector, the discount rates in the private market are above the two discount rates in the first two discount rate scenarios (Kohyama 2006). According to the U.S. Department of Energy (2009d), the average discount rate for the commercial sector is 7 percent after considering discount rate variables including risk free asset return, equity risk premium, cost of debt, percent debt financing, and systematic firm risk. Therefore, this study chose 7 percent as the third discount rate scenario for LCCA. However, as the discount rates for the OMB and the U.S. Department of Energy are almost equal, these were effectively the same and the study compared the effect of 3 percent and 7 percent.

8.5 Residual Value

The residual value represents the remaining value of alternatives in selected independent variables. As discussed in the Chapter 4, this study only considered the residual values for specific components replaced within the study period. However, the life expectancy of lighting fixtures and HVAC systems is twenty years, the same as the study period, and thus the analysis does not need to account for the residual value of these GBSTs since their service life ends at the same time as the study period.

8.6 Study Period

The study period is the number of years over which LCCs is determined for the various alternatives. Like other key elements such as discount rates and various costs, the study period must be established before the LCCA is begun. As the study period in LCCA is related to all costs, especially replacement costs, discount rates, and investment decision making, guidance on this matter has been provided by the Federal Energy Management Program (FEMP). FEMP rules, laid out in 10 CFR 436, require that the LCC study period cannot exceed 25 years (CFR 2004; USDOE 2005). The USPS recommends 20 years for LCCA. Therefore, this study considered a study period of 20 years based on the FEMP guidelines and the USPS recommendations.

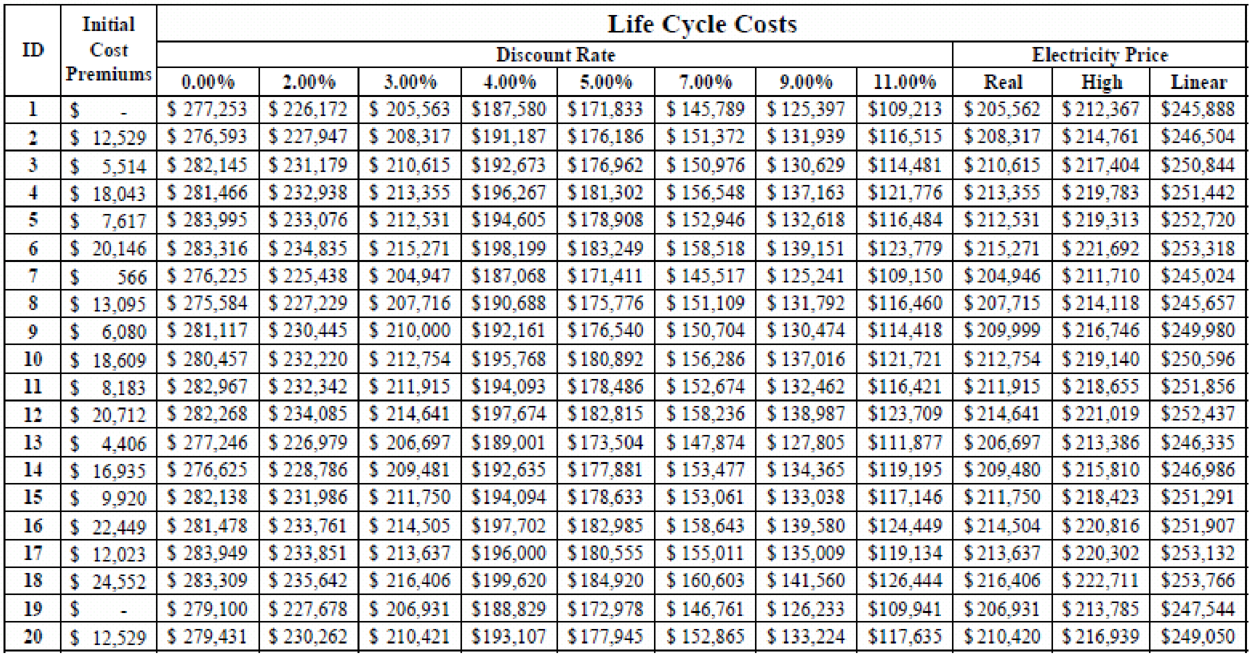
8.7 Assumptions, Uncertainty and Sensitivity Analysis

All costs, escalation rates, and discount rates are uncertain due to imprecision in both the underlying data and the modeling assumptions. To account for uncertainties and assumptions, this study conducted a sensitivity analysis for both discount rates and future electricity prices.

8.8 Life Cycle Costs

This section shows the LCCs of each scenario calculated by the Excel-based LCCA tool. This calculated LCC is used to answer the study's research objective: “To identify the relationships between first costs related to GBSTs and LCCs”. Table 8.3 shows the LCCs, along with the first costs of the scenarios. Additional LCCs along with associated scenarios are listed in Appendix H.

Table 8.3 First costs and LCCs



ID	Initial Cost Premiums	Life Cycle Costs										
		Discount Rate								Electricity Price		
		0.00%	2.00%	3.00%	4.00%	5.00%	7.00%	9.00%	11.00%	Real	High	Linear
1	$ -	$ 277,253	$ 226,172	$ 205,563	$187,580	$ 171,833	$ 145,789	$ 125,397	$109,213	$ 205,562	$ 212,367	$245,888
2	$ 12,529	$ 276,593	$ 227,947	$ 208,317	$191,187	$ 176,186	$ 151,372	$ 131,939	$116,515	$ 208,317	$ 214,761	$246,504
3	$ 5,514	$ 282,145	$ 231,179	$ 210,615	$192,673	$ 176,962	$ 150,976	$ 130,629	$114,481	$ 210,615	$ 217,404	$250,844
4	$ 18,043	$ 281,466	$ 232,938	$ 213,355	$196,267	$ 181,302	$ 156,548	$ 137,163	$121,776	$ 213,355	$ 219,783	$251,442
5	$ 7,617	$ 283,995	$ 233,076	$ 212,531	$194,605	$ 178,908	$ 152,946	$ 132,618	$116,484	$ 212,531	$ 219,313	$252,720
6	$ 20,146	$ 283,316	$ 234,835	$ 215,271	$198,199	$ 183,249	$ 158,518	$ 139,151	$123,779	$ 215,271	$ 221,692	$253,318
7	$ 566	$ 276,225	$ 225,438	$ 204,947	$187,068	$ 171,411	$ 145,517	$ 125,241	$109,150	$ 204,946	$ 211,710	$245,024
8	$ 13,095	$ 275,584	$ 227,229	$ 207,716	$190,688	$ 175,776	$ 151,109	$ 131,792	$116,460	$ 207,715	$ 214,118	$245,657
9	$ 6,080	$ 281,117	$ 230,445	$ 210,000	$192,161	$ 176,540	$ 150,704	$ 130,474	$114,418	$ 209,999	$ 216,746	$249,980
10	$ 18,609	$ 280,457	$ 232,220	$ 212,754	$195,768	$ 180,892	$ 156,286	$ 137,016	$121,721	$ 212,754	$ 219,140	$250,596
11	$ 8,183	$ 282,967	$ 232,342	$ 211,915	$194,093	$ 178,486	$ 152,674	$ 132,462	$116,421	$ 211,915	$ 218,655	$251,856
12	$ 20,712	$ 282,268	$ 234,085	$ 214,641	$197,674	$ 182,815	$ 158,236	$ 138,987	$123,709	$ 214,641	$ 221,019	$252,437
13	$ 4,406	$ 277,246	$ 226,979	$ 206,697	$189,001	$ 173,504	$ 147,874	$ 127,805	$111,877	$ 206,697	$ 213,386	$246,335
14	$ 16,935	$ 276,625	$ 228,786	$ 209,481	$192,635	$ 177,881	$ 153,477	$ 134,365	$119,195	$ 209,480	$ 215,810	$246,986
15	$ 9,920	$ 282,138	$ 231,986	$ 211,750	$194,094	$ 178,633	$ 153,061	$ 133,038	$117,146	$ 211,750	$ 218,423	$251,291
16	$ 22,449	$ 281,478	$ 233,761	$ 214,505	$197,702	$ 182,985	$ 158,643	$ 139,580	$124,449	$ 214,504	$ 220,816	$251,907
17	$ 12,023	$ 283,949	$ 233,851	$ 213,637	$196,000	$ 180,555	$ 155,011	$ 135,009	$119,134	$ 213,637	$ 220,302	$253,132
18	$ 24,552	$ 283,309	$ 235,642	$ 216,406	$199,620	$ 184,920	$ 160,603	$ 141,560	$126,444	$ 216,406	$ 222,711	$253,766
19	$ -	$ 279,100	$ 227,678	$ 206,931	$188,829	$ 172,978	$ 146,761	$ 126,233	$109,941	$ 206,931	$ 213,785	$247,544
20	$ 12,529	$ 279,431	$ 230,262	$ 210,421	$193,107	$ 177,945	$ 152,865	$ 133,224	$117,635	$ 210,420	$ 216,939	$249,050

8.9 Conclusion

This chapter described the LCCA model developed using an Excel spreadsheet that utilized the same financial principles as those employed by a discount cash flow analysis. As this LCCA model required all costs as inputs, the chapter's subsections described this cost data, including the incremental costs of first costs, maintenance costs, repair and replacement costs, and energy costs. In addition, sensitivity analysis was performed based on the escalation rate of electricity prices and discount ratings. This chapter concluded with LCC of the each scenario in this study, which is used in further analysis described in the next chapter.

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CHAPTER 9: FINDINGS AND DISCUSSION

9.1 Introduction

This chapter describes the research findings of this study and discusses their significance and implications in public green facilities. The chapter starts by identifying the relationship between the first costs needed to implement individual GBSTs and their LCC in the USPS facility studied, then goes on to examine how multiple GBSTs can be integrated to minimize first costs and LCCs and thereby maximize benefits. Graphs of the relationships between the first cost premiums and both GBSTs and LCC are also provided to illustrate the effect of different energy cost scenarios. Finally, this chapter develops a series of regression models to identify the relationships between first cost premiums related to GBSTs and LCC and describe their outcomes, and concludes by considering their application to public green facilities.

9.2 Relationship Between Green Building Strategies and Technologies and Their First and Life Cycle Costs

Green building strategies and technologies designed to improve the energy performance of the facility have an effect not only on the first costs required to implement them but also the facility's LCC. For this study, five GBSTs were selected, namely the orientation of the facility, the level of wall and roof insulation, the lighting systems, and the HVAC systems. This section describes how each of these alternative GBSTs are likely to affect the first cost, the operating costs, which mainly consist of the annual utility cost, and the LCC over the facility's expected life. These relationships could serve as benchmark values for those designing and constructing similar post office facilities in equivalent geographical regions, thus supporting the construction of green buildings in the USPS. In addition, these relationships could help the USPS to revise its standard drawings and specifications for new post office facilities to minimize energy costs. The following subchapters consider in turn each of the individual GBSTs examined in this study.

9.2.1 Building Orientation

Building orientation is one of the most important design criteria for passive solar design, as it directly affects the annual energy consumption of the facility. Based on the assumption that building orientation would have no effect on first costs, maintenance costs, or repair and replacement costs, this study started by identifying the annual energy consumption of the facility based on four different alternative orientations to calculate the operating costs. Estimating annual energy consumption using an energy simulation tool, the base case of the building orientation, where the front door of the post office faced south, was compared with three alternatives (Table 9.1). As Table 9.1 shows, the south facing building orientation had the lowest annual electricity consumption, at 121,030 KWh and the north facing building orientation had the highest, at 121,890 KWh. Thus, choosing a south facing orientation could save 860 KWh annually, simply by changing the building orientation from north to south. A comparison of annual operating costs on the basis of these four alternative building orientations indicated that the south facing building orientation would reduce operating costs by $86 compared to the north facing building orientation (Table 9.1). In conducting an LCCA to calculate the LCC for each of the four alternatives, this south facing building orientation can reduce operating costs by $1,369 over 20 years (based on a 3% discount rate and "real" electricity price index) compared to the north facing building orientation (Table 9.1, Table 9.2 and Figure 9.1). The LCC saving of changing building orientation is minimal because the post office facility is relatively uniform building geometry and lack of glazing.

Table 9.1 Annual energy consumption and costs based on different building orientations

Alternatives	Annual Energy Consumption (KWh)	Annual Energy Cost ($)	First Cost Premium ($)	Life Cycle Cost[8] ($)
South (Base)	121,030 KWh	$13,313	$0	$191,838
North	121,890 KWh	$13,408	$0	$193,207
West	121,560 KWh	$13,372	$0	$192,687
East	121,070 KWh	$13,318	$0	$191,910

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[8] Discount rate of 3% and "real" electricity price index

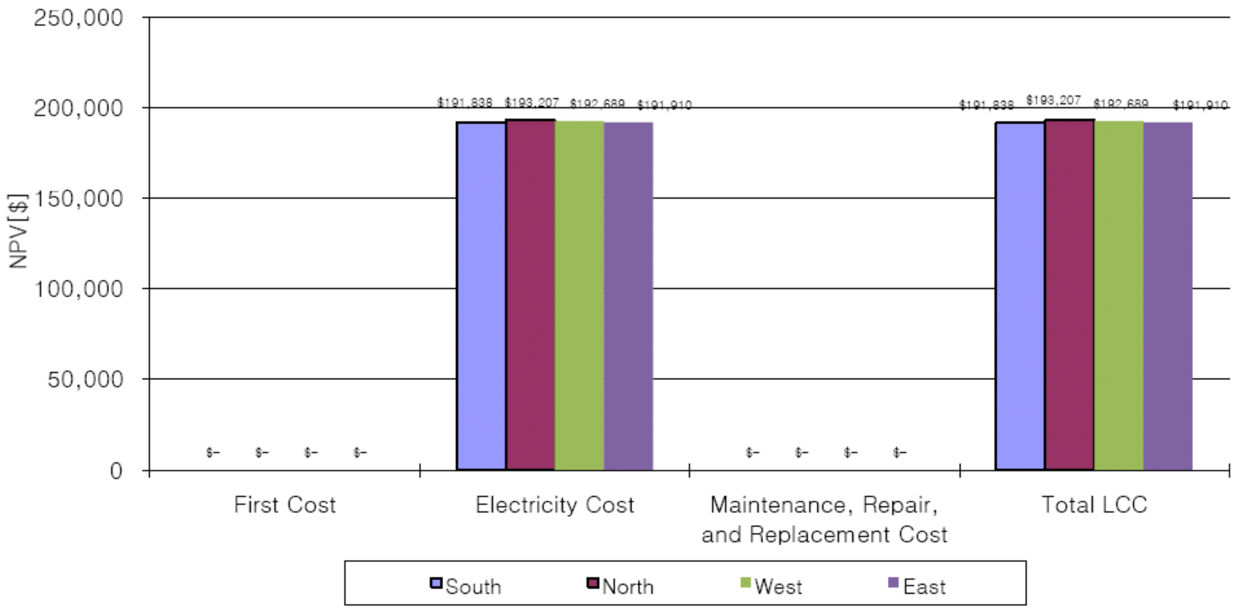

Figure 9.1 Costs based on four different building orientation alternatives

Table 9.2 Composition of LCC

Alternatives	First Cost	Electricity Cost	Maintenance, Repair, and Replacement Cost	Total LCC	Base - Alternative
South (Base)	$0	$191,838	$0	$191,838	$0
North	$0	$193,207	$0	$193,207	$(1,369)
West	$0	$192,689	$0	$192,689	$(850)
East	$0	$191,910	$0	$191,910	$(72)

Applying sensitivity analysis, which reveals where analysis results may be subject to uncertainties such as discount rates and future electricity prices, it was possible to identify the how LCC might change in each of the four alternatives. In the sensitivity analysis of the discount rate, the saving of LCC between the south orientation and the north orientation decreased from $1,369 to $971 when the discount rate increased from 3% to 7% (Table 9.3). This indicates that the benefit of the southern building orientation compared to other orientations could be diminished in high discount rate environments. However, changing the shape (width and length ratio) of the post office facility itself is possible to increase the potential saving of south orientation. For example, the change of facility shape from a square to rectangular shape with ratio of 1 (width) / 3 (length) and east-west (E-W) elongated orientation minimizes annual operational energy consumption if done in conjunction with installing proper shading devices.

Table 9.3 Sensitivity analysis for different discount rates

Alter.	0%	2%	**3%**	4%	5%	**7%**	9%	11%
South	$258,805	$211,075	**$191,838**	$175,066	$160,387	**$136,132**	$117,159	$102,114
North	$260,652	$212,581	**$193,207**	$176,315	$161,532	**$137,103**	$117,995	$102,843
West	$259,952	$212,010	**$192,689**	$175,841	$161,098	**$136,735**	$117,678	$102,567
East	$ 258,902	$211,154	**$191,910**	$175,131	$160,448	**$ 136,183**	$117,203	$102,152

Uncertainty in future electricity prices also produced different LCCs for the four alternatives. As shown in Table 9.4, comparing LCC between the south and north facing orientations reveals an increase in savings from $1,369 to $1,657 for the linear electricity price index compared to the real electricity price index. This result indicates that if the price of electricity is high over the facility's lifetime, the benefits of the south orientation also increase gradually over time. If there is a significant increase of energy prices including electricity price similar to the year of 2007 and 2008, the annual energy saving of south orientation is significantly increased compared to other orientation.

Based on the result of LCC among the four orientation alternatives, a southern orientation is clearly the preferred orientation to improve energy performance, with the northern orientation being the worst for energy conservation. Thus, this study recommends the following order of preference with regard to the building orientation for USPS facilities:

1) South
2) East
3) West
4) North

Table 9.4 Sensitivity analysis for future electricity prices

Alternatives	Real Electricity Price	High Electricity Price	Linear Electricity Price
South	$191,838	$198,643	$232,163
North	$193,207	$200,061	$233,820
West	$192,689	$199,524	$233,192
East	$191,910	$198,718	$232,251

In addition, this study suggests that the USPS should revise its *AS-503 Standard Design Guide*, which provides standard drawings and specifications for USPS post office facilities, to minimize annual energy consumption and thus annual operating costs by recommending that buildings be oriented to face south wherever practicable.

9.2.2 Insulation

As insulation is used in post office facilities to reduce energy consumption and increase thermal comfort, it is important to identify how much insulation should be used to gain maximum benefits considering the first cost premium, reduction in annual energy consumption, and the LCC. Thus, this study examined the optimal level of wall and roof insulation that should be installed to maximize benefits.

9.2.2.1 Wall Insulation

For this study three alternative levels of wall insulation were examined, namely R-15, R-21, and R-30. First, it was necessary to identify the first cost premium for each. As Table 9.5 indicates, the estimated cost premium associated with increasing the level of wall insulation from R-15 to R-21 is $566 and increasing the level of wall insulation from R-15 to R-30 incurs a significant first cost premium of $4,406. However, as the table also shows, the higher level of wall insulation will reduce annual energy consumption, which automatically reduces the annual operating costs.

Table 9.5 Energy consumption and costs for wall insulation

Alternatives	First Cost ($)	First Cost Premium ($)	Annual Energy Consumption (KWH)	Annual Energy Cost ($)	Annual Energy Saving ($)	LCC[9] ($)
R – 15 (Base)	$4,080	$0	121,030 KWh	$13,313	$0	$195,875
R – 21	$4,646	$566	120,280 KWh	$13,231	$82	$195,302
R – 30	$8,486	$4,406	118,960 KWh	$13,086	$227	$197,053

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[9] Discount rate of 3% and real electricity price index

Going on to examine the relationships between the level of wall insulation and the associated energy saving opportunities, Table 9.6 shows that increasing the level of wall insulation from R-15 to R-21 will reduce the space cooling load by 0.5% and the space heating load by an additional 1.05%. Increasing the level of wall insulation from R-15 to R-30 boosts this effect, reducing the space cooling load by 1.3% and the space heating load by 2.9%, thus reducing both annual energy consumption and annual operating costs. From Table 9.6, improving the level of wall insulation from R-15 to R-21 reduces the annual energy cost by $82 (0.62% of the operating cost) and improving the wall insulation from R-15 to R-30 can reduce the annual energy cost by $227 (1.7% of the operating cost).

Table 9.6 Electricity savings achievable by improving the level of wall insulation

	Electricity KWh (x000)			R-15 to 21		R-15 to 30	
	R-15	R-21	R-30	Elec. Sav.	Saving (%)	Elec. Sav.	Saving (%)
Space Cooling	13.960	13.890	13.780	0.070	0.50%	0.180	1.3%
Space Heating	64.110	63.440	62.280	0.670	1.05%	1.830	2.9%
Vent. Fans	16.270	16.250	16.210	0.020	0.12%	0.060	0.4%
Pumps & Aux.	0.600	0.600	0.600	0.000	0.00%	0.000	0.0%
Task Lights	0.430	0.430	0.430	0.000	0.00%	0.000	0.0%
Area Lights	25.670	25.670	25.670	0.000	0.00%	0.000	0.0%
Total	121.030	120.280	118.960	0.750	0.62%	2.070	1.7%

By comparing LCC of the three wall insulation alternatives (Figure 9.2), the R-21 wall insulation results in the lowest LCC of $195,302 for a discount rate of 3% and the real electricity price index. This indicates that increasing the level of wall insulation from R-15 to R-21 produces an overall saving of $572 over twenty years. However, increasing the level of wall insulation from R-15 to R-30 does not achieve sufficient energy savings over twenty years to offset the first cost premium of $4,406; increasing the level of wall insulation from R-15 to R-30 increases the LCC by $1,178 because of the high first cost premium for R-30 wall insulation.

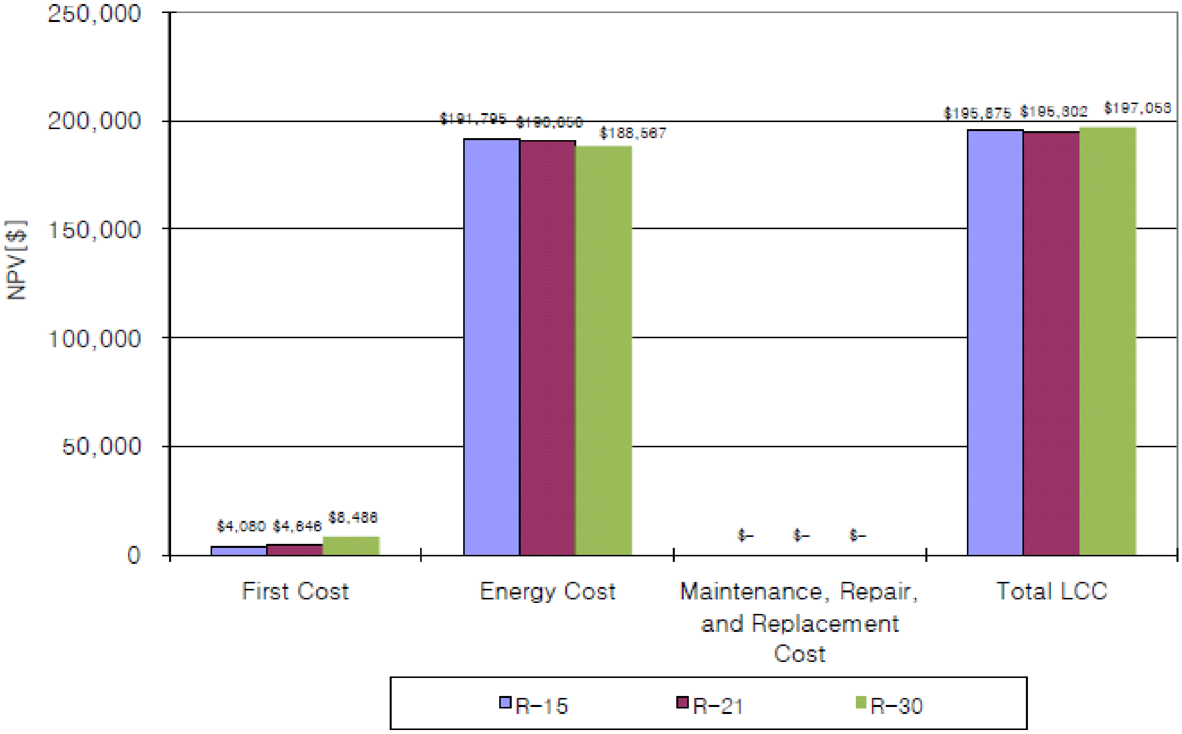


Figure 9.2 Costs based on three different wall insulation alternatives

As the present value of a future amount is sensitive to the discount rate by which the future amount is discounted, this study also compared the effect of two different discount rates, namely 3% and 7%. From the sensitivity analysis of the discount rate, when the discount rate is increased to 7% from 3%, the net saving to improve the wall insulation level from R-15 to R-21 decreases from $572 to $242 (Table 9.7). Comparing R-15 and R-30, increasing the discount rate from 3% to 7% also worsens the net present value, increasing it to $(2,115) from $(1,178). This result indicates that if the discount rate increases from 3% to 7%, the saving in the net present value between R-15 and R-21 decreases.

Table 9.7 Sensitivity analysis for the discount rates (Wall insulation)

Alter.	0%	2%	**3%**	4%	5%	**7%**	9%	11%
R-15	$262,826	$215,107	**$195,875**	$179,106	$164,431	**$140,181**	$121,213	$106,171
R-21	$261,857	$214,421	**$195,303**	$178,633	$164,045	**$139,940**	$121,084	$106,131
R-30	$262,878	$215,962	**$197,053**	$180,567	$166,139	**$142,297**	$123,648	$108,859
Net (R-15 to R-21)	$970	$687	**$572**	$473	$386	**$242**	$129	$40
Net (R-15 to R-30)	$(51)	$(855)	**$(1,178)**	$(1,460)	$(1,707)	**$(2,115)**	$(2,435)	$(2,688)

In addition to the sensitivity analysis of the discount rates, this study also conducted a sensitivity analysis for the future cost of electricity. Based on the results of this analysis shown in Table 9.8 and Figure 9.3, the net saving between R-15 and R-21 increases from $573 (for the real electricity price index) to $612 (for the high electricity price) and $812 (for the linear electricity price index). In addition, the net loss incurred by improving the level of wall insulation from R-15 to R-30 decreases from $(1,178) to $(1,064) for the high electricity price index and $(500) for the linear electricity price index. This result indicates that if electricity prices increase more rapidly over the study period, R-21 achieves a better result than R-15. In addition, higher electricity costs in the future will also tend to offset the first cost premium for R-30 wall insulation.

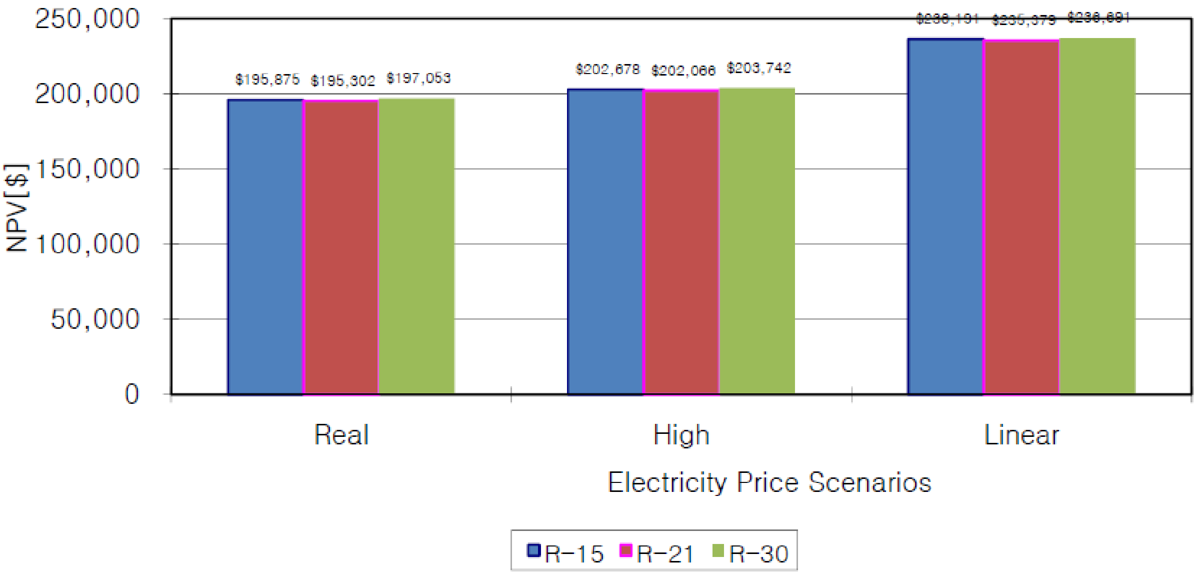
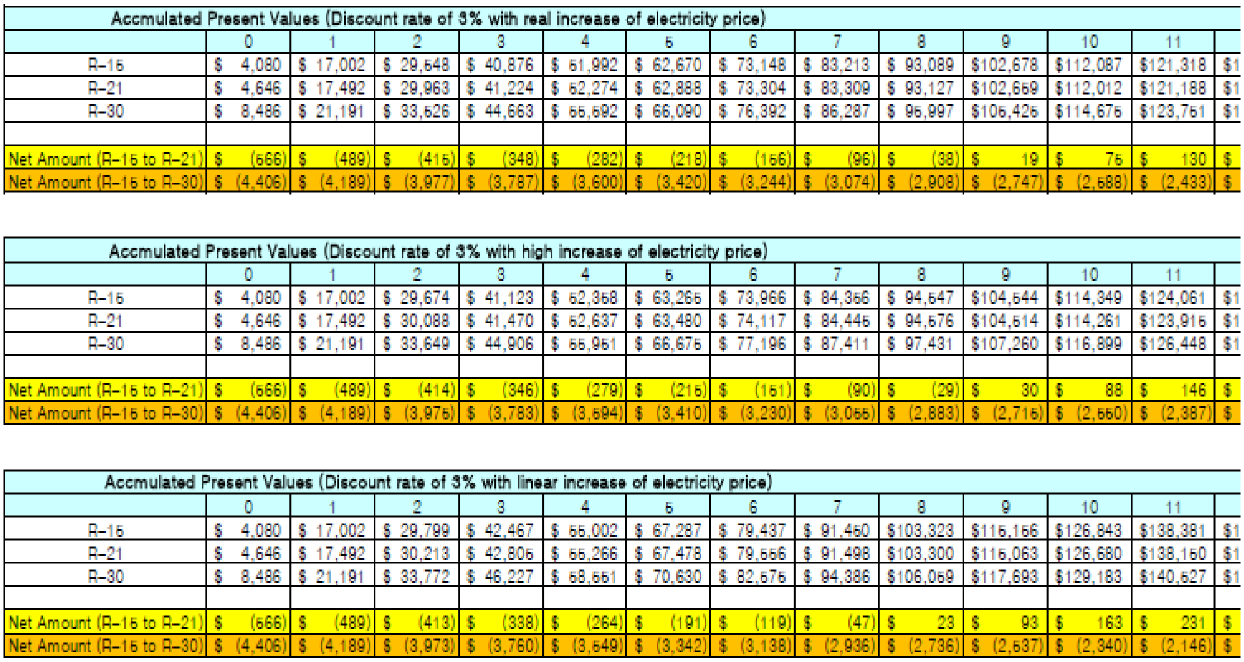


Figure 9.3 Sensitivity analysis for future electricity prices (wall insulation)

Table 9.8 Net cash flow amount among three alternatives

	Real	High	Linear
R – 15	$ 195,875	$ 202,678	$ 236,191
R – 21	$ 195,302	$ 202,066	$ 235,379
R – 30	$ 197,053	$ 203,742	$ 236,691
Net Amount (R-15 to R-21)	$ 573	$ 612	$ 812
Net Amount (R-15 to R-30)	$ (1,178)	$ (1,064)	$ (500)

In addition to sensitivity analysis, this study also conducted a breakeven analysis to determine the number of years needed to cover the first cost premium. From Figure 9.4, the breakeven point for improving the level of wall insulation from R-15 to R-21 is in Year 9 for a discount rate of 3% and both the real and higher electricity indexes because at this point the net cost changes from negative to positive. For the linear electricity price index, the breakeven point is brought forward to Year 8.



Accmulated Present Values (Discount rate of 3% with real increase of electricity price)

	0	1	2	3	4	5	6	7	8	9	10	11	
R-15	$ 4,080	$ 17,002	$ 29,548	$ 40,876	$ 51,992	$ 62,670	$ 73,148	$ 83,213	$ 93,089	$102,678	$112,087	$121,318	$1
R-21	$ 4,646	$ 17,492	$ 29,963	$ 41,224	$ 52,274	$ 62,888	$ 73,304	$ 83,309	$ 93,127	$102,669	$112,012	$121,188	$1
R-30	$ 8,486	$ 21,191	$ 33,526	$ 44,663	$ 55,592	$ 66,090	$ 76,392	$ 86,287	$ 96,997	$105,425	$114,675	$123,751	$1
Net Amount (R-15 to R-21)	$ (566)	$ (489)	$ (415)	$ (348)	$ (282)	$ (218)	$ (156)	$ (96)	$ (38)	$ 19	$ 75	$ 130	$
Net Amount (R-15 to R-30)	$ (4,406)	$ (4,189)	$ (3,977)	$ (3,787)	$ (3,600)	$ (3,420)	$ (3,244)	$ (3,074)	$ (2,908)	$ (2,747)	$ (2,588)	$ (2,433)	$

Accmulated Present Values (Discount rate of 3% with high increase of electricity price)

	0	1	2	3	4	5	6	7	8	9	10	11	
R-15	$ 4,080	$ 17,002	$ 29,674	$ 41,123	$ 52,358	$ 63,265	$ 73,966	$ 84,356	$ 94,547	$104,544	$114,349	$124,061	$1
R-21	$ 4,646	$ 17,492	$ 30,088	$ 41,470	$ 52,637	$ 63,480	$ 74,117	$ 84,446	$ 94,576	$104,514	$114,261	$123,915	$1
R-30	$ 8,486	$ 21,191	$ 33,649	$ 44,906	$ 55,951	$ 66,675	$ 77,196	$ 87,411	$ 97,431	$107,260	$116,899	$126,448	$1
Net Amount (R-15 to R-21)	$ (566)	$ (489)	$ (414)	$ (346)	$ (279)	$ (215)	$ (151)	$ (90)	$ (29)	$ 30	$ 88	$ 146	$
Net Amount (R-15 to R-30)	$ (4,406)	$ (4,189)	$ (3,975)	$ (3,783)	$ (3,594)	$ (3,410)	$ (3,230)	$ (3,055)	$ (2,883)	$ (2,716)	$ (2,550)	$ (2,387)	$

Accmulated Present Values (Discount rate of 3% with linear increase of electricity price)

	0	1	2	3	4	5	6	7	8	9	10	11	
R-15	$ 4,080	$ 17,002	$ 29,799	$ 42,467	$ 55,002	$ 67,287	$ 79,437	$ 91,450	$103,323	$115,156	$126,843	$138,381	$1
R-21	$ 4,646	$ 17,492	$ 30,213	$ 42,805	$ 55,266	$ 67,478	$ 79,556	$ 91,498	$103,300	$115,063	$126,680	$138,150	$1
R-30	$ 8,486	$ 21,191	$ 33,772	$ 46,227	$ 58,551	$ 70,630	$ 82,575	$ 94,386	$106,059	$117,693	$129,183	$140,527	$1
Net Amount (R-15 to R-21)	$ (566)	$ (489)	$ (413)	$ (338)	$ (264)	$ (191)	$ (119)	$ (47)	$ 23	$ 93	$ 163	$ 231	$
Net Amount (R-15 to R-30)	$ (4,406)	$ (4,189)	$ (3,973)	$ (3,760)	$ (3,549)	$ (3,342)	$ (3,138)	$ (2,936)	$ (2,736)	$ (2,537)	$ (2,340)	$ (2,146)	$

Figure 9.4 Accumulated present values and net cash flow

Based on this comparison of the first costs incurred for each level of wall insulation and LCC, R-21 appears to offer the most efficient level of wall insulation that both optimizes energy performance and minimizes LCC over the facility's lifetime of twenty years reflected by the study period.

9.2.2.2 Roof Insulation

As this study also considered the level of roof insulation as a GBST to optimize energy performance in the USPS facility, it was necessary to identify the relationship between the first cost premiums of three alternatives (R-30, R-49, and R-60) and LCC. Based on the first cost estimates for the three alternatives, the roof insulation of R-49 requires an additional $5,514 on top of the base cost for R-30, while R-60 demands an additional first cost of $7,617. However, improving the level of roof insulation reduces annual energy consumption, as shown in Tables 9.9 and 9.10. Comparing R-30 and R-49, the R-49 roof insulation reduces the space cooling load by 0.2% and the space heating load by 0.5%. The R-60 roof insulation achieves better results, reducing the space cooling load by 0.3% and the space heating load by 0.6% compared to the base case of R-30. Improving the level of roof insulation to R-49 achieves annual energy savings of $32 compared to R-30 roof insulation, while R-60 saves $45 annually compared with R-30 roof insulation.

Table 9.9 Energy consumption and costs for roof insulation

Alternatives	First Cost ($)	First Cost Premium ($)	Annual Energy Consumption (KWH)	Annual Energy Cost ($)	Annual Energy Saving	Net Present Value[10] ($)
R – 30 (Base)	$10,390	$0	121,030 KWh	$13,313	$0	$202,147
R – 49	$15,904	$5,514	120,740 KWh	$13,281	$32	$207,281
R – 60	$18,007	$7,617	120,620 KWh	$13,268	$45	$209,197

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[10] Discount rate of 3% and real electricity price index

Table 9.10 Electricity savings achieved by improving roof insulation

	Electricity KWh (x000)			R-30 to 49		R-30 to 60	
	R-30	R-49	R-60	Elec. Sav.	Saving (%)	Elec. Sav.	Saving (%)
Space Cooling	13.960	13.930	13.920	0.030	0.2%	0.040	0.3%
Space Heating	64.110	63.800	63.730	0.310	0.5%	0.380	0.6%
Vent. Fans	16.270	16.270	16.270	0.000	0.0%	0.000	0.0%
Pumps & Aux.	0.600	0.600	0.600	0.000	0.0%	0.000	0.0%
Task Lights	0.430	0.430	0.430	0.000	0.0%	0.000	0.0%
Area Lights	25.670	25.670	25.670	0.000	0.0%	0.000	0.0%
Total	121.030	120.740	120.620	0.290	0.2%	0.410	0.3%

As improving the wall insulation reduces annual energy costs while at the same time incurring a first cost premium, this study conducted LCCA to calculate the LCC of the three alternative levels of roof insulation. The R-30 roof insulation resulted in the lowest LCC, $202,147 with a discount rate of 3% and the real electricity price index, as shown in Figure 9.5. The LCCA revealed that improving the level of roof insulation to R-49 and R-60 increased the LCC to $5,134 and $7,050, respectively, compared to the R-30 roof insulation based on the high first cost premium and relatively minor annual energy cost saving. This result indicates that the R-30 roof insulation achieved the optimal level of roof insulation based on the first cost premiums and LCC.

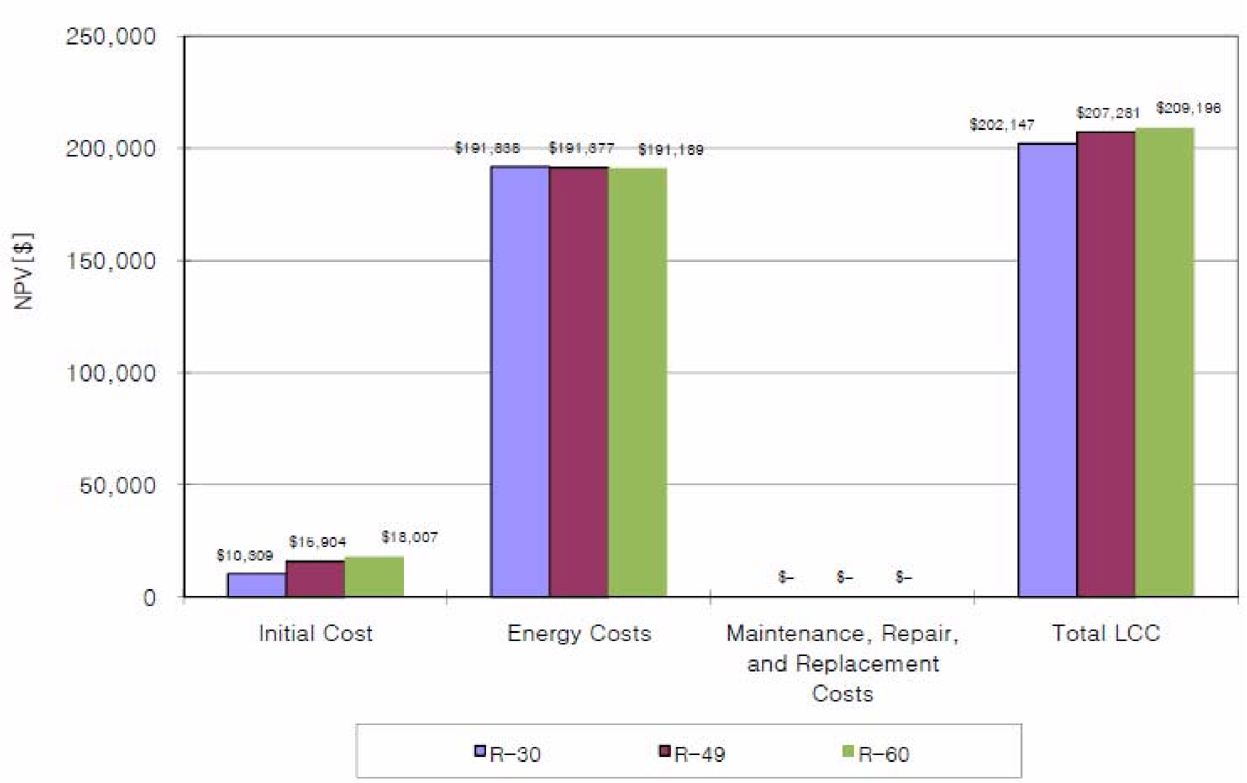


Figure 9.5 Costs based on three different roof insulation alternatives

Conducting sensitivity analysis for the discount rate revealed that increasing the discount rate to 7% from 3% also increased the overall loss in LCC between R-49 and R-60 roof insulation, as shown in Table 9.11a. This result indicates that selecting R-30 roof insulation was the best alternative to minimize LCC because each of the other alternatives incurred significant additional cost premiums accompanied by relatively insignificant energy cost saving opportunities.

Table 9.11a Sensitivity analysis for different discount rates (Roof insulation)

Alter.	0%	2%	**3%**	4%	5%	**7%**	9%	11%
R-30 (Base)	$269,114	$221,384	**$202,147**	$185,375	$170,696	**$146,441**	$127,468	$112,423
R-49	$274,087	$226,471	**$207,281**	$190,549	$175,906	**$151,709**	$132,782	$117,773
R-60	275,937	$228,368	**$209,197**	$192,481	$177,852	**$153,679**	$134,770	$119,776
Net (R-30 to R-49)	$(4,973)	$(5,088)	**$(5,134)**	$(5,174)	$(5,209)	**$(5,268)**	$(5,313)	$(5,350)
Net (R-30 to R-60)	$(6,823)	$(6,985)	**$(7,050)**	$(7,106)	$(7,156)	**$ (7,238)**	$(7,302)	$(7,353)

A sensitivity analysis for the future electricity price index (Figure 9.6 and Table 9.11b) revealed that improving the level of roof insulation to R-49 and R-60 would not be cost effective in either of the two alternative electricity price index scenarios examined. No breakeven analyses were conducted because of the consistently negative net cash flow. Hence, based on the results of this analysis investing in an additional first cost premium to boost the roof insulation could not be recommended in this study.

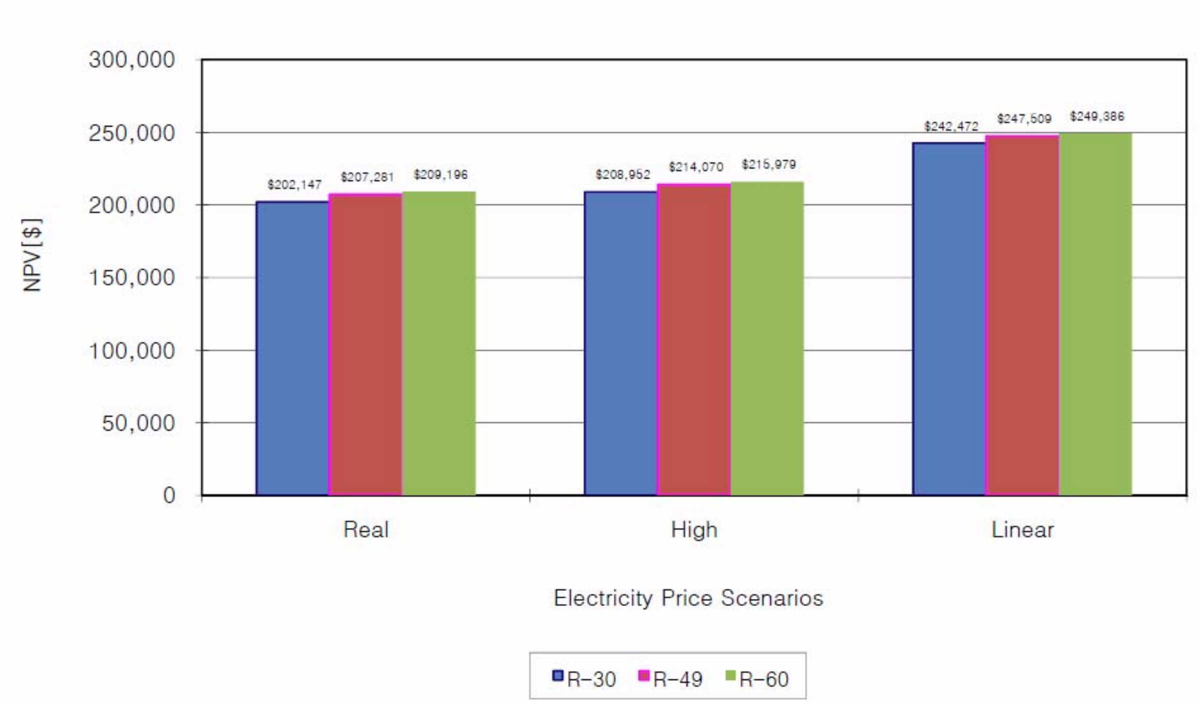


Figure 9.6 Sensitivity analysis for future electricity price (Roof insulation)

Table 9.11b Net cash flow amount among three roof insulation alternatives

Alternatives	Real	High	Linear
R-30	$ 202,147	$ 208,952	$ 242,472
R-49	$ 207,281	$ 214,070	$ 247,509
R-60	$ 209,196	$ 215,979	$ 249,386
Net Amount (R-30 to R-49)	$ (5,134)	$ (5,118)	$ (5,037)
Net Amount (R-30 to R-60)	$ (7,049)	$ (7,027)	$ (6,914)

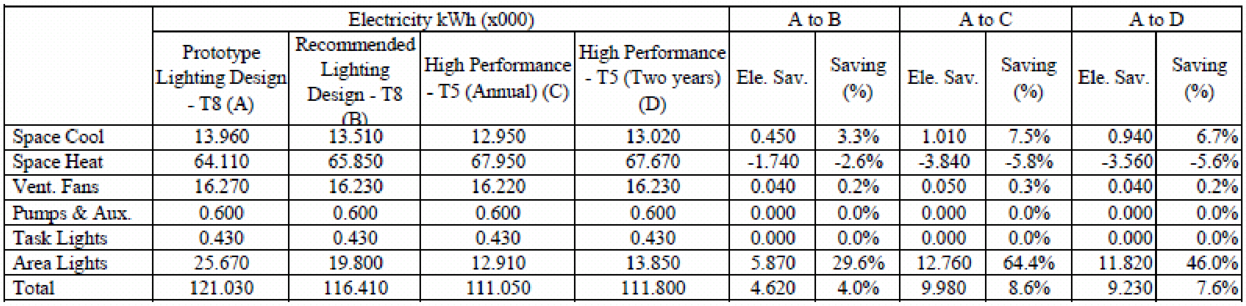
9.2.3 Lighting

As lighting is a major source of energy consumption in USPS facilities, it was necessary to identify the relationships between the first cost premium for installing different lighting fixtures and lamp types and their LCC. In addition, maintenance of the lighting fixtures affects not only the number of lighting fixtures needed in particular areas but also their annual energy consumption. Consequently, this study compared four alternatives, namely the T8 lighting system currently used, the T8 lighting standard design, high performance T5 light fixtures with annual cleaning, and high performance T5 light fixtures cleaned every two years (Table 9.12). Figure 9.7 shows that the lighting fixtures currently used in USPS facilities for ambient lighting consume about 26,670 KWh, 22% of the total energy consumption. However, the current ambient lighting system is actually over-designed and installed so that it consumes additional electricity compared to the USPS standard design guide in Appendix G. Thus, if a post office facility is designed based on the standard design guide for lighting, it is possible to significantly reduce the first, maintenance, annual energy, and repair and replacement costs incurred due to lighting (Figure 9.7 and Table 9.12). If the prototype post office followed the standard light design guide, this would reduce the electricity consumption due to ambient lighting from 25,670 KWh to 19,800 KWh, offset slightly by the associated increase in the heating load from 64,110 KWh to 65,850 KWh and decreasing the cooling load from 13,960 KWh to 13,510 KWh.

Considering the LCC over twenty years, a post office facility following standard lighting design guidelines could save $26,992 based on a 3% discount rate and the real electricity price index.

In addition, upgrading lighting fixtures and lamps from the existing lighting (T8 fixtures and lamps) to high performance lighting (T5 lighting fixtures and lamps) could save 9,980 KWh ($1,098) annually. Over twenty years, this produces savings of $30,817, which easily offsets the first cost of installing them of $1,063. As the high performance lighting requires T5 lamps, which are four times more expensive than T8 lamps, this also incurs additional costs related to replacing lamps. However, since T5 lighting fixtures with lamps are more efficient, this should reduce annual energy consumption by 5,360 KWh (116,410 KWh - 111,050 KWh). This energy saving also contributes to offsetting the first cost and maintenance premium associated with installing T5 lighting fixtures and lamps. In addition, as T8 lamps have dropped in price considerably over the past 10 years, it is likely that T5s will as well. If it considers, changing T8 to T5 lighting fixtures will bring significant operation cost saving as well as LCC saving.

Comparing the effects of the two different intervals for cleaning the lighting fixtures, the outcome depends on the number of lighting fixtures as well as the first, maintenance, annual energy, repair and replacement, and life cycle costs. The comparison between cleaning the high performance lighting system annually and every two years indicates that cleaning the lighting fixtures could affect the number of lighting fixtures needed in particular spaces, which automatically reduces the first construction costs, annual energy cost, and repair and replacement cost even though it incurs additional maintenance cost for annually cleaning the lighting fixtures. From Table 9.12, cleaning the lighting fixtures and lamps every year should reduce the energy consumption by 800KWh annually, with an energy saving of $83. Furthermore, LCCA indicates that annual cleaning of lighting fixtures and lamps costs $1,845 less over the facility's lifetime compared to cleaning lighting fixtures every two years, based on the 3% discount rate and the real electricity price index. If the USPS uses in-house personnel for cleaning task, the LCC saving of annual cleaning will increase because it does not need to pay profits to external cleaning company.



	Electricity kWh (x000)				A to B		A to C		A to D	
	Prototype Lighting Design - T8 (A)	Recommended Lighting Design - T8 (B)	High Performance - T5 (Annual) (C)	High Performance - T5 (Two years) (D)	Ele. Sav.	Saving (%)	Ele. Sav.	Saving (%)	Ele. Sav.	Saving (%)
Space Cool	13.960	13.510	12.950	13.020	0.450	3.3%	1.010	7.5%	0.940	6.7%
Space Heat	64.110	65.850	67.950	67.670	-1.740	-2.6%	-3.840	-5.8%	-3.560	-5.6%
Vent. Fans	16.270	16.230	16.220	16.230	0.040	0.2%	0.050	0.3%	0.040	0.2%
Pumps & Aux.	0.600	0.600	0.600	0.600	0.000	0.0%	0.000	0.0%	0.000	0.0%
Task Lights	0.430	0.430	0.430	0.430	0.000	0.0%	0.000	0.0%	0.000	0.0%
Area Lights	25.670	19.800	12.910	13.850	5.870	29.6%	12.760	64.4%	11.820	46.0%
Total	121.030	116.410	111.050	111.800	4.620	4.0%	9.980	8.6%	9.230	7.6%

Figure 9.7 Electricity saving by improving lighting

Table 9.12 Costs for lighting alternatives

Alternatives	# Lighting Fixtures	First Cost	Maintenance Cost	Annual Energy Consumption	Annual Energy Cost	Repair and Replacement Cost	Net Present Value
Current Lighting Design - T8	62	$14,694	$1,230	121.000 KWh x1000	$13,310	$8,494 (year 10)	$231,152
Recommended Lighting Design - T8	30	$7,347	$614	116.000 KWh x 1000	$12,810	$4,247 (year 10)	$204,160
High Performance - T5 (Annual cleaning)	29	$8,410	$846	111.000 KWh x1000	$12,220	$4,466 (year 10)	$200,335
High Performance - T5 (Two yearly cleaning)	32	$9,280	$808	111.800 KWh x1000	$12,300	$4,928 (year 10)	$202,180

Based on the data shown in Figure 9.8 and Table 9.12, high performance lighting (T5) with annual cleaning incurs an additional first cost premium of $1,063 compared to the recommended lighting design (T8). In addition to this first cost premium, high performance lighting (T5) requires an additional maintenance cost of $232 and supplementary repair and replacement costs of $ 219. However, high performance lighting (T5) with annual cleaning could reduce energy costs by $590 annually and LCC by $3,825 over twenty years. Comparing the effects of annual cleaning vs. biennial cleaning, high performance lighting (T5) with annual cleaning incurs a first cost premium of $870 and a maintenance cost premium of $38 but reduces annual operating costs by $83 and repair and replacement costs by $462 every decade. Overall, this leads to savings of $1,845 over 20 years (Table 9.12).

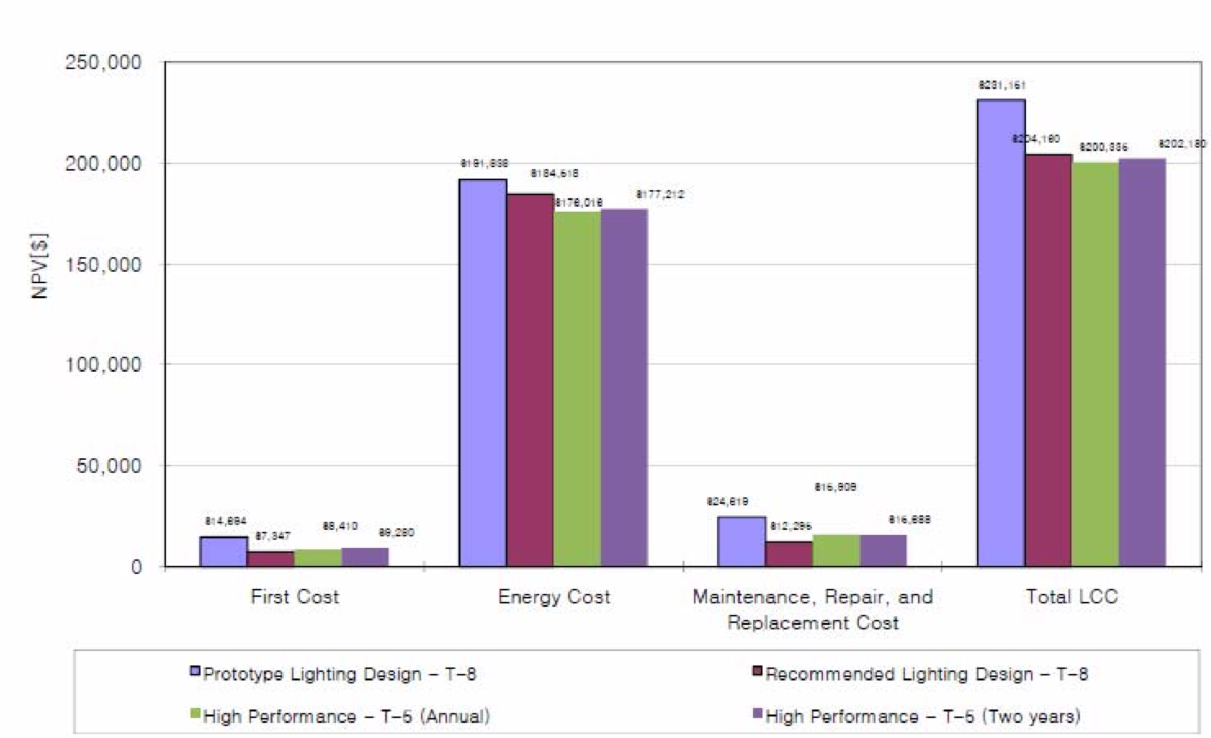


Figure 9.8 Costs based on four lighting alternatives

Changing discount rates from 3% to 7% affects the net present values of the four different lighting alternatives, as shown in Figure 9.9 and Table 9.13. As the figure reveals, if the discount rate increases from 3% to 7%, the net present value decreases for all four lighting alternatives. In addition, the net cash flow (NPV of alternatives – NPV of base design) decreases when the discount rate increases. At a discount rate of 7%, high performance lighting (T5) with annual cleaning resulted in the lowest net present value, $144,547, among the four lighting alternatives.

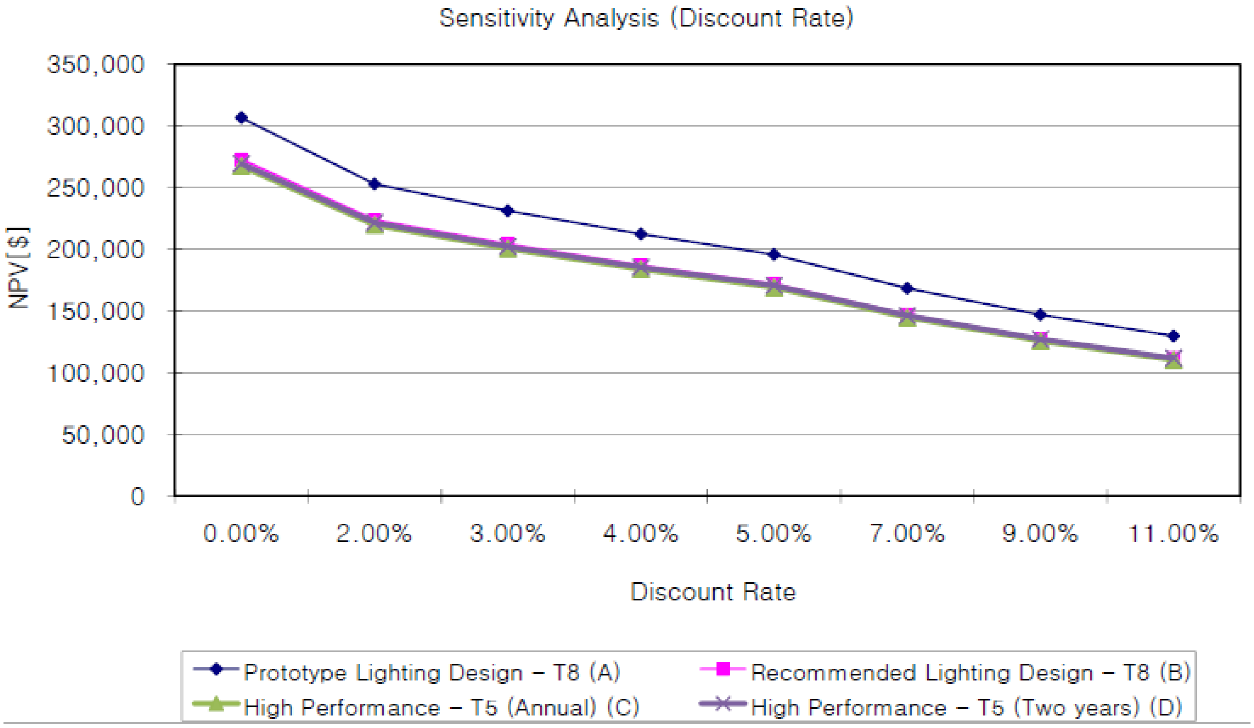


Figure 9.9 Sensitivity analysis for discount rates in lighting

Table 9.13 Sensitivity analysis for discount rates in lighting

Alternatives	0%	2%	**3%**	4%	5%	**7%**	9%	11%
Prototype Lighting Design-T8	$306,593	$252,849	**$231,152**	$212,214	$195,624	**$168,175**	$146,669	$129,594
Recommended Lighting Design-T8	$272,803	$223,891	**$204,160**	$186,846	$171,873	**$146,948**	$127,435	$111,950
High Performance - T5 (Annual)	$267,256	$219,573	**$200,336**	$183,551	$168,854	**$144,547**	$125,516	$110,412
High Performance - T5 (Biannual)	$269,441	$221,517	**$202,180**	$185,309	$170,534	**$146,098**	$126,964	$111,779

The net present value of the four alternatives also fluctuates based on the future electricity price index chosen. From Figure 9.10 and Table 9.14, the net cash flow between the existing lighting design (T8) and the recommended lighting design (T8) increased by $1,540, from $26,991 in the real electricity price index to $28,531 in the linear electricity price index. This result indicates that the benefit of alternative lighting increases when the future price of electricity is rising.

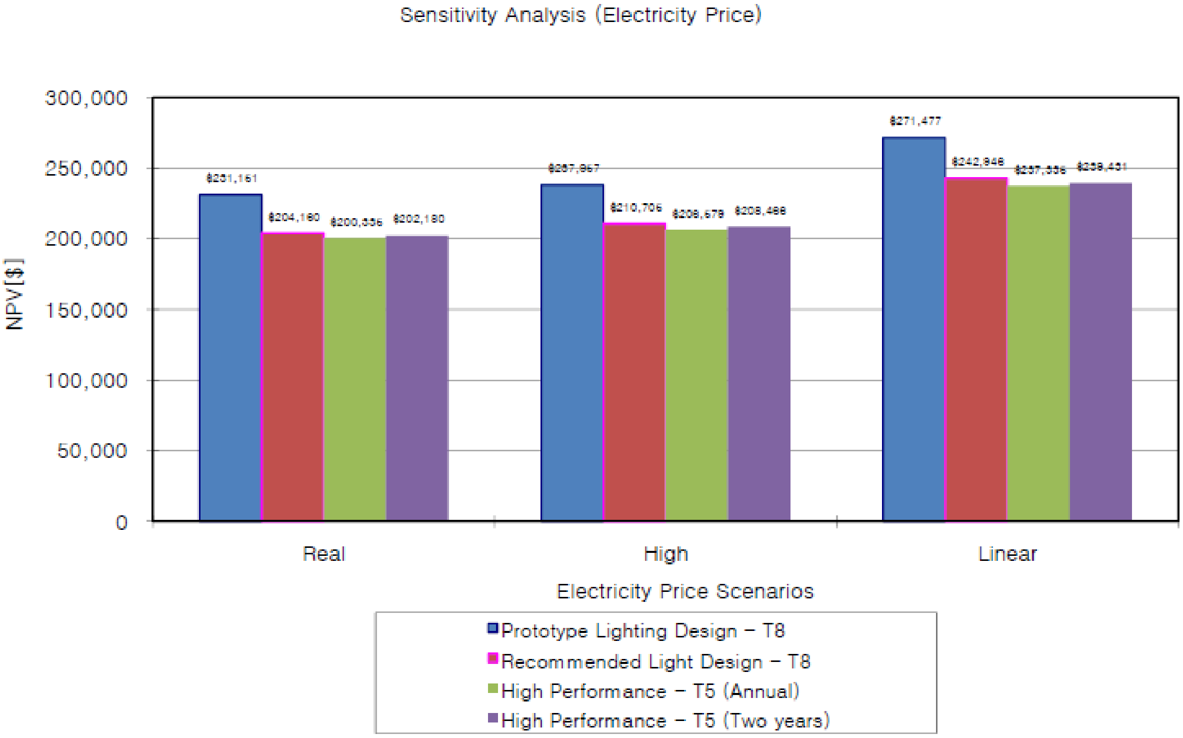
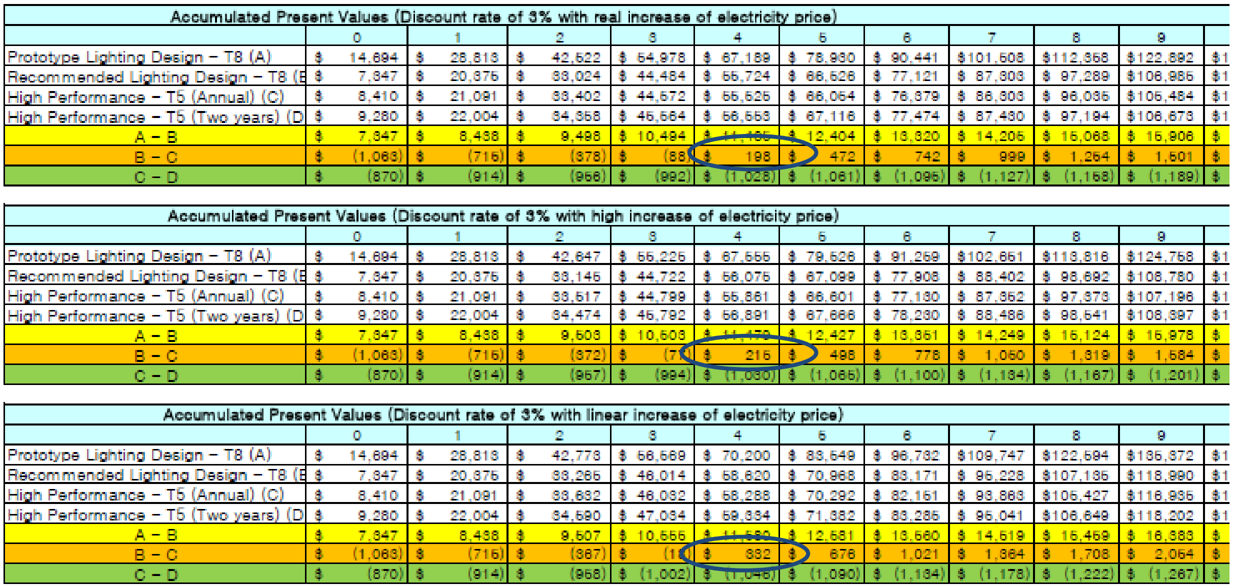


Figure 9.10 Sensitivity analysis for future electricity prices in lighting

Table 9.14 Sensitivity analysis for future electricity prices in lighting

Alternatives	Real	High	Linear
Prototype Lighting Design-T8	$231,151	$237,957	$271,477
Recommended Lighting Design-T8	$204,160	$210,705	$242,946
High Performance -T5 (Annual)	$200,335	$206,579	$237,335
High Performance -T5 (Biannual)	$202,180	$208,466	$239,431

This study also conducted a breakeven analysis to determine how long it would take to cover the first cost premium for each alternative. As Figure 9.11 shows, the breakeven point for changing from the recommended lighting design (T8) to the high performance lighting (T5) system with annual cleaning was Year 4 in all three future electricity price index options.



Accumulated Present Values (Discount rate of 3% with real increase of electricity price)										
	0	1	2	3	4	5	6	7	8	9	
Prototype Lighting Design – T8 (A)	$ 14,694	$ 28,813	$ 42,522	$ 54,978	$ 67,189	$ 78,930	$ 90,441	$101,508	$112,358	$122,892	$1
Recommended Lighting Design – T8 (E	$ 7,347	$ 20,375	$ 33,024	$ 44,484	$ 55,724	$ 66,526	$ 77,121	$ 87,303	$ 97,289	$106,986	$1
High Performance – T5 (Annual) (C)	$ 8,410	$ 21,091	$ 33,402	$ 44,572	$ 55,526	$ 66,054	$ 76,379	$ 86,303	$ 96,035	$105,484	$1
High Performance – T5 (Two years) (D	$ 9,280	$ 22,004	$ 34,358	$ 45,564	$ 56,553	$ 67,116	$ 77,474	$ 87,430	$ 97,194	$106,673	$1
A – B	$ 7,347	$ 8,438	$ 9,498	$ 10,494	$ 11,465	$ 12,404	$ 13,320	$ 14,205	$ 15,068	$ 15,906	$
B – C	$ (1,063)	$ (716)	$ (378)	$ (88)	$ 198	$ 472	$ 742	$ 999	$ 1,254	$ 1,501	$
C – D	$ (870)	$ (914)	$ (956)	$ (992)	$ (1,028)	$ (1,061)	$ (1,096)	$ (1,127)	$ (1,158)	$ (1,189)	$

Accumulated Present Values (Discount rate of 3% with high increase of electricity price)										
	0	1	2	3	4	5	6	7	8	9	
Prototype Lighting Design – T8 (A)	$ 14,694	$ 28,813	$ 42,647	$ 55,225	$ 67,555	$ 79,526	$ 91,269	$102,651	$113,816	$124,758	$1
Recommended Lighting Design – T8 (E	$ 7,347	$ 20,375	$ 33,146	$ 44,722	$ 56,076	$ 67,099	$ 77,908	$ 88,402	$ 98,692	$108,780	$1
High Performance – T5 (Annual) (C)	$ 8,410	$ 21,091	$ 33,517	$ 44,799	$ 55,861	$ 66,601	$ 77,130	$ 87,352	$ 97,373	$107,196	$1
High Performance – T5 (Two years) (D	$ 9,280	$ 22,004	$ 34,474	$ 45,792	$ 56,891	$ 67,666	$ 78,230	$ 88,486	$ 98,541	$108,397	$1
A – B	$ 7,347	$ 8,438	$ 9,503	$ 10,503	$ 11,479	$ 12,427	$ 13,361	$ 14,249	$ 15,124	$ 15,978	$
B – C	$ (1,063)	$ (716)	$ (372)	$ (77)	$ 216	$ 498	$ 778	$ 1,050	$ 1,319	$ 1,584	$
C – D	$ (870)	$ (914)	$ (957)	$ (994)	$ (1,030)	$ (1,065)	$ (1,100)	$ (1,134)	$ (1,167)	$ (1,201)	$

Accumulated Present Values (Discount rate of 3% with linear increase of electricity price)										
	0	1	2	3	4	5	6	7	8	9	
Prototype Lighting Design – T8 (A)	$ 14,694	$ 28,813	$ 42,773	$ 56,569	$ 70,200	$ 83,549	$ 96,732	$109,747	$122,594	$135,372	$1
Recommended Lighting Design – T8 (E	$ 7,347	$ 20,375	$ 33,265	$ 46,014	$ 58,620	$ 70,968	$ 83,171	$ 95,228	$107,135	$118,990	$1
High Performance – T5 (Annual) (C)	$ 8,410	$ 21,091	$ 33,632	$ 46,032	$ 58,288	$ 70,292	$ 82,151	$ 93,863	$105,427	$116,936	$1
High Performance – T5 (Two years) (D	$ 9,280	$ 22,004	$ 34,590	$ 47,034	$ 59,334	$ 71,382	$ 83,285	$ 95,041	$106,649	$118,202	$1
A – B	$ 7,347	$ 8,438	$ 9,507	$ 10,555	$ 11,580	$ 12,581	$ 13,560	$ 14,519	$ 15,459	$ 16,383	$
B – C	$ (1,063)	$ (716)	$ (367)	$ (18)	$ 332	$ 676	$ 1,021	$ 1,364	$ 1,708	$ 2,054	$
C – D	$ (870)	$ (914)	$ (958)	$ (1,002)	$ (1,046)	$ (1,090)	$ (1,134)	$ (1,178)	$ (1,222)	$ (1,267)	$

Figure 9.11 Accumulated present values and net cash flow

Based on this comparison of four alternative lighting options, this study recommends the use of high performance lighting (T5) with annual cleaning because it produces the optimal solution, both minimizing LCC and with lower first costs compared to the existing lighting design (T8). In addition, this study recommends that the USPS should revise their design guide to emphasize the importance of lighting design, which will not only save on first costs but also LCC.

9.2.4 Efficiency of HVAC System

The efficiency of heat pumps affects not only the cost of running the heat pump systems in the building but also the maintenance, repair and replacement costs of these systems. In Table 9.15, the high performance heat pump system requires a first cost premium of $12,529 compared to the cost of installing a standard heat pump system. However, the high performance heat pump system reduces annual energy consumption by 6,420 KWh, from 121,030 KWh to 114,610 KWh which automatically reduces the annual cost of running the system by $706. However, the high performance heat pump system also incurs additional repair costs of $536 due to the high price of parts. As Figure 9.12 indicates, a high performance heat pump system could reduce energy costs by $10,273 even though it requires higher additional first, maintenance, repair and replacement costs. Comparing net present value between the installed standard heat pump system and the high performance heat pump system, the standard heat pump system could save $2,754 over twenty years compared to the high performance heat pump systems shown in Table 9.15 and Figure 9.12. This is primarily because the first price of the high performance heat pump is 28.9% higher than that of a standard heat pump, so the savings in the annual energy cost is insufficient to offset the high first cost.

Table 9.15 Costs for efficiency of HVAC systems

Alternatives	First Cost	Maintenance Cost	Annual Energy Consumption	Annual Energy Cost	Repair and Replacement Cost	Net Present Value[11]
Heat Pump • EER-12 • COP-2.5	$43,204	$654	121.030 KWh x1000	$13,313	$5,368 (year 10)	$248,767
High Performance Heat Pump • EER-16.15 • COP-2.8	$55,733	$654	114.610 KWh x 1000	$12,607	$5,904 (year 10)	$251,521

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[11] 3% discount rate and real electricity price index

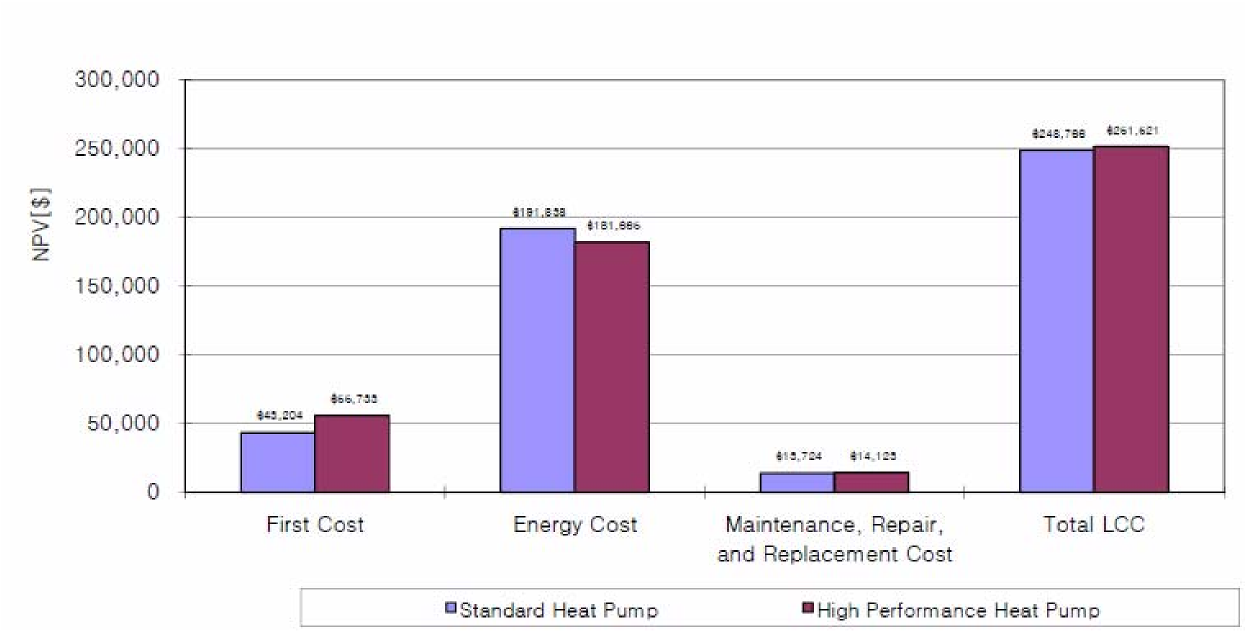

Figure 9.12 Net present value of HVAC systems

In Table 9.16 and Figure 9.13, the negative net cash flow between the standard heat pump system and the high efficient heat pump system indicate that the standard heat pump system is the more cost effective alternative for heat pump systems. If the discount rate rises from 3% to 7%, the negative cash flow also increases, as shown in Table 9.16, further favoring the standard heat pump system.

Table 9.16 Sensitivity analysis for the discount rates (Heat pump system)

Alternatives	0%	2%	**3%**	4%	5%	**7%**	9%	11%
Standard Heat Pump (A)	$320,457	$269,376	**$248,767**	$230,784	$215,037	**$188,993**	$168,601	$152,417
High Performance Heat Pump (B)	$319,797	$271,151	**$251,521**	$234,391	$219,390	**$194,576**	$175,143	$159,719
Net Amount (A-B)	$660	$(1,775)	**$(2,754)**	$(3,607)	$(4,353)	**$(5,582)**	$(6,542)	$(7,303)

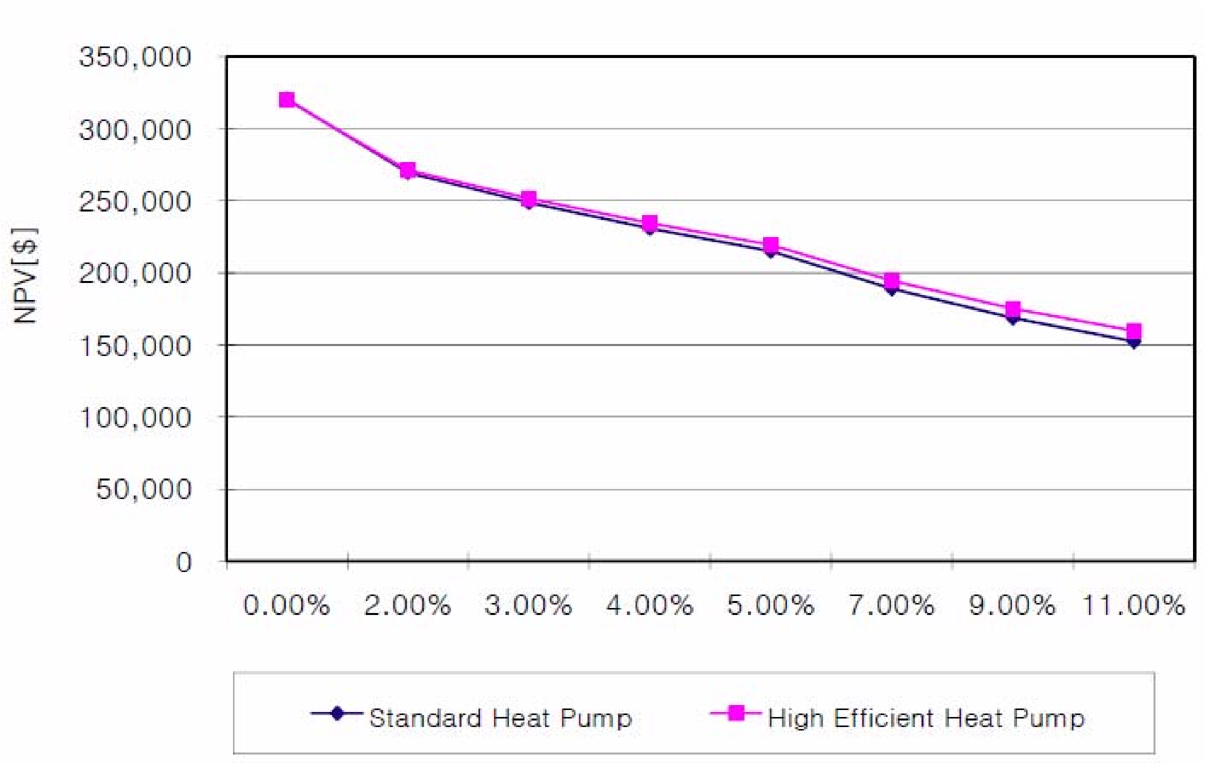

Figure 9.13 Sensitivity analysis for discount rates in the efficiency of HVAC systems

Examining the effect of changing the prediction of future electricity prices and how they affect the net cash flow between the standard heat pump system the and high efficient heat pump system, Figure 9.14 and Table 9.17, the linear prediction of electricity pricing results in \$(616) of net cash flow instead of the \$(2,755) of net cash flow in the real electricity prediction. This result indicates that higher electricity prices in the future will favor the more efficient heat pump system, even though the standard heat pump system currently produces a better result. Overall, with the current situation, the standard heat pump system is the more cost effective heating system over twenty years because the more efficient heat pump system requires high additional first, repair, and replacement costs.

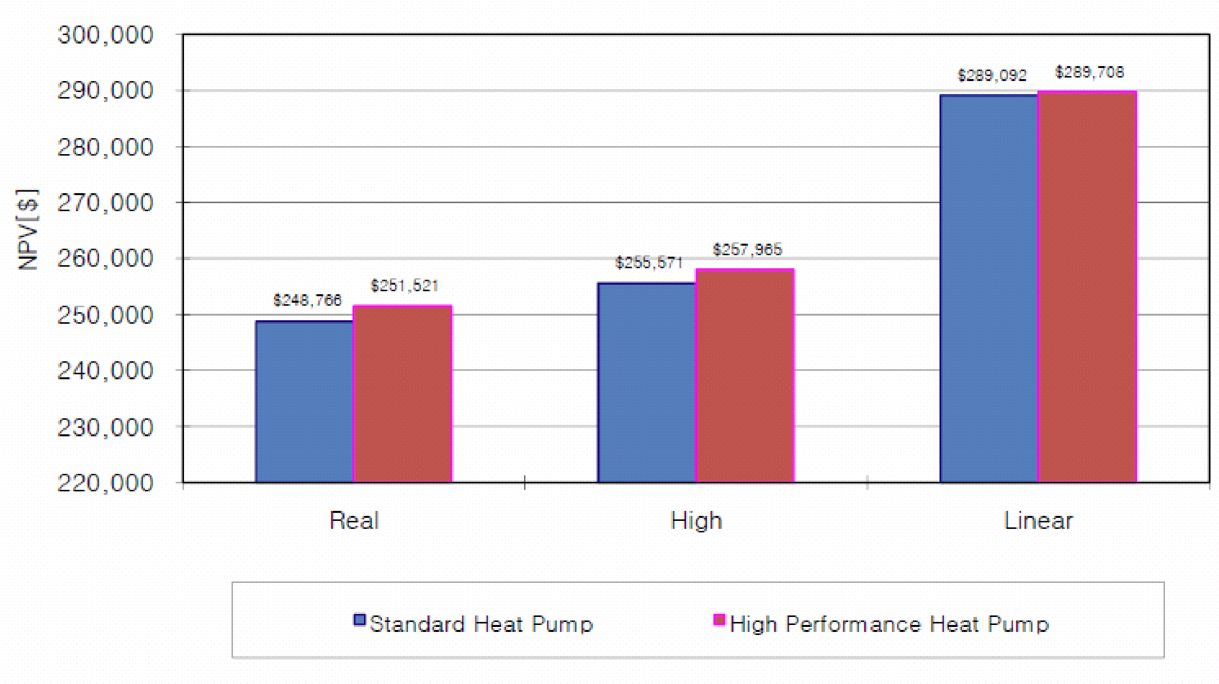

Figure 9.14 Sensitivity analysis for electricity price in the efficiency of heat pump systems

Table 9.17 Sensitivity analysis for the future electricity prices

	Real	**High**	**Linear**
Standard Heat Pump	$ 248,766	$ 255,571	$ 289,092
High Efficiency Heat Pump	$ 251,521	$ 257,965	$ 289,708
Net Cash Flow	$ (2,755)	$ (2,394)	$ (616)

In this section, the relationships among the first cost premium for a range of individual alternatives for each GBST were investigated, along with their annual consumption, and the impact of LCC. In addition, sensitivity analyses were conducted to identify how uncertainties such as the discount rate and future electricity prices affected LCC. Breakeven analyses identified the tipping points at which the first cost premiums of alternatives were covered. The following section describes the effect of integrating several of these GBST options to identify synergistic effects between the first cost premium and LCC.

9.3 Integration of Alternatives in GBSTs

It is very important to correctly identify the best way of integrating GBST alternatives in order to achieve optimum energy performance and to seek out design synergies in the building. Hence, this section discusses how first costs relate to various scenarios of GBSTs and LCC.

9.3.1 Best and Worst Integration of Alternatives to Minimize LCC

The first part of this section examines how the lowest LCC was identified from each of the many different scenarios developed in Appendix F. By comparing the LCC of all the scenarios, it was possible to identify the specific scenario with the lowest LCC and the scenario with the highest LCC. The LCC of each scenario is summarized in Appendix H. Three different scenarios were identified for each, namely the base scenario, the best scenario and worst scenario (Table 9.18). As the table shows, the best scenario for the integration alternatives in GBSTs combined south orientation, R-21 wall insulation, R-30 roof insulation, and a standard heat pump system for an overall LCC of $204,947. An additional first investment of $556 would be needed to improve the wall insulation to R-36. The best scenario could save $616 compared to the base scenario and $33,073 over twenty years with a discount rate of 3% and the real electricity cost index. The worst scenario would combine north orientation, R-30 wall insulation, R-50 roof insulation, and a high efficiency heat pump system. Although this scenario would cut annual energy consumption by 7,540 KWh compared to the base case, it would require an additional first investment of $24,552 for the enhanced wall and roof insulation, and the high performance heat pump system.

Table 9.18 Base, best and worst scenarios (The discount rate of 3% and real electricity price index)

Scenarios	Integration	First Cost Premium	Annual Energy Consumption	Annual Energy Cost	Life Cycle Cost[12]
Base Scenario	Orientation – South Wall Insulation – R-15 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$0	121,030 KWh	$13,313	$205,563
Best Scenario	Orientation - South Wall Insulation – R-21 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$566	120,280 KWh	$13,231	$204,947
Worst Scenario	Orientation - North Wall Insulation – R-30 Roof Insulation – R-60 Heat Pump – High Performance Heat Pump	$24,552	113,490 KWh	$12,484	$238,020

9.3.2 Best Integration of Alternatives in GBSTs for the Lowest LCCs

Now let us consider the most efficient alternatives in GBSTs to minimize LCC under different uncertainties, namely the discount rate and the future electricity price index. Table 9.19, below, describes the lowest LCC scenarios for different discount rates and future electricity price escalation options. At a discount rate of 0%, the post office facility with south orientation, R-21 wall insulation, R-30 roof insulation and the high efficiency heat pump system resulted in the minimum LCC compared to the other scenarios. However, at a discount rate of 7% and both high and linear electricity price indexes, the post office facility with south orientation, R-21 wall and R-30 roof insulation and the standard heat pump system produced the lowest LCC over twenty years. After comparing LCC of many different scenarios of integrating alternatives in GBSTs, this study recommends that the USPS should specify and emphasize the following alternatives for GBSTs in its design guide as these will produce the most efficient results and optimize energy performance. The integration of alternatives in GBST is:

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[12] Discount rate of 3% and real electricity price index

- Orientation – South
- Wall Insulation – R-21
- Roof Insulation – R-30
- Heat Pump – High Efficient Heat Pump System.

Table 9.19 Minimum LCC scenarios in different uncertainties

Uncertainties	Integration	First Cost Premiums	Annual Energy Consumption	Annual Energy Cost	Life Cycle Cost[13]
Discount rate of 0 %	Orientation – South Wall Insulation – R-21 Roof Insulation – R-30 Heat Pump – High Performance Pump	$13,095	113,870 KWh	$12,526	$275,584
Discount Rate of 7%	Orientation - South Wall Insulation – R-21 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$566	120,280 KWh	$13,231	$145,517
High Electricity	Orientation - South Wall Insulation – R-21 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$566	120,280 KWh	$13,231	$211,710
Linear Electricity	Orientation - South Wall Insulation – R-21 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$566	120,280 KWh	$13,231	$245,024

9.3.3 Best Integration of Alternatives in GBSTs To Minimize Energy Consumption

Several scenarios were identified that would minimize annual energy consumption without considering the first cost premium for GBST alternatives. In Table 9.20, the integration of south orientation, R-30 wall insulation, R-60 insulation, and high performance heat pump system could reduce annual energy consumption by 8,900 KWh, from 121,030 KWh (7.4%) in the base case

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[13] Discount rate of 3% and the real electricity price index

to112,130 KWh. However, this integration requires an additional investment of $24,552 to implement these alternatives. From the five best scenarios for reducing annual energy consumption, the integration of south orientation, R-30 wall insulation, R-30 roof insulation and high efficiency heat pump system resulted in the lowest LCC of $209,481, compared to the LCC of $217,559 in the integration of west orientation, R-30 wall insulation, R-60 roof insulation and high efficiency heat pump system, with $24,552 in first cost premium. At a discount rate of 7%, Scenario 14 has the lowest LCC of $153,477 among the five scenarios depicted in Table 9.21. Furthermore, for the high and linear electricity price indexes, Scenario 14 also resulted in the lowest LCC, $215,810, in the high electricity price index, and $246,968 in the linear electricity price index among the five scenarios (Table 9.21). Based on these results, this study recommends that the best scenario for both minimizing annual electricity consumption and LCC under two uncertainties was to integrate the following alternatives in GBSTs:

- Orientation – South
- Wall Insulation – R-30
- Roof Insulation – R-30
- Heat Pump – High Efficiency Heat Pump System.

Table 9.20 Minimum annual energy consumption scenarios

ID	Integration	First Cost Premiums	Annual Energy Consumption	Annual Energy Costs	Life Cycle Costs[14]
18	Orientation – South Wall Insulation – R-30 Roof Insulation – R-30 Heat Pump – High Efficient Heat Pump	$24,552	112,130 KWh	$12,334	$216,406
16	Orientation - South Wall Insulation – R-30 Roof Insulation – R-49 Heat Pump – High Efficient Heat Pump	$22,449	112,250 KWh	$12,348	$214,505
72	Orientation - East Wall Insulation – R-30 Roof Insulation – R-60 Heat Pump – High Efficient Heat Pump	$24,552	112,510 KWh	$12,376	$217,011
14	Orientation - South Wall Insulation – R-30 Roof Insulation – R-30 Heat Pump – High Efficient Heat Pump	$16,935	112,560 KWh	$12,382	$209,481
54	Orientation - West Wall Insulation – R-30 Roof Insulation – R-60 Heat Pump – High Efficient Heat Pump	$24,552	112,850 KWh	$12,414	$217,559

Table 9.21 Scenarios with minimum energy consumption

ID	Annual Energy Consumption	Annual Energy Costs	First Cost Premiums	Life Cycle Costs				
				Discount Rate		Electricity Price		
				3%	7%	Real	High	Linear
18	112,130	$12,334	$24,552	$216,406	$160,603	$216,406	$222,711	$253,766
16	112,250	$12,348	$22,449	$214,505	$158,643	$214,505	$220,816	$251,907
72	112,510	$12,376	$24,552	$217,011	$161,033	$217,011	$223,337	$254,498
14	112,560	$12,382	$16,935	$209,481	$153,477	$209,481	$215,810	$246,986
54	112,850	$12,414	$24,552	$217,559	$161,421	$217,559	$223,904	$255,161

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[14] Discount rate of 3% and real electricity price index

9.3.4 *Best Scenarios for the Lowest First Cost*

Let us now consider specific scenarios that minimize the first cost premiums in order to identify the relationship between first cost premiums and LCCs. As Scenario 1 was defined as the base scenario of this study, there was no first cost premium incurred. In addition, changing the orientation of the USPS office facility was assumed to incur no first cost premium, so none is shown in Table 9.22. The next cheapest way to implement GBST alternatives is to increase the level of wall insulation from R-15 to R-21, which only requires $566 as a first cost premium. Among the five scenarios considered, the integration of south orientation, R-21 wall insulation, R-30 roof insulation and the standard heat pump system resulted in the lowest LCC of $204,947 over 20 years (Table 9.22). A sensitivity analysis of the discount rate and future electricity price index for this scenario also resulted in the lowest LCC (Table 9.23):

- Discount rate of 0% - $276,225
- Discount rate of 3% - $204,947
- Discount rate of 7% - $145,517
- High electricity - $211,710
- Linear electricity - $245,024.

Of the five scenarios that required minimal first cost premiums, this study recommends that the following GBST alternatives should be implemented:

- Orientation – South
- Wall Insulation – R-21
- Roof Insulation – R-30
- Heat Pump – Standard heat pump system

Table 9.22 Minimum first cost premium scenarios

ID	Integration	First Cost Premium	Annual Energy Consumption	Annual Energy Cost	Life Cycle Cost[15]
1	Orientation – South Wall Insulation – R-15 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$0	121,030 KWh	$13,313	$205,563
55	Orientation – East Wall Insulation – R-15 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$0	121,070 KWh	$13,318	$205,635
37	Orientation – West Wall Insulation – R-15 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$0	121,560 KWh	$13,372	$206,413
19	Orientation – North Wall Insulation – R-15 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$0	121,890 KWh	$13,408	$206,931
7	Orientation – South Wall Insulation – R-21 Roof Insulation – R-30 Heat Pump – Standard Heat Pump	$566	120,280 KWh	$13,231	$204,947

Table 9.23 Scenarios with minimum first cost premiums

ID	Annual Energy Consumption	Annual Energy Costs	First Cost Premiums	Life Cycle Costs				
				Discount Rate		Electricity Price		
				3%	7%	Real	High	Linear
5	121,030	$13,313	$0	$205,563	$145,789	$205,563	$212,562	$245,888
55	121,070	$13,318	$0	$205,635	$145,840	$205,635	$212,442	$245,975
37	121,560	$13,372	$0	$206,413	$146,393	$206,413	$213,248	$246,916
19	121,890	$13,408	$0	$206,931	$146,761	$206,931	$213,785	$247,544
7	120,280	$13,231	$566	$204,947	$145,517	$204,947	$211,710	$245,024

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[15] Discount rate of 3% and real electricity price index

9.3.5 Relationship between First Cost Premium and LCC

A useful way to show the relationship between the first cost premium and LCC for each scenario is to plot them in the form of a scatter graph. Consequently, the scatter graphs shown in Figures 9.15, 9.17, 9.18, and 9.18 were constructed. In Figure 9.15, the scatter graph illustrates the trend between the first cost premium and LCC of each scenario with a 3% discount rate and the real electricity price index. This graph is useful for facility capital programming, including capital planning and budgeting. Based on this scatter graph, the USPS can allocate additional financial resources to facilities that minimize the LCC of their facility. In addition, this type of scatter graph can be used to recommend the optimal integration of alternatives in GBSTs that would lead to LCC savings of the same order as the first cost premium. In Figures 9.17, 9.18 and 9.19, the graphs demonstrate how uncertainties such as the discount rate and future electricity prices affect the LCC of each scenario. From these scatter graphs, as the first cost premium is increased to incorporate various GBST alternatives, the LCC is also increased. This trend indicates whether or not additional investment in GBST alternatives would be cost effective under current conditions.

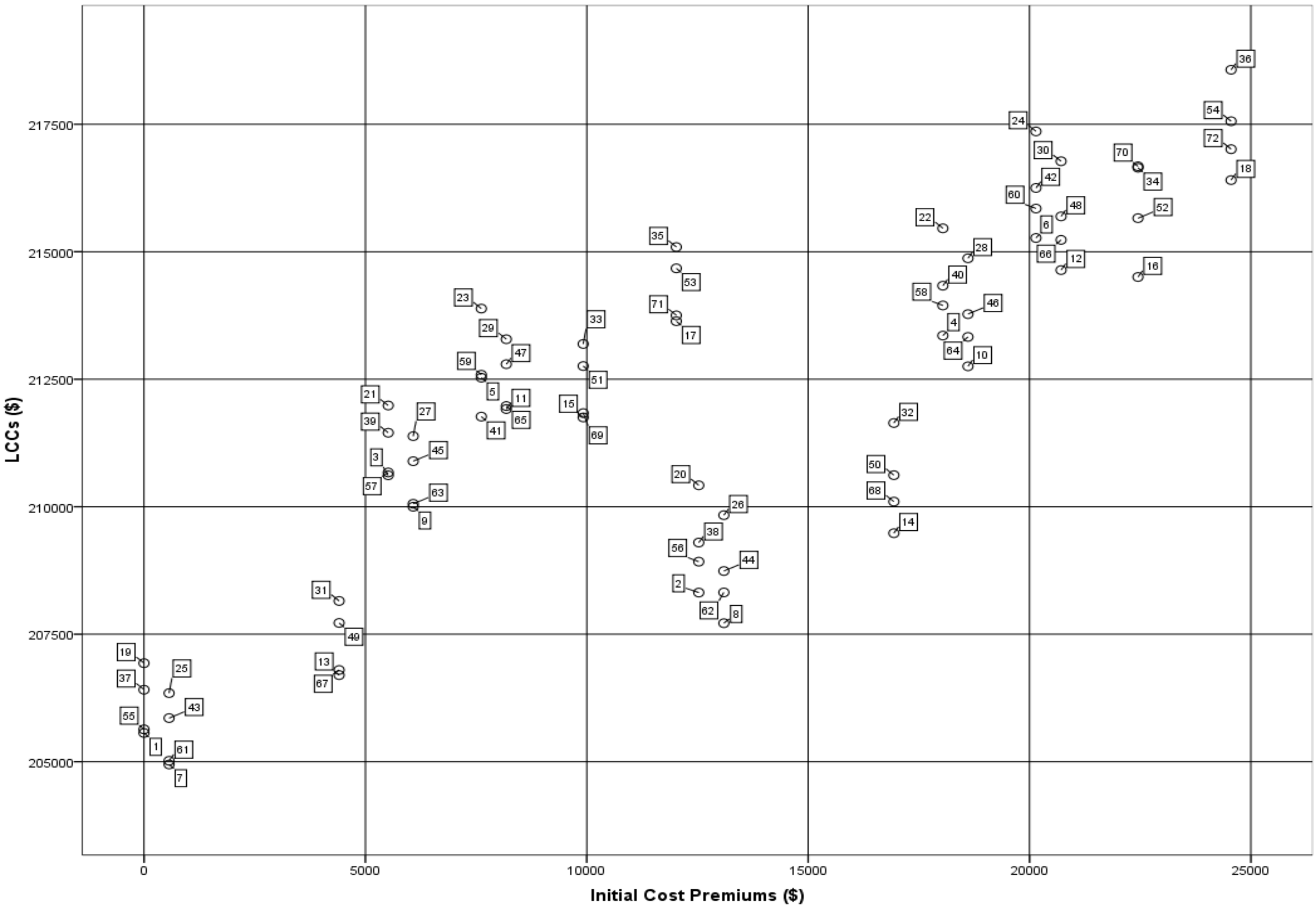

Figure 9.15 Relationship between first cost premium and LCC (Discount rate of 3% and real electricity price index)

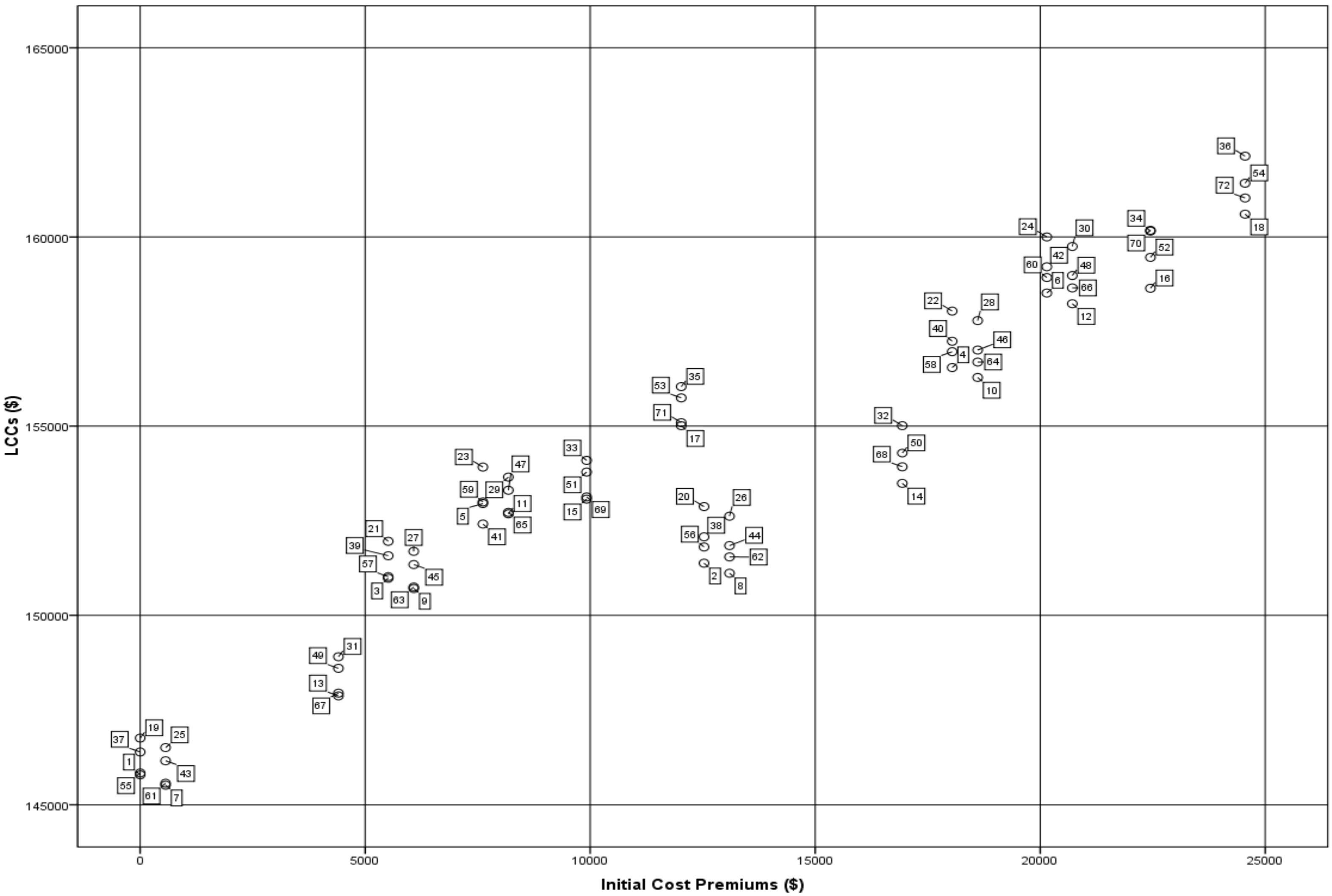

Figure 9.16 Relationship between first cost premium and LCC (Discount rate of 7% and real electricity price index)

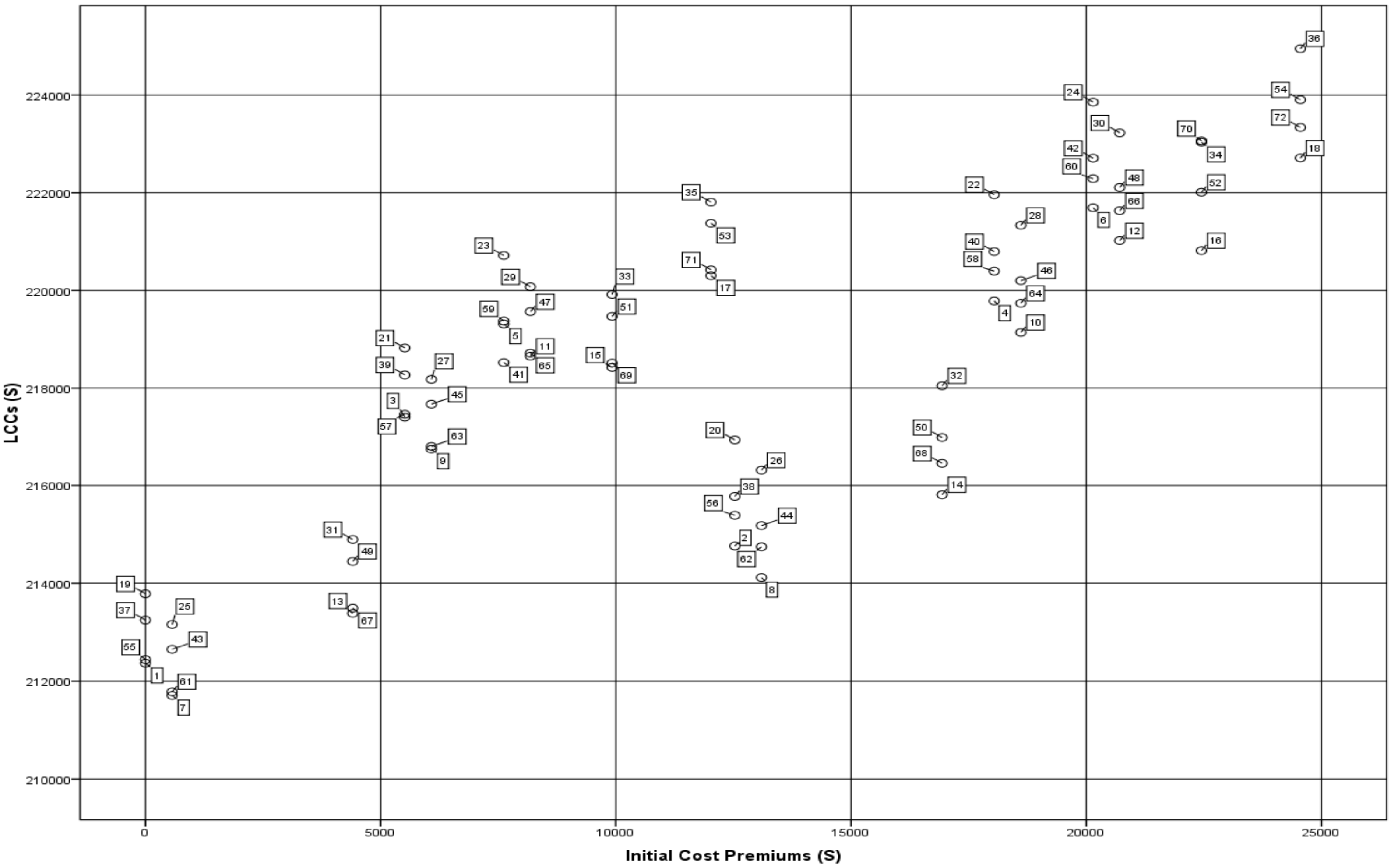

Figure 9.17 Relationship between first cost premium and LCC (Discount rate of 3% and high electricity price index)

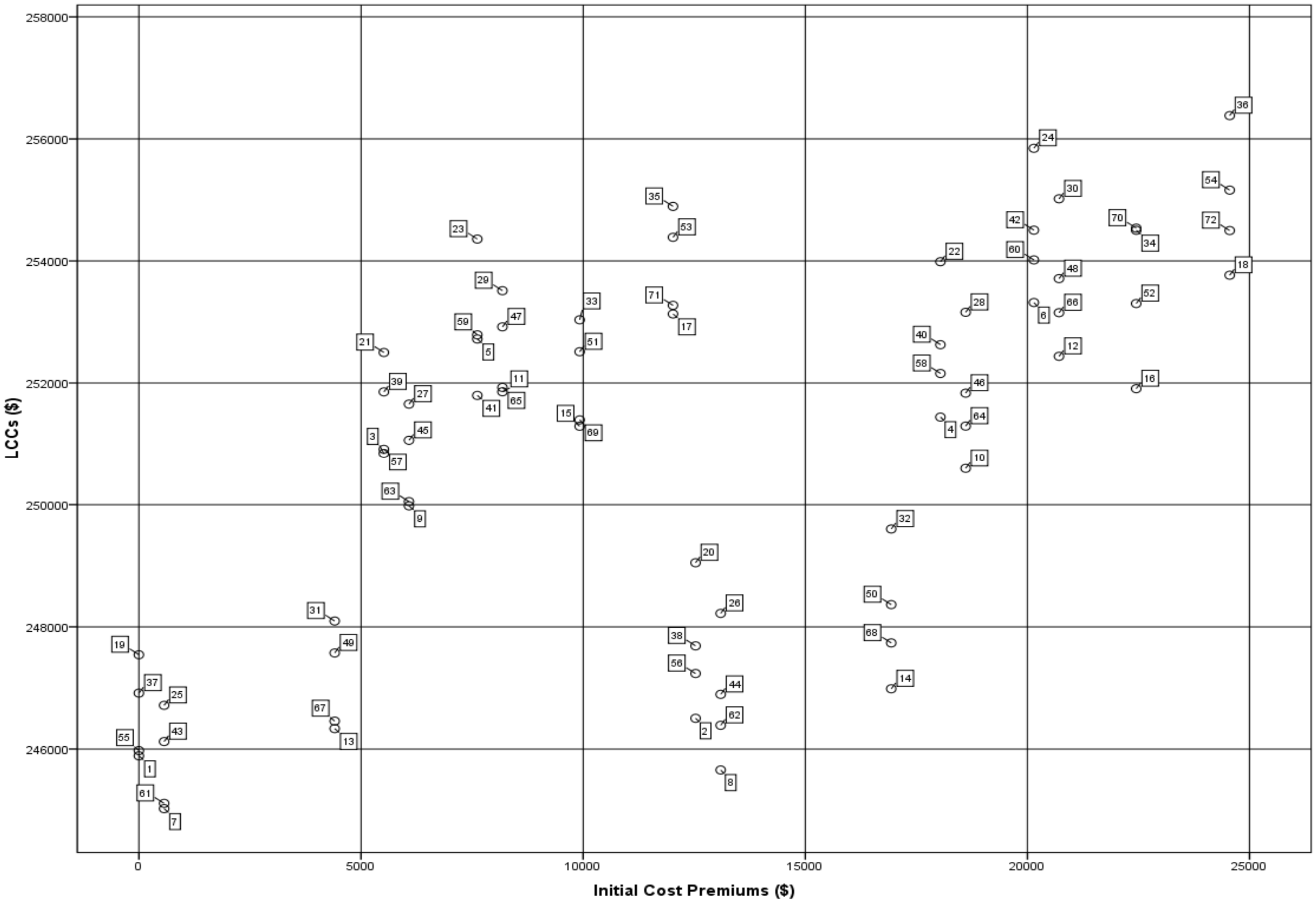

Figure 9.18 Relationship between first cost premium and LCC (Discount rate of 3% and linear electricity price index)

9.4 Multiple Regression to Identify Relationship between First Cost Premium Related to GBSTs and LCC

Multiple regression analysis was performed to identify the relationship among GBST alternatives, first cost premium, and LCC. First, the relationship between GBST alternatives and first cost premium was examined, after which the relationship between these alternatives and annual energy cost premium was studied. Finally, the relationship between the GBST alternatives and LCC was identified.

9.4.1 Alternative GBSTs and First Cost Premium

This subsection describes the development of a model to delineate the relationship between GBST alternatives and their associated first cost premiums using multiple regression analysis. First, the variables are described in terms of a dependent variable and independent variable that can be used for multiple regression analysis. This is followed by examination of the results of the multiple regression analysis.

9.4.1.1 Variables

This study adopted first cost premium as a dependent variable. As an independent variable, this study utilized four building orientations (South, North, West, and East), two heat pump systems (HP_A= Standard Heat Pump System and HP_B=High Performance Heat Pump System), three levels of roof insulation (RI_R-30, RI_R-49, and RI_R-60), and three levels of wall insulation (WI_R-15, WI_R-21, and WI_R-30). When the data set including a dependent variable and independent variables described consists of categorical data, it is necessary to use categorical regression with a dummy variable (Bowerman and O'Connell 2003; Howell 2007). Thus, the categorical variables were converted into dummy variables: the three building orientation dummy variables (North, West, and East), one heat pump (HP) dummy variable (HP_B), two roof insulation (RI) dummy variables (RI_R-49 and RI_R-60), and two wall insulation (WI) dummy variables (WI_R-21 and WI_R-30), respectively. The conversion into dummy variables enabled this study to have a straightforward interpretation. In other words, the reference groups (South, HP_A, RI_R-30, and W_R15, respectively) would be located on the intercept and, thus the effects on other groups would be interpreted as compared to the reference group of South, RI_R-30, WI_R-15, and HP_A.

9.4.1.2 Analysis and Results

As the main statistical analysis, the study adopted multiple regression analysis. Here, all the variables of interest were entered into the model. From the multiple regression, the analysis model was specified with the three building orientation dummy variables (North, West, and East), one HP dummy variable (HP_B), two RI dummy variables (RI_R-49 and RI_R-60), and two WI dummy variables (WI_R-21 and WI_R-30) as,

$$Y_i = \beta_0 + \beta_1\,(North) + \beta_2\,(West) + \beta_3\,(East) + \beta_4\,(HP\_B) + \beta_5\,(RI\_R\text{-}49) + \\ \beta_6\,(RI\_R\text{-}60) + \beta_7\,(WI\_R\text{-}21) + \beta_8\,(WI\_R\text{-}30) + e$$

> where Y_i indicates a dependent variable; β_0 is the intercept; β_1 indicates the difference between North and South ; β_2 indicates the difference between West and South; β_3 indicates the difference between East and South; β_4 indicates the difference between HP_B and HP_A ; β_5 indicates the difference between RI_R-49 and RI_R-30; β_6 indicates the difference between RI_R-60 and RI_R-30; β_7 indicates the difference between WI_R-21 and WI_R-15; β_8 indicates the difference between WI_R-30 and W_R15; and e is the error, or residual.

The regression model indicated a statistically significant effect, having approximately 100 % of the total variance explained by the model (Total R^2 = 1, p<.01) because of using one simulated first cost premium data in this study. In Table 9.24, since all the betas of building orientation are zero, these results indicated that the building orientation did not show a significant association with a first cost premium. In terms of the heat pump systems, the significant difference was noted. Compared with the heat pump system, the first cost premium of HP_B was greater (HP_B: b=2.032, P<0.01). With regards to the Roof Insulation (RI), a difference in first cost premium was detected, with both RI_R-49 and RI_R-60 having significantly higher first cost premiums than RI_R-30 (RI_R-49: b=0.895, p<.01; RI_R-60: b=1.237, p<.01). In terms of Wall Insulation (WI), the first cost premium of WI_R-21 was significantly higher than that of WI_R-15 by 0.092 dollars (b=0.092, p<.01). In addition, the first cost premium of WI_R-30 was also higher than that of WI_R-15 (b=0.715, p<.01).

Table 9.24 Results of multiple regression analysis

	β (*SE*)
Constant	-0.002 (0.001)
North	0.000 (0.001)
West	0.000 (0.001)
East	0.000 (0.001)
HP_B	2.032** (0.001)
RI_R-49	0.895** (0.001)
RI_R-60	1.237** (0.001)
WI_R-21	0.092** (0.001)
WI_R-30	0.715** (0.001)
Total R^2	1.000**

** indicate p<0.01; * indicate p<0.05

9.4.2 Alternative GBSTs and Annual Energy Cost Premium

This subsection describes the model constructed to examine the relationship between alternative GBSTs and annual energy cost premiums using multiple regression analysis. First, variables are described in terms of the dependent variables and independent variables used in multiple regression analysis, after which the results of the multiple regression analysis are interpreted.

9.4.2.1 Variables

This study adopted annual energy cost premium as a dependent variable. As independent variables, the study utilized the First Cost Premium (FCP). Additional independent variables were the four building orientation variables (South, North, West, and East), two heat pump systems (HP_A= Standard Heat Pump System and HP_B=High Performance Heat Pump System), three roof insulation variables (RI_R-30, RI_R-49, and RI_R-60), three wall insulation variables (WI_R-15, WI_R-21, and WI_R-30) and the first cost premium of incorporating alternative GBSTs. The categorical variables were converted into dummy variables: the three building orientation dummy variables (North, West, and East), one HP dummy variable (HP_B), two RI dummy variables (RI_R-49 and RI_R-60), and two WI dummy variables (WI_R-21 and

WI_R-30), respectively. The conversion into dummy variables enabled this study to have a straight forward interpretation. In other words, the reference groups (South, HP_A, RI_R-30, and W_R15, respectively) would be located on the intercept and, thus the effects on other groups would be interpreted as compared to the reference group.

9.4.2.2 Analysis and Results

This study also adopted multiple regression analysis, entering all the variables of interest into the model. However, one variable, the first cost premium, was deleted from the regression model because of the insignificant effect on dependent variable caused by its high collinearity with other variables. Therefore, the multiple regression analysis was specified with the three building orientation dummy variables (North, West, and East), two RI dummy variables (RI_R-49 and RI_R-60), two WI dummy variables (WI_R-21 and WI_R-30), and one HP dummy variable (HP_B) as,

$$Y_i = \beta_0 + \beta_1 (North) + \beta_2 (West) + \beta_3 (East) + \beta_4 (RI\_R\text{-}49) + \beta_5 (RI\_R\text{-}60) + \\ \beta_6 (WI\_R\text{-}21) + \beta_7 (WI\_R\text{-}30) + \beta_8 (HP\_B) + e$$

> where Y_i indicates a dependent variable; β_0 is the intercept; β_1 indicates the difference between North and South ; β_2 indicates the difference between West and South; β_3 indicates the difference between East and South; β_4 indicates the difference between RI_R-49 and RI_R-30; β_5 indicates the difference between RI_R-60 and RI_R-30; β_6 indicates the difference between WI_R-21 and WI_R-15; β_7 indicates the difference between WI_R-30 and W_R15; β_8 indicates the different between HP_B and HP_A; and e is the error, or residual.

The regression model indicated a statistically significant effect, having approximately 99 % of the total variance explained by the model (Total R^2 = 0.994, p<.01). The results indicate that the difference was noted in terms of the building orientation. Compared with South, the annual energy costs of the other three orientations were greater (North: b=0.020, p<.01; West: b= 0.010, p<.01; East: b=0.005, p<.01). With regard to the Roof Insulation (RI), a difference in annual energy cost was detected with both RI_R-49 and RI_R-60 (RI_R-49: b= - 0.05, p<.01; RI_R-60: b= - 0.009, p<.01). In terms of Wall Insulation (WI), the annual energy cost of WI_R-21 was low (b=-0.012, p<.01). In addition, the annual energy cost of WI_R-30 was also lower than that of WI_R-15 (b= - 0.034, p<.01). In terms of HP, there was a significant gap in the energy cost premium between HP_A and B. Comparing the heat pump systems, the energy cost premium of HP_B was lower than that for HP_A (HP_B: b= - .109, P<0.01) (Table 9.25).

Table 9.25 Results of multiple regression analysis

	β (*SE*)
Constant	-0.004* (0.002)
North	0.020** (0.002)
West	0.010** (0.002)
East	0.005** (0.002)
RI_R-49	- 0.005** (0.001)
RI_R-60	- 0.009** (0.001)
WI_R-21	- 0.012** (0.001)
WI_R-30	- 0.034** (0.001)
HP_B	-0.109** (0.001)
Total R^2	0.994**

** indicate p<0.01; * indicate p<0.05

9.4.3 Alternatives of GBSTs and LCC

Now let us considered the relationship between the cost components of LCC related to GBSTs and LCC. First, this study described a set of independent variables including first cost premium, annual energy cost, repair and replacement cost premium, maintenance cost premium, and LCC. The following section describes the results of the multiple regression analysis.

9.4.3.1 Variables

The present study adopted LLC as a dependent variable. As independent variables, the study utilized the First Cost Premium (FCP), Energy Cost Premium (ECP), and Repair and Replacement Cost Premium (RRCP). However, annual maintenance cost was excluded because it was constant for all the scenarios. Also, the study used four building orientation variables (South, North, West, and East), two HP variables (HP_A and HP_B), three RI variables (RI_R-

30, RI_R-49 and RI_R-60), and three WI_R-21 variables (WI_R-15, WI_R-21 and WI_R-30). The categorical variables were converted into dummy variables: the three building orientation dummy variables (North, West, and East), one HP dummy variable (HP_B), two RI dummy variables (RI_R-49 and RI_R-60), and two WI dummy variables (WI_R-21 and WI_R-30), respectively. The conversion into dummy variables enabled the present study to have a straight forward interpretation. In other words, the reference groups (South, HP_A, RI_R-30, and WI_R-15, respectively) would be located on the intercept and, thus the effects on other groups could be interpreted as compared to the reference group.

9.4.3.2 Analysis and Results

As the main statistical analysis, the study also adopted multiple regression analysis. The present study entered all the variables of interests into the model. However, two variables – FCP and HP_B- were deleted from the regression model because of the insignificant effect on dependent variable caused by high collinearity with other variables. Therefore, the multiple regression analysis was specified with ECP, PRCP, three building orientation dummy variables (North, West, and East), two RI dummy variables (RI_R-49 and RI_R-60), and two WI dummy variables (WI_R-21 and WI_R-30) as,

$$Y_i = \beta_0 + \beta_1 (ECP) + \beta_2 (PRCP) + \beta_3 (North) + \beta_4 (West) + \beta_5 (East) + \\ \beta_6 (RI\_R\text{-}49) + \beta_7 (RI\_R\text{-}60) + \beta_8 (WI\_R\text{-}21) + \beta_9 (WI\_R\text{-}30) + e$$

where Y_i indicates a dependent variable; β_0 is the intercept; β_1 indicates the effect of energy cost premium on LCC; β_2 indicates the effect of repair and replacement cost premium, β_3 indicates the difference between North and South; β_4 indicates the difference between West and South; β_5 indicates the difference between East and South ; β_6 indicates the difference between RI_R-49 and RI_R-30; β_7 indicates the difference between RI_R-60 and RI_R-30; β_8 indicates the difference between WI_R-21 and WI_R-15; β_9 indicates the difference between WI_R-30 and WI_R-15; and e is the error, or residual.

The regression model indicates a statistically significant effect, with approximately 99 % of the total variance explained by the model (Total R^2 = 0.997, p<.01). The results indicated the increase of annual energy cost increased the premium of LCC (b=7.805, p<0.01), and the incremental cost of repair and replacement cost also added to the LCC premium (b=15.218, p<0.01). In terms of the building orientation, the significant difference was noted. Compared with South, the LLC of the other three orientations were greater (North: b=0.130, p<.01; West: b= 0.068, p<.01; East: b=0.030, p<.01. With regard to roof insulation, a difference in LLC was detected with RI_R-49 and RI_R-60 having higher LLC than RI_R-30 (RI_R-49: b=0.867, p<.01 and RI_R-60: b=1.185, p<0.01). In terms of wall insulation, the premium of LLC of WI_R-30 was significantly higher than that of WI_R-15 by $0.484/SF (b=0.484, p<.01), but there was no significant difference of LCC premium between WI_R-15 and WI_R-21 (Table 9.26).

Table 9.26 Results of Multiple Regression Analysis

	β (*SE*)
Constant	-0.020 (0.062)
Energy Cost Premium	7.805** (0.797)
Repair and Replacement Cost Premium	15.218** (0.971)
North	0.130** (0.019)
West	0.068** (0.013)
East	0.030** (0.011)
RI_R-49	0.867** (0.010)
RI_R-60	0.1.185** (0.011)
WI_R-21	0.009 (0.013)
WI_R-30	0.484** (0.029)
Total R^2	0.997**

** indicate p<0.01; * indicate p<0.05

With three categorical regression models, facility decision makers can recognize the relationship between first cost of GBST alternatives and their impacts of annual energy consumption and life cycle impact. For example, with the change of building orientation from south to north, three models demonstrate that changing orientation does not incur an additional first cost but increases the annual energy cost by 0.020/SF and the LCC of $0.130 compared to the south orientation. In addition, the improvement of wall insulation from R-15 to R-30 can increase the first cost of $0.715/SF, reduce the annual energy cost of $0.034/SF, and increase the LCC cost of $0.484/SF compared to the wall insulation level of R-15. From these regression models, facility decision makers can distinguish the relationship between the first cost impacts of GBST alternatives and their LCC influences.

9.5 Conclusion

This chapter described the research findings of this study and discussed their significance for the construction of new public green facilities. First, the relationship between the first cost premium related to selected GBSTs and LCC in USPS facilities was examined. With regard to building orientation, a southern building orientation resulted in the lowest LCC, followed by east, west, and north, in order of preference. The wall insulation level of R-21 was found to be the most efficient level of wall insulation compared to either R-15 or R-30 because it produced the lowest LCC. For the roof insulation, this study concluded that a roof insulation level of R-30 was the most efficient level to minimize LCC. The choice of high performance lighting (T5) with annual cleaning resulted in the lowest LCC compared to the other alternatives tested, so this study recommended this type of installation be selected and an annual cleaning schedule adhered to for both the lighting fixtures and bulbs. To maximize the benefits of the high performance lighting (T5) with annual cleaning, this study recommended that the USPS should verify the lighting design for the new facility project, as implementing the suggested level of lighting would reduce the number of lighting fixtures and bulbs. Finally, this study concluded that a standard heat pump system would be the most cost effective in the long term compared to a high performance heat pump system because the annual energy cost savings failed to offset the first cost premium of the high performance heat pump system. However, it should be noted that the high performance heat pump system could reduce the facility's annual energy consumption.

When the integration of alternative GBSTs was considered, the study recommended the incorporation of the following alternatives to minimize the LCC over a twenty year period:

- Building orientation – South
- Wall insulation – R-21
- Roof insulation – R-30
- Heat pump system – Standard heat pump system.

The least favorable integration of GBST alternatives, which produced the highest LCC of the options considered, was as follows:

- Building orientation – North
- Wall insulation – R-30
- Roof insulation – R-60
- Heat pump system – High performance heat pump system.

The integration that had the greatest impact on reducing the facility's annual energy cost was to incorporate the following GBST alternatives:

- Building orientation – South
- Wall insulation – R-30
- Roof insulation – R-60
- Heat pump system – High performance heat pump system.

The series of scatter graphs developed for this study described the relationships between the first cost premium and LCC of each scenario. Due to the graphical representation of the scatter graph, it was possible to identify the relationship between the first cost premium associated with incorporating various GBST alternatives and the LCC of each. These scatter graphs may help facility decision makers to visualize the relationship between the first cost premium of various scenarios and their LCC impacts.

Three regression models were developed for this study to identify the relationship between the first cost premium of different GBST alternatives and LCC. The first model looked at the relationship between alternative GBSTs and their first cost premium. This model indicated that improving the wall insulation from R-15 to R-21 and R-30 would incur first cost premiums of \$0.092/SF and \$0.715/SF, respectively. The model also indicated that upgrading the heat pump system from a standard heat pump to a high performance system would increase the first cost premium by \$2.032/SF. Finally, the multiple regression model indicated that to improve the roof insulation level from R-30 to R-49 and R-60 would incur first cost premiums of \$0.895/SF and \$1.237/SF, respectively.

In addition, this study developed a model to describe the relationship of several alternative GBSTs and their annual energy consumption. The model revealed that changing the building orientation towards the south improved the annual energy cost by $0.020/SF compared to North, $0.010/SF (West), and $0.005/SF (East). In addition, boosting the wall insulation level reduced annual energy costs by $0.012/SF (R-21) and $0.034/SF (R-30) compared to the base wall insulation level of R-15. With regard to the roof insulation level, improving the roof insulation from R-30 to R-49 or R-60 could reduce annual energy costs by $0.005/SF and $0.009/SF, respectively. Finally, upgrading the heat pump system from the standard model to a high performance heat pump system reduced annual energy consumption by $0.109/SF.

Finally, this study also developed a model to indentify the relationship between the LCC premium and that of its cost components for various GBST alternatives. From the model, changing the building orientation from the south to north, west, or east increased the LCC premium by $0.130/SF (North), $0.068/SF (West), and $0.030 (East). Based on this result, it seems reasonable to prioritize the selection of a building orientation that minimizes this LCC premium. In addition, improving the level of roof insulation from R-30 to R-49 and R-60 increased the LCC premium by $0.867/SF (R-49) and $1.185 (R-60) compared to a roof insulation base level of R-30. Finally, increasing the level of wall insulation to R-30 also increased the LCC premium by $0.484/SF compared to the wall insulation base level of R-15.

By examining these three statistical models, it is now possible to understand the relationship between the first cost premium incurred by installing various GBST alternatives and LCC in green public facilities. The final chapter of this study will summarize this study, discuss its limitations and introduce further study opportunities.

CHAPTER 10: CONCLUSION AND FUTURE RESEARCH

10.1 Introduction

This chapter starts by summarizing the findings of this research in the context of prior research and background studies in the areas of public facility construction and operations, public decision making, green building practices in the built environment, and the green building movement in the public sector. The findings make a contribution to the body of knowledge in these areas and will be particularly useful for those working on compiling currently employed green building strategies and strategies to achieve the goals of green building, and identify strategies and tools that can be used for decision making when constructing new public facilities in institutional owners which have many similar facility types in a same region. The study employed a systematic approach to identify the relationships between GBST alternatives, first cost premiums, operating costs, annual energy costs, and LCC, making it possible to develop an order of preference for selected GBST alternatives that can then be used to benchmark GBST alternatives in other similar types of projects. Integrated design strategies were also identified that minimize the first cost premiums of GBSTs and LCC, and maximize annual energy savings. Finally, an approach has been proposed whereby regression models are applied in order to identify the relationships between GBSTs and the first cost premium, operating costs, and LCC under conditions of incomplete and poor historical facility data. These regression models will allow planners to identify the relationship between GBST alternatives and their first cost premium, as well as any increased operating costs and LCC that their adoption would incur.

After describing the research findings, the limitations and challenges associated with this research will be discussed, and the chapter concludes by outlining further research directions and topics.

10.2 Research Findings

The following subsections describe research findings from this study. First, this study identifies challenges and issues related to facility and the green building movement in the public sector.

10.2.1 Challenges and Issues Associated with Public Facilities and the Green Building Movement in the Public Sector

This study conducted an in-depth background study in the areas of public facilities in the United States, identifying and compiling a review of literature describing the many challenges and issues associated with their maintenance and operation. These include the many unneeded facility assets that government agencies are currently responsible for, the deterioration of these facility assets, the lack of reliable facility data, the rapid increase in energy costs, the shortage of financial capital for facility assets, and the promise held by the green building movement in addressing these problems of the public sector. This background study related to public facilities was used to identify areas and topics that public agencies and researchers could usefully concentrate on solving. In addition, this study summarized and synthesized the current status of the green building movement in the public sector by reviewing government laws including the Energy Independence and Security Act of 2007 and the Energy Policy Act of 2005; federal mandates such as a series of presidential Executive Orders including *E.O. 13514 – Federal Leadership in Environmental, Energy, and Economic Performance* and *E.O. 13423 – Strengthening Federal Environmental, Energy, and Transportation Management*; and implementation guidance such as *Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding*. Public green building laws and policies at the state and local government levels were also examined. By synthesizing those public laws and policies, this study was able to identify the focal areas and direction of the green building movement in the public sector in the U.S. and assess the challenges and issues associated with it. This in-depth background study enabled the researcher to evaluate the current status of research into green building construction and design practices in the public sector.

10.2.2 Compiling Green Building Strategies and Technologies

A compilation of the green building strategies and technologies recognized in the construction industry was performed for this study as part of the Sustainable Facility Asset Management (SFAM) project at Virginia Tech. Since there were many GBSTs to achieve the goals of green building, this study proposed the sorting strategy to identify specific GBSTs. This strategy can be expected to help planners in public agencies, reducing the somewhat chaotic jumble of suggested strategies into a reasonable structure. This study was a first steps toward enabling them to identify which types of GBSTs will maximize benefits under the tight budget constraints in the public sector. This will facilitate the process of selecting the most appropriate GBSTs for each project from a financial standpoint, supporting the goals of green building while at the same time husbanding scarce financial resources.

10.2.3 Developing a Large Facility Data Set

As many public agencies find it hard to collect and maintain accurate facility data, especially in areas such as information on the facility itself, its operation and maintenance, and utility consumption data, an approach to generating facility data with which to conduct statistical analysis is one research contribution of this study. Although designed originally for the U.S. Postal Service, this approach may be applied to other public agencies, for example the U.S. Department of Defense (USDOD) or the U.S. General Service Administration (USGSA), which are responsible for many facilities. Facility data generated using the approach developed in this research can also be used to conduct both statistical analyses and benchmark studies to identify the relationship between the first cost related to GBSTs and LCC.

10.2.4 Relationship between GBST Alternatives, the First Cost Premium, and Operating and Life Cycle Costs

This study identified the relationships between each of five selected GBSTs, namely the orientation of the facility, the level of wall and roof insulation, the lighting system, and the HVAC system, in order to optimize energy performance and their first and life cycle costs. With regard to building orientation, a southern building orientation resulted in the lowest LCC, followed by east, west, and north, in order of preference, because the building orientation affected the annual energy consumption. The fact that changes in the costs of GBSTs were not accounted for in this study, but it could have a positive impact as GBSTs become more mainstream. The wall insulation level of R-21 was found to be the most efficient level of wall insulation compared to the other options tested, namely R-15 and R-30, because it produced the lowest LCC. Although installing a wall insulation level of R-21 incurred a first cost premium compared to the base level of R-15, this was offset by the annual energy savings. For the roof insulation, an insulation level of R-30 was the most efficient level, minimizing LLC while at the same time avoiding the significant first cost premium of installing thicker layers, namely R-49 and R-60, for which the annual energy saving failed to compensate over the facility's expected lifetime of twenty years. The choice of high performance lighting (T-5) with annual cleaning resulted in the lowest LCC of the four alternatives tested, so this study recommended this type of installation, along with the introduction of an annual cleaning schedule for both the lighting fixtures and bulbs to maintain their high performance. In addition, if T-5 lamps drop in price as an example of technology price drop, the benefits of incorporating T-5 lighting fixture and lamps are increased. However, in order to achieve the full benefits of the high performance lighting (T-5) with annual cleaning option, it will first be necessary to verify the proposed lighting design, which will reduce the number of lighting fixture in facilities even though the cost of fixtures and bulbs could incur a significant first cost premium for each fixture and bulb. Finally, this study concluded that a standard heat pump system would be the most cost effective in the long term compared to a high performance heat pump system because the annual energy cost savings failed to offset the current first cost premium of the high performance heat pump system. However, it should be noted that the high performance heat pump system could reduce the facility’s annual energy consumption. Therefore, if public agencies are required to significantly reduce annual energy consumption to support government laws and public policies, a high performance heat pump system may be considered as a viable GBST. These findings can be used to revise the standard design guide of the USPS to optimize energy performance while at the same time making best use of meager facility budgets.

The combination of alternative GBSTs was also considered in this study in order to identify any synergistic effects. Based on the study's analysis, the incorporation of the following alternatives is recommended to minimize the LCC over the twenty year period of the facility's expected lifetime:

- Building orientation – South
- Wall insulation – R-21
- Roof insulation – R-30
- Heat pump system – Standard heat pump system.

The study also identified the least favorable integration of GBST alternatives, producing the highest LCC of the options considered, as follows:

- Building orientation – North
- Wall insulation – R-30
- Roof insulation – R-60
- Heat pump system – High performance heat pump system.

Since this combination produces the highest LCC of all the options considered, the USPS should specify in its standard design guide that the above integration be avoided in order to minimize unnecessary strain on facility budgets. In addition, facility managers in the USPS should be made aware of these synergies, especially project architects charged with designing USPS facilities.

Finally, the combination that was shown to have the greatest impact on reducing the facility's annual energy cost incorporates the following GBST alternatives:

- Building orientation – South
- Wall insulation – R-30
- Roof insulation – R-60
- Heat pump system – High performance heat pump system.

This combination is recommended to the USPS to enable it to minimize its annual energy cost in line with the requirements set by the EPACT of 2005, EISA of 2007, the Presidential Executive Orders *E.O. 13514 – Federal Leadership in Environmental, Energy, and Economic Performance* and the *E.O. 13423 – Strengthening Federal Environmental, Energy, and Transportation Management, Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding*, and other applicable directives at the national, state and local levels.

Furthermore, this study developed three regression models with which to identify relationships between GBST alternatives, their first costs, their annual energy cost and their LCC. The first model looked at the relationship between alternative GBSTs and their first cost premium. This model indicated that improving the wall insulation from R-15 to R-21 or R-30 would incur first cost premiums of 13% or 108%, respectively. The model also indicated that upgrading the heat pump system from a standard heat pump to a high performance system would increase the first cost premium by of 30. Finally, the multiple regression models indicated that to improve the roof insulation level from R-30 to R-49 or R-60 would incur first cost premiums of 53% or 74%, respectively. This regression model compared the first cost premium of GBST alternatives on the basis of a standard design of GBST alternatives that could then be used as a benchmark point.

This study also developed a regression model with which to describe the relationship between various GBST alternatives and their annual energy consumption. The model revealed that changing the building orientation towards the south improved the annual energy cost compared to North, West, and East. In addition, boosting the wall insulation level to R-21 and R-30 reduced annual energy costs of compared to the base wall insulation level of R-15. With regard to the roof insulation level, improving the roof insulation from R-30 to R-49 or R-60 could reduce annual energy costs. Finally, upgrading the heat pump system from the standard model to a high performance heat pump system will reduce annual energy consumption by $0.109/SF.

Finally, this study developed a model to identify the relationship between the LCC premium and its cost components for various GBST alternatives. From the model, changing the building orientation from south to north, west, or east increased the LCC premium. Based on this result, it seems reasonable to prioritize the selection of a building orientation that minimizes this LCC premium. In addition, improving the level of roof insulation from R-30 to R-49 and R-60 increased the LCC premium compared to a roof insulation base level of R-30. Finally, increasing the level of wall insulation to R-30 also increased the LCC premium compared to the wall insulation base level of R-15.

By examining these three statistical models, it is now possible to understand the relationship between the first cost premium incurred by installing various GBST alternatives and LCC in the USPS facilities. This model possibly provides a basis for that facility decision makers and architects should be encouraged to recognize the relationships between GBST alternatives and LCC in the earliest planning stages, before precise LCCA has been conducted, at the time budgets are set for capital projects, especially when trying to allocate limited funds across multiple projects.

As LCC savings by incorporating GBSTs into USPS facilities are sensitive to energy prices, there will be additional LCC savings opportunities if the price of the future electricity radically increases. Although the scope of this research was limited to focusing on only a few GBSTs, there are likely more significant opportunities to be found for reducing annual energy costs and LCCs if there are architectural and operation changes in the USPS facilities. Such changes, however, were outside the scope of this research. Finally, while the findings of the methodology developed in this research are not necessarily generalizable to other contexts, the methodology itself could be used to generate recommendations for other building types in other contexts if sufficient simulated data sets can be built.

10.3 Limitations of the Study

Although this study contributes significantly to the body of knowledge in the areas of public facility management and green building movement in the public sector, it is subject to several limitations.

First, as the operational data for the USPS facility was collected via a discussion with two post masters, the energy analyst, and the energy director at the USPS HQ Facility Energy Management Program in Greensboro, NC, the collected operation data from the prototype post office facility may not generalize and represent the operation of all post office facilities. The annual energy consumption was modeled based on these operational data along with facility assets, so there is a chance that errors are associated with the annual energy consumption figures suggested by the discussion. Because of this limitation, it is necessary to conduct further studies that collect actual facility operation data, preferably for more than one facility, for years. In addition, many facility assets should be studied in order to generalize the operation patterns and occupants and users’ behaviors in a typical USPS facility.

Second, even though eQuest, the energy modeling tool used in this study, was used to predict the annual energy consumption of the prototype post office facility, there will be an inevitable limitation due to the disconnect between actual energy consumption and the energy consumption predicted by eQuest. For example, it is difficult to correctly model air infiltration through doors and other building openings. In this study, annual energy consumption of all combinations was simulated based on the identical situation. Thus, energy savings by changing combination of GBSTs was used in this study.

Third, this study used repair and replacement cost data listed in R.S. Means' book and collected from product vendors to conduct the LCCA. However, these cost data may not fully incorporate all the repair and replacement costs that apply to USPS facilities. Therefore, further studies should investigate the actual repair and replacement costs for buildings over their 20 year lifetimes by reviewing figures for as many comparable USPS facilities as possible.

Fourth, since this study was limited to the consideration of specific GBSTs, namely those assumed to “Optimize Energy Performance”, the results may not definitively represent the impacts of the combination of those GBSTs. The combination of this approach did not take into account potential integrated design synergies where the actual facility design was tailored to account for multiple strategies. This study also deliberately chose GBSTs that would have a direct economic impact so that there was a limitation for GBSTs which had no such impact such as recycled content carpet.

Therefore, further studies are need to identify the precise relationships between a wide range of GBST alternatives, along with their first, operating and LCC costs.

Taking into account the above four limitations of this study, the chapter concludes by describing potential further research opportunities to address these issues.

10.4 Further Research Opportunities

This study investigated the relationship between GBST alternatives, their first cost premiums, energy cost savings and LCC savings. However, this is a vast area that is far from well understood, and there are many opportunities to conduct further research in the areas of designing, constructing and operating public green facilities.

10.4.1 Collecting Additional Facility Data

The first area for further study is to collect additional facility and occupant behavior data from other post office facilities to generalize and represent the operations of all post office facilities. The more reliable data set will improve the reliability and generalizability of the study. In addition, further study includes additional investigation for other similar types of post office facilities to enhance the reliability and generalizability.

10.4.2 Improving Energy Modeling

Although this study was able to develop energy models sufficient to compare the life cycle cost impacts of different alternatives, the energy data used in this study was of a very coarse resolution and did not closely reflect the nuances of building operation and occupant behavior. As better utility data becomes available in the future, future studies can improve the accuracy of energy modeling used to calculate LCC with this approach.”

10.4.3 Incorporating Other GBSTs into Regression Models

This study only considered five GBSTs in detail that could be used to optimize energy performance in USPS facilities. Future studies might incorporate other GBSTs into these regression models to help facility decision makers to use these models for a more sophisticated selection of GBST alternatives. As it is impossible to integrate all GBSTs into one model, the further study will develop clusters of GBSTs which can be incorporated into each other. Thus, the further study will develop a model for each cluster which shows the relationship between the first cost and LCC.

10.4.4 Application to Other Institutional Owners

Finally, this approach may also be used by other institutional owners, including organizations such as universities and school districts that have many similar types of facilities and a long-term program of continuing investment in their facilities.

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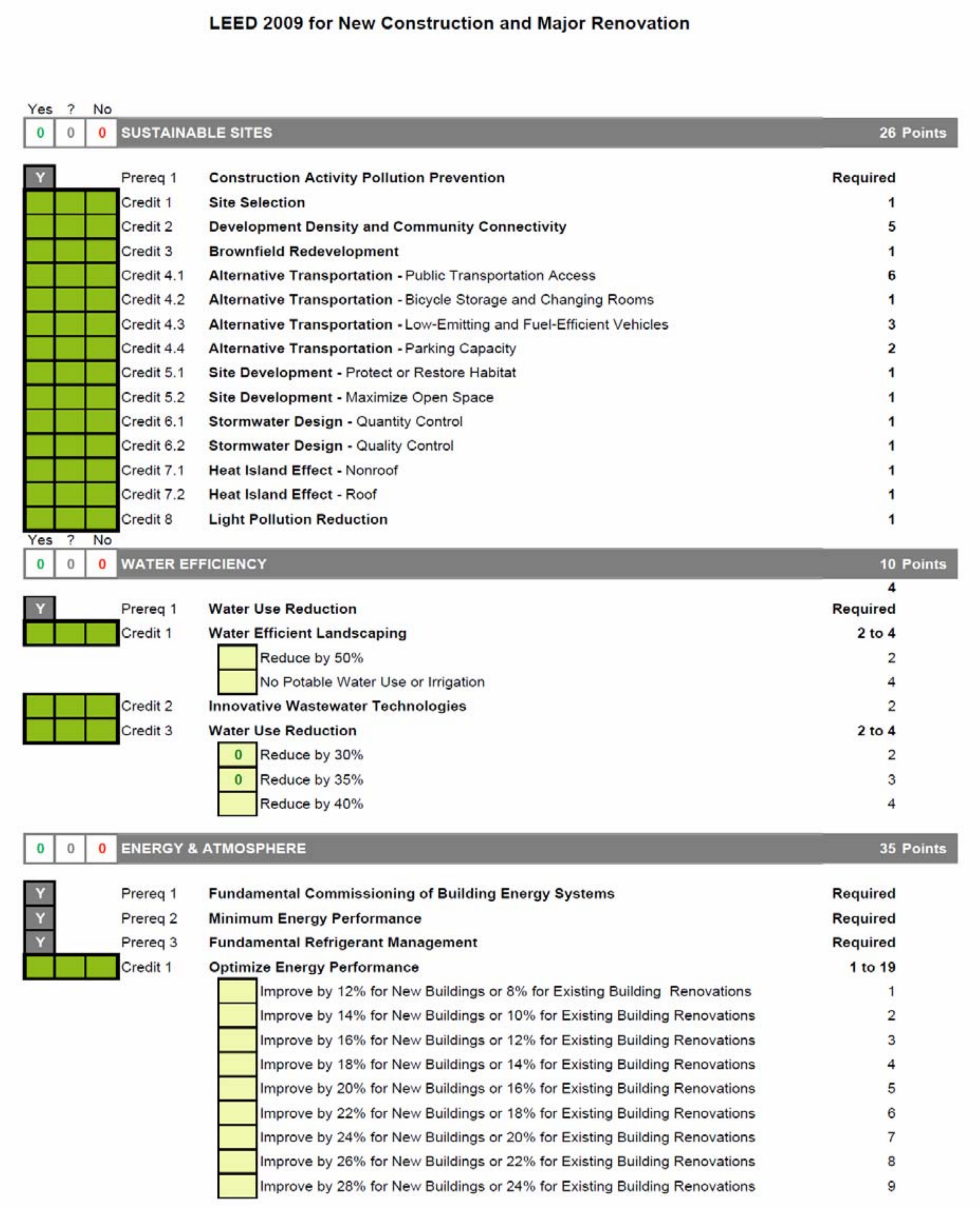
APPPENDICES

Appendix A:

Leadership in Energy Environmental Design (LEED) Credits and Points (USGBC 2009)



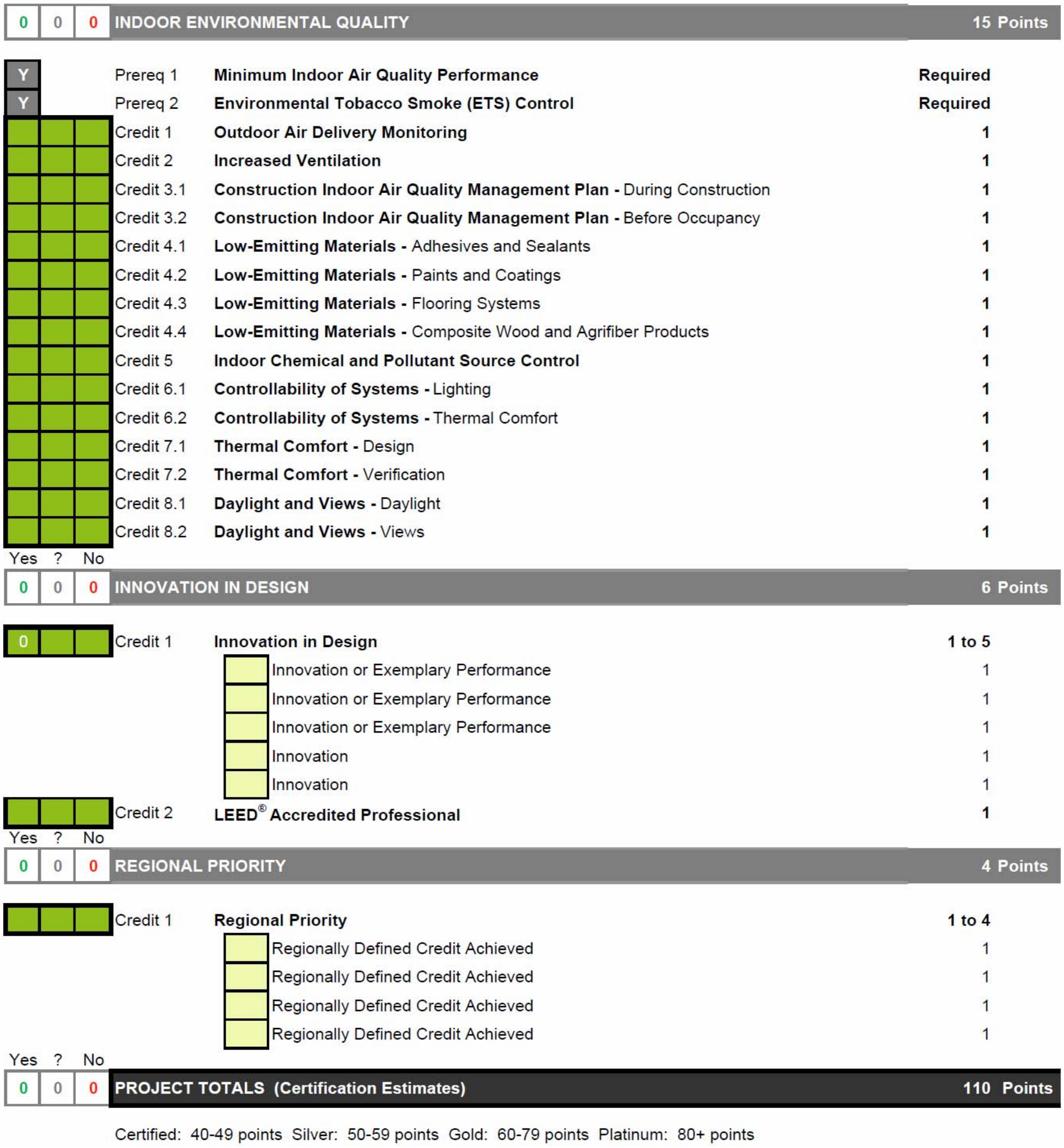
LEED 2009 for New Construction and Major Renovation

Yes	?	No				
0	0	0	**SUSTAINABLE SITES**			**26 Points**
Y			Prereq 1		**Construction Activity Pollution Prevention**	**Required**
			Credit 1		**Site Selection**	**1**
			Credit 2		**Development Density and Community Connectivity**	**5**
			Credit 3		**Brownfield Redevelopment**	**1**
			Credit 4.1		**Alternative Transportation -** Public Transportation Access	**6**
			Credit 4.2		**Alternative Transportation -** Bicycle Storage and Changing Rooms	**1**
			Credit 4.3		**Alternative Transportation -** Low-Emitting and Fuel-Efficient Vehicles	**3**
			Credit 4.4		**Alternative Transportation -** Parking Capacity	**2**
			Credit 5.1		**Site Development -** Protect or Restore Habitat	**1**
			Credit 5.2		**Site Development -** Maximize Open Space	**1**
			Credit 6.1		**Stormwater Design -** Quantity Control	**1**
			Credit 6.2		**Stormwater Design -** Quality Control	**1**
			Credit 7.1		**Heat Island Effect -** Nonroof	**1**
			Credit 7.2		**Heat Island Effect** - Roof	**1**
			Credit 8		**Light Pollution Reduction**	**1**

Yes	?	No				
0	0	0	**WATER EFFICIENCY**			**10 Points**
						4
Y			Prereq 1		**Water Use Reduction**	**Required**
			Credit 1		**Water Efficient Landscaping**	**2 to 4**
				☐	Reduce by 50%	2
				☐	No Potable Water Use or Irrigation	4
			Credit 2		**Innovative Wastewater Technologies**	2
			Credit 3		**Water Use Reduction**	**2 to 4**
				0	Reduce by 30%	2
				0	Reduce by 35%	3
				☐	Reduce by 40%	4

0	0	0	**ENERGY & ATMOSPHERE**			**35 Points**
Y			Prereq 1		**Fundamental Commissioning of Building Energy Systems**	**Required**
Y			Prereq 2		**Minimum Energy Performance**	**Required**
Y			Prereq 3		**Fundamental Refrigerant Management**	**Required**
			Credit 1		**Optimize Energy Performance**	**1 to 19**
				☐	Improve by 12% for New Buildings or 8% for Existing Building Renovations	1
				☐	Improve by 14% for New Buildings or 10% for Existing Building Renovations	2
				☐	Improve by 16% for New Buildings or 12% for Existing Building Renovations	3
				☐	Improve by 18% for New Buildings or 14% for Existing Building Renovations	4
				☐	Improve by 20% for New Buildings or 16% for Existing Building Renovations	5
				☐	Improve by 22% for New Buildings or 18% for Existing Building Renovations	6
				☐	Improve by 24% for New Buildings or 20% for Existing Building Renovations	7
				☐	Improve by 26% for New Buildings or 22% for Existing Building Renovations	8
				☐	Improve by 28% for New Buildings or 24% for Existing Building Renovations	9

				☐ Improve by 30% for New Buildings or 26% for Existing Building Renovations	10
				☐ Improve by 32% for New Buildings or 28% for Existing Building Renovations	11
				☐ Improve by 34% for New Buildings or 30% for Existing Building Renovations	12
				☐ Improve by 36% for New Buildings or 32% for Existing Building Renovations	13
				☐ Improve by 38% for New Buildings or 34% for Existing Building Renovations	14
				☐ Improve by 40% for New Buildings or 36% for Existing Building Renovations	15
				☐ Improve by 42% for New Buildings or 38% for Existing Building Renovations	16
				☐ Improve by 44% for New Buildings or 40% for Existing Building Renovations	17
				☐ Improve by 46% for New Buildings or 42% for Existing Building Renovations	18
				☐ Improve by 48% + for New Buildings or 42% for Existing Building Renovations	19
			Credit 2	**On-Site Renewable Energy**	**1 to 7**
				☐ 1% Renewable Energy	1
				☐ 3% Renewable Energy	2
				☐ 5% Renewable Energy	3
				☐ 7% Renewable Energy	4
				☐ 9% Renewable Energy	5
				☐ 11% Renewable Energy	6
				☐ 13% Renewable Energy	7
			Credit 3	**Enhanced Commissioning**	**2**
			Credit 4	**Enhanced Refrigerant Management**	**2**
			Credit 5	**Measurement and Verification**	**3**
			Credit 6	**Green Power**	**2**
Yes	?	No			
0	0	0	**MATERIALS & RESOURCES**		**14 Points**
Y			Prereq 1	**Storage and Collection of Recyclables**	**Required**
			Credit 1.1	**Building Reuse** - Maintain Existing Walls, Floors and Roof	**1 to 3**
				☐ Reuse 55%	1
				☐ Reuse 75%	2
				☐ Reuse 95%	3
			Credit 1.2	**Building Reuse -** Maintain Interior Nonstructural Elements	**1**
			Credit 2	**Construction Waste Management**	**1 to 2**
				☐ 50% Recycled or Salvaged	1
				☐ 75% Recycled or Salvaged	2
			Credit 3	**Materials Reuse**	**1 to 2**
				☐ Reuse 5%	1
				☐ Reuse 10%	2
			Credit 4	**Recycled Content**	**1 to 2**
				☐ 10% of Content	1
				☐ 20% of Content	2
			Credit 5	**Regional Materials**	**1 to 2**
				☐ 10% of Materials	1
				☐ 20% of Materials	2
			Credit 6	**Rapidly Renewable Materials**	**1**
			Credit 7	**Certified Wood**	**1**



0	0	0	**INDOOR ENVIRONMENTAL QUALITY**		**15 Points**
Y			Prereq 1	**Minimum Indoor Air Quality Performance**	**Required**
Y			Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	**Required**
🟩	🟩	🟩	Credit 1	**Outdoor Air Delivery Monitoring**	**1**
🟩	🟩	🟩	Credit 2	**Increased Ventilation**	**1**
🟩	🟩	🟩	Credit 3.1	**Construction Indoor Air Quality Management Plan -** During Construction	**1**
🟩	🟩	🟩	Credit 3.2	**Construction Indoor Air Quality Management Plan -** Before Occupancy	**1**
🟩	🟩	🟩	Credit 4.1	**Low-Emitting Materials -** Adhesives and Sealants	**1**
🟩	🟩	🟩	Credit 4.2	**Low-Emitting Materials -** Paints and Coatings	**1**
🟩	🟩	🟩	Credit 4.3	**Low-Emitting Materials -** Flooring Systems	**1**
🟩	🟩	🟩	Credit 4.4	**Low-Emitting Materials -** Composite Wood and Agrifiber Products	**1**
🟩	🟩	🟩	Credit 5	**Indoor Chemical and Pollutant Source Control**	**1**
🟩	🟩	🟩	Credit 6.1	**Controllability of Systems -** Lighting	**1**
🟩	🟩	🟩	Credit 6.2	**Controllability of Systems -** Thermal Comfort	**1**
🟩	🟩	🟩	Credit 7.1	**Thermal Comfort -** Design	**1**
🟩	🟩	🟩	Credit 7.2	**Thermal Comfort -** Verification	**1**
🟩	🟩	🟩	Credit 8.1	**Daylight and Views -** Daylight	**1**
🟩	🟩	🟩	Credit 8.2	**Daylight and Views -** Views	**1**
Yes	?	No			
0	0	0	**INNOVATION IN DESIGN**		**6 Points**
0	🟩	🟩	Credit 1	**Innovation in Design**	**1 to 5**
				🟨 Innovation or Exemplary Performance	1
				🟨 Innovation or Exemplary Performance	1
				🟨 Innovation or Exemplary Performance	1
				🟨 Innovation	1
				🟨 Innovation	1
🟩	🟩	🟩	Credit 2	**LEED® Accredited Professional**	**1**
Yes	?	No			
0	0	0	**REGIONAL PRIORITY**		**4 Points**
🟩	🟩	🟩	Credit 1	**Regional Priority**	**1 to 4**
				🟨 Regionally Defined Credit Achieved	1
				🟨 Regionally Defined Credit Achieved	1
				🟨 Regionally Defined Credit Achieved	1
				🟨 Regionally Defined Credit Achieved	1
Yes	?	No			
0	0	0	**PROJECT TOTALS (Certification Estimates)**		**110 Points**

Certified: 40-49 points Silver: 50-59 points Gold: 60-79 points Platinum: 80+ points

Appendix B:

Green Globes Rating System

Section	**Areas and Sub-Areas of Assessment**
A – Project Management (50 points)	
A.1 (20)	Integrated design process
A.2 (10)	Environmental purchasing (Including energy efficient products)
A.3 (15)	Commissioning
A.4 (5)	Emergency response plan
B – Site (115 points)	
B.1 (30)	Development area (site selection, development density, site remediation)
B.2 (30)	Ecological impacts (native planting and vegetation, heat islands, night sky)
B.3 (20)	Watershed features (site grading, stormwater management, previous cover, rainwater capture)
B.4 (35)	Site ecology enhancement
C – Energy (380 points)	
C.1 (100)	Energy performance
C.2 (114)	Reduced energy demand (space optimization, microclimatic response to site, day-lighting, envelope design, metering)
C.3 (66)	Integration of energy efficient systems
C.4 (20)	Renewable energy sources (on-site renewable energy technologies)
C.5 (80)	Energy-efficient transportation (public transportation, cycling facilities)
D – Water (85 Points)	
D.1 (30)	Water performance
D.2 (45)	Water conserving features (sub-metering, devices, cooling towers, landscaping and irrigation strategies)
D.3 (10)	On-site treatment of water (greywater system, on-site wastewater treatment)
E – Resources (100 Points)	
E.1 (40)	Low impact systems and materials (selection of building materials based on the low environmental impact)
E.2 (15)	Minimal consumption of resources (reused, recycled, local, low-maintenance materials, certified wood)
E.3 (15)	Reuse of existing buildings
E.4 (15)	Building durability, adaptability and disassembly
E.6 (5)	Reduction, reuse and recycling of demolition waste
E.7 (10)	Recycling and composting facilities
F – Emissions, Effluents & Other Impacts (70 Points)	
F.1 (15)	Air emissions (low emission burners)
F.2 (20)	Ozone depletion
F.3 (10)	Avoiding sewer and waterway contamination
F.4 (25)	Pollution minimization (storage tanks, PCBs, radon, asbestos, pest management, hazardous materials)
G – Indoor Environment (200 Points)	

G.1 (55)	Ventilation system (intakes, ventilation rates, delivery, CO2 monitoring, controls, parking areas, ease of maintenance)
G.2 (45)	Control of indoor pollutants (mould, AHU, humidification, Legionella cooling towers/ hot water, building materials, local exhaust)
G.3 (50)	Lighting (visual access, heights & depths of perimeter spaces, daylight factor, ballasts, glare, task lighting, controls)
G.4(50)	Thermal comfort (thermal conditions meet ASHRAE 55)
G.5 (20)	Acoustic comfort (zoning, transmission, vibration control, acoustic privacy, reverberation, mechanical noise)

(ECD Energy and Environment Canada 2004)

Appendix C:

Executive Orders, Acts, Public Agencies’ Approach for Green Building

Appendix C1: Executive Order 13423: Strengthening Federal Environmental, Energy, and Transportation Management

Section	Areas	Content
Sec. 2. (a)	Energy Efficiency	Reduce energy intensity by 3% annually through 2015 or by 30% by 2015, related to the baseline of the agency’s use in fiscal year 2003
Sec. 2. (a)	Greenhouse Gases	Reduce energy intensity by 3% annually through 2015 or by 30% by 2015, reduce greenhouse gas emissions
Sec. 2. (b)	Renewable Energy	At least 50% of current renewable energy purchases must come from new renewable sources
Sec. 2. (c)	Water Conservation	Reduce water consumption intensity by 20% annually through 2015, related to the baseline of the agency’s use in fiscal year 2007
Sec. 2. (d)	Procurement	Expand purchases of environmentally-sound goods and services, including biobased, environmentally preferable, energy-efficient, water-efficient, and recycled-content products, and use of paper of at least 30 percent post-consumer fiber content
Sec. 2. (e)	Pollution Prevention	Reduces the quantity of toxic and hazardous chemicals and materials acquired, used, or disposed of by the agency, increases diversion of solid waste as appropriate, and maintains cost-effective waste prevention and recycling programs in its facilities
Sec. 2. (f)	Federal Readership in High Performance and Sustainable Building	Comply with Federal Readership in High Performance and Sustainable Building
Sec. 2. (g)	Vehicles	Increase purchase of alternative fuel, hybrid, and plug-in hybrid electric vehicles when commercially available
Sec. 2. (g)	Petroleum Conservation	Reduce petroleum consumption in fleet vehicles by 2% annually, related to agency baselines for fiscal year 20005
Sec. 2. (g)	Alternative Fuel Use	Increase alternative fuel consumption at least 10% annually, related to agency baselines for fiscal year 20005

Sec. 2. (h)	Electronics Management	Annually, 95% of electronic products purchased must meet Electronic Product Environmental Assessment Tool standards where applicable; enable Energy Star® features on 100% of computers and monitors; and reuse, donate, sell, or recycle 100% of electronic products using environmentally sound management practices

(E. O. 13423 2007)

Appendix C2: Energy Policy Act of 2005: Design and Construction Requirements

Section	Areas	Content
Sec. 102	Energy Efficiency	Reduce energy consumption per gross square foot from 2006 to 2015 based on the energy consumption in fiscal year 2003
Sec. 103	Energy Measurement and Accountability	Provide utility meters on all new federal building
Sec. 104	Procurement of Energy Efficient Products	Procure Energy Star products or Federal Energy Management Program (FEMP) designated products
Sec. 108	Recovered Mineral Components	Use recovered mineral components in concrete (fly ash, blast furnace slag, etc.)
Sec. 109	Energy Efficiency	Achieve energy consumption levels that are at least 30% below the levels established in the ASHRAE 90.1-2004 standard
Sec. 203	Renewable Energy Requirement	Requires that the Federal Government's renewable electricity consumption meet or exceed 3% from fiscal year 2007-2008, with increase to at least 5% in fiscal years 2010-2012 and 705% in 2013 and thereafter
Sec. 204	Photovoltaic (PV) energy use	Requires the installation of 20,000 solar energy systems in Federal buildings by 2010
Sec. 546	Water Savings	Reduce water consumption if life cycle cost is effective
Sec. 701	Alternative Fuel Use	Require duel-fueled vehicles

(NAVFAC 2007; U.S. Congress 2005a)

Appendix C3: Energy Independence and Security Act of 2007

Goals	Areas	Content
Sec. 323	Energy Efficiency and Renewable Energy Systems	Use of energy efficient or renewable energy measures, including PV Requires for energy lighting fixtures and bulbs
Sec. 431	Energy Saving	Reduce energy consumption per gross square foot from 2006 to 2015 based on the energy consumption in fiscal year 2003
Sec. 432	Energy and Water Efficiency	Implement energy and water efficiency measures; meter energy and water consumption
Sec. 522	Energy Efficient Product	Prohibit the purchase of incandescent light bulbs for use
Sec. 523	Hot Water Demand	Require 30% of the hot water demand in new buildings to be met with solar hot water equipment
Sec. 525	Energy Efficient Product	Procure Energy Star and FEMP-designated products

Appendix C4: WBDG – Green Building Design

	Areas	Content
A	Optimize Site Potential	• Select proper site selection • Consider reuse or rehabilitation of existing buildings • Select proper landscape • Consider parking issues • Consider perimeter lighting
B	Optimize Energy Use	• Concern the impact of greenhouse gases • Increase energy efficiency • Utilize renewable energy resources
C	Protect and Conserve Water	• Reduce fresh water consumption • Reduce, control, or treat site-runoff • Use water efficiently • Reuse or recycled water for on-site use
D	Environmentally Preferable Products	• Minimize life-cycle environmental impacts such as global warming, resource depletion, and human toxicity • Improve worker safety and health
E	Indoor Environmental Quality	• Maximize daylighting • Have appropriate ventilation • Have moisture control • Avoid the use of materials with high-VOC emissions • Mitigate chemical, biological, and radiological attack
F	Operational and Maintenance Practices	• Require less water, energy, and toxic chemicals and cleaners to maintain

Appendix C5: Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding

I.	Employ Integrated Design Principles	
	Integrated Design	Use a collaborative, integrated planning and design process
	Commissioning	Employ total building commissioning practices
II.	Optimize Energy Performance	
	Energy Efficiency	Reduce the energy cost budget by 30% compared to the baseline building performance rating per the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
	Measurement and Verification	Install building level utility meters in new major construction and renovation projects to track and continuously optimize performance
III.	Protect and Conserve Water	
	Indoor Water	Employ strategies that in aggregate use a minimum of 20% less potable water than the indoor water use baseline calculated for the building
	Outdoor Water	• Use water efficient landscape and irrigation strategies • Employ design and construction strategies that reduce storm water runoff and polluted sit water runoff
IV.	Enhance Indoor Environmental Quality	
	Ventilation and Thermal comfort	• Meet the current ASHRAE Standard 55-2004 (Thermal Environmental Conditions for Human Occupancy) • Meet the current ASHRAE Standard 62.1-2004 (Ventilation for Acceptable Indoor Air Quality)
	Moisture	Establish and implement a moisture control strategy
	Daylighitng	Achieve a minimum of daylight factor of 2 % in 75 % of all space occupied for critical visual tasks
	Low-Emitting Materials	Specify materials and products with low pollutant emissions
	Protect Indoor Air Quality during Construction	• Follow the recommended approach of the Sheet Metal and Air Conditioning Contractor's National Association Indoor Air Quality Guidelines for Occupied Buildings under Construction • Conduct a minimum 72 hour flush-out • Continue flush-out as necessary to minimize exposure to contaminants from new building materials
V.	Reduce Environmental Impact of Materials	
	Recycled Content	Use products meeting or exceeding EPA's recycled content recommendations
	Biobased Content	Use products meeting or exceeding USDA's biobased content recommendations

	Construction Waste	- Identify local recycling and salvage operations that could process site related waste - Recycle or salvage at least 50% construction, demolition and land clearing waste
	Ozone Depleting Compounds	- Eliminate the use of ozone depleting compounds during and after construction

Appendix C6: Public Agencies' Approaches for Green Building (Federal Level)

Name of Agent	Date (update)	Causes (Type)	Content
U.S. Department of Energy	2/29/2008	Executive Order 13423 Regulation	On February 29, 2008, Secretary of Energy Samuel Bodman issued an memorandum to DOE leadership directing heads of departments to adhere to Executive Order 13423, "Strengthening Federal Environmental, Energy and Transportation Management (72 FR 3919; Jan. 24, 2007)" by building all new Department buildings of $5M or greater to earn LEED Gold certification. The memorandum also gives preferences to LEED Gold when selecting new leased space.
U.S. Department of Health and Human Services	11/7/2007	Policy	The Department of Health and Human Services issued a Sustainable Buildings Implementation Plan, requiring new construction or major renovation projects of applicable buildings built with Federal funds over $3 million to achieve LEED certification, Green Globes certification, or certification by another ANSI accredited green building standard.

Name of Agent	Date (update)	Causes (Type)	Content
Smithsonian Institution	11/13/2006 (11/19/2007)	Executive Order 13123: Greening the Government through Efficient Energy Management	The Smithsonian Institution issued "Smithsonian Directive 422" in response to Executive Order 13123: Greening the Government through Efficient Energy Management. The directive articulates the Smithsonian's goal to design, build, and maintain facilities that are eligible for, and that obtain, LEED certification. Initially, the Smithsonian requires all new buildings and renovation work to aim for a minimum of LEED certification. In addition, the Smithsonian will integrate the LEED checklist and guidelines into the planning, engineering, design, construction, deconstruction, and maintenance of Smithsonian facilities.
U.S. Department of Agriculture	6/19/2006 (6/6/2008)	Policy	The Department of Agriculture issued a Departmental Regulation that requires new construction or major renovation of covered facilities to achieve a minimum of LEED Silver. The USDA has integrated these requirements along with strategies for improving energy and water use in existing buildings into their Sustainable Buildings Implementation Plan, issued in August, 2007.
National Aeronautics and Space Administration	1/1/0001 (11/19/2007) *(6/13/2011)	Policy	New construction and major renovations of NASA facilities projects planned for FY 2006 and beyond are required to meet LEED Silver certification, and strive for LEED Gold. FY 2004 and FY 2005 projects will strive to meet LEED Silver certification. All other building projects will strive to follow the LEED rating system as much as possible. The LEED goal for NASA facilities projects will be reviewed, renewed or changed every three years.

Name of Agent	Date (update)	Causes (Type)	Content
U.S. Air Force	1/1/0001 (11/27/2007)	Policy under development	The Air Force has developed a LEED Application Guide for Lodging projects and has conducted LEED training seminars for its design and construction personnel. The Air Force encourages the use of LEED for new or major renovations for MILCON projects and has created an online design guide for sustainable development structured after LEED. An online Sustainable Training course is also being developed.
U.S. Army	1/1/0001 (11/19/2007)	Policy	The Army adopted LEED into its Sustainable Project Rating Tool (SPiRiT), but does not require certification of its projects. In January 2006, the Army issued a memorandum stating that it will transition from SPiRiT to LEED beginning in FY 2008. All new vertical construction projects will achieve LEED Silver certification. Additionally, the Army will adopt LEED for Homes when it is released.
U.S. Department of Agriculture - Forest Service	1/1/0001 (6/6/2008)	Policy	U.S. Forest Service requires LEED registration and certification at the Silver level for all new construction of office buildings, visitor centers, research facilities, and climate controlled warehouses 2,500 GSF or greater in size.
U.S. Department of Interior	1/1/0001 (11/19/2007)		The Department of the Interior signed a Memorandum of Understanding with the USGBC supporting the use of LEED for Existing Buildings by its facilities. The DOI also signed a memorandum with the GSA and the USGBC supporting LEED for all partnered projects.
U.S. Department of State	1/1/0001 (11/19/2007)		The Department of State has committed to using LEED on the construction of new embassies worldwide over the next 10 years and has worked with the USGBC to coordinate a green charrette for the project teams in early 2001. The Department has several projects registered for LEED certification.

Name of Agent	Date (update)	Causes (Type)	Content
U.S. Department of the Navy	1/1/0001 (11/30/2007)		The Navy was the first federal agency to certify a LEED project: the Bachelor Enlisted Quarters at the Great Lakes Naval Training Center (LEED for New Construction pilot). The Navy continues to pursue sustainable development in its facilities, requiring all applicable projects to meet the LEED Certified level, unless justifiable conditions exist that limit accomplishment of the LEED credits necessary for achieving the LEED Certified level. Submission to the USGBC for certification is not a requirement, but is recommended for high visibility and showcase projects. The Navy uses LEED as a tool in applying sustainable development principles and as a metric to measure the sustainability achieved. The Navy has provided support for the development of the LEED for Homes and has participated in the LEED Existing Buildings and Multiple Buildings committees.
U.S. Environmental Protection Agency	1/1/0001 (11/19/2007)		The Environmental Protection Agency requires all its new facility construction and new building acquisition projects 20,000 square feet or larger achieve LEED Gold certification. The Agency currently has multiple projects registered for LEED for New Construction certification and supported the development of LEED for Existing Buildings. The Agency requires GSA to provide new major office leases that meet the Energy Star requirements. EPA's Chelmsford, MA lab is the first Gold-rated federal building.

Name of Agent	Date (update)	Causes (Type)	Content
U.S. General Services Administration	1/1/0001 (4/24/2008)		In order to objectively measure its sustainable design achievements, GSA decided in 2000 that beginning in 2003 all capital building projects must earn LEED Certified, with a target of LEED Silver. In 2008, in response to the changing market, GSA began requiring all lease construction to earn LEED Silver certification. The General Services Administration is the nation's largest civilian landlord; managing space in over 8,600 owned and leased buildings for over one million federal employees. GSA was U.S. Green Building Council's first federal member and supported the development of LEED for Commercial Interiors. As of January 2008, GSA has 24 certified projects including courthouses, laboratories, office buildings, a border station, and a childcare facility.

*( ): This sign represents the expiration date of the policy.

Appendix C7: Public Agencies’ Approaches for Green Building (State Level)

Policy Path: Regulatory

Name of State	Date (update)	Causes (Type)	Content
Ohio	9/27/2007 (3/14/2008)	Resolution	The Ohio School Facilities Commission (OSFC) passed Resolution #07-124, approving the incorporation of energy efficiency and sustainable design features into all future and some previously approved school projects. All K-12 public school projects approved by the OSFC are required to meet a minimum of LEED for Schools Silver certification, with strong encouragement to achieve the Gold level. There is additional emphasis on maximizing Energy & Atmosphere credits. The resolution directs OSFC to cover all LEED registration and certification fees and to provide a supplemental allowance.

Policy Path: Legislative

Name of State	Date (update)	Causes (Type)	Content
Arkansas	1/1/0001 (11/26/2007)	Statute/Ordinance	Governor Mike Huckabee signed Act 1770 in July 2005 encouraging all state agencies to use green design strategies, including LEED. The bill also creates a "Legislative Task Force on Sustainable Building Design & Practices" which is to meet and continue to review, discuss and advise on issues related to sustainable building design.
Colorado	4/16/2007 (11/26/2007)	Statute/Ordinance	Governor Bill Ritter signed Senate Bill 51 into law requiring any new or renovated building whose total project cost includes 25 percent or more in state funds to be designed and built to a high performance green building standard. The new law requires the State Architect to select an independent third-party certification program, such as LEED. The project must achieve the highest level performance certification possible, which is determined by calculating whether the increased initial costs can be recouped from decreased operational costs within 15 years.

Name of State	Date (update)	Causes (Type)	Content
Connecticut	6/4/2007 (11/26/2007)	Statute/Ordinance	Governor Rell signed House Bill 7432, stating that not later than January 1, 2008, the Secretary of the Office of Policy and Management, after consulting with the State's commissioners of public works, environmental protection and public safety, shall adopt, in accordance with the provisions of chapter 54 of the general statutes, regulations for buildings consistent with or exceeding LEED Silver for new commercial construction and major renovation projects, or an equivalent standard, and thereafter update such regulations as the secretary deems necessary. Once enacted, these regulations will apply to the following types of projects, provided that they receive $2 million or more in state funding: a) new state facility construction of $5 million or more approved and funded on or after January 1, 2008; b) state facility renovations of $2 million or more approved and funded on or after January 1, 2008; c) new public school construction of $5 million or more authorized on or after January 1, 2009; and d) public school renovations of $2 million or more authorized on or after January 1, 2009. The law also requires the State Building Inspector and the Codes and Standards Committee to revise the State Building Code to meet or exceed LEED Silver for all private buildings constructed after January 1, 2009 of $5 million or more and for all renovations beginning after January 1, 2010 of $2 million or more. Exempt from these code requirements are residential buildings of four units or less and certain buildings, as determined by the Institute for Sustainable Energy, where costs may outweigh benefits. HB 7432 further authorizes $30 million in state bonds, the sale proceeds of which are to be allocated to fund on-site renewable energy projects in state buildings pursuing LEED certification.

Name of State	Date (update)	Causes (Type)	Content
Hawaii	6/26/2006 (11/26/2007)	Statute/Ordinance	Governor Lingle signed HB #2175, thus requiring each state agency to design and construct buildings to meet the LEED Silver certified level, or a comparable standard. The law applies to all new state-owned construction of 5,000 square feet or greater, including K-12 public schools. The Hawaii state legislature amended its provisions to Hawaiian counties with HRS 46 19.6, requiring priority processing for all construction or development permits for projects that achieve LEED Silver or equivalent.
Illinois	Aug 24, 2007 (3/14/2008)	Statute/Ordinance	The Illinois State Senate amended the School Construction Law (Public Act #95-0416) with the governor's approval, directing the Capital Development Board to only issue grants to school projects with LEED for Schools or comparable rating system certification, or to projects that meet the standards set forth by the Capital Development Board's Green Building Advisory Committee.
Kentucky	8/30/2007 (11/26/2007)	Statute/Ordinance	Governor Fletcher signed HB1 into law, a bill that included an addition to KRS 56.776 that would instruct the Finance and Administration Cabinet to use LEED or other rating systems to develop green building incentives for private development in the Commonwealth of Kentucky.
Maryland	1/1/0001 (11/26/2007)	Statute/Ordinance	The House and Senate passed legislation in April 2005 requiring a green building standard, such as LEED (Silver), be used for state capital projects.

Name of State	Date (update)	Causes (Type)	Content
Maryland	APR 24, 2008 (6/6/2008)	Statute/Ordinance	Governor O'Malley signed SB 208 into law, requiring all new public construction and major renovation projects intended for human occupation and of 7,500 square feet or greater to earn LEED Silver certification or a comparable standard. The High Performance Building Act further requires that MD public schools using state funds earn LEED Silver certification or a comparable standard, adding that "50% of the local share of extra costs" incurred in building the green school will be paid by the State
Minnesota	5/25/2007 (11/26/2007)	Statute/Ordinance	Governor Pawlenty signed into law the Next Generation Energy Act of 2007 setting a roadmap towards a smarter energy future and requiring utilities provide technical assistance for commercial or residential projects that incorporate green building principles in their construction. By December 31, 2010, the Act established a goal of 100 commercial buildings achieving LEED certification, or equivalent, by December 31, 2010
Nevada	6/17/2005 (11/26/2007)	Statute/Ordinance	Governor Guinn signed AB3 requiring all state funded buildings be LEED Certified or higher in accordance with LEED or an equivalent standard. During each biennium, at least two occupied public buildings whose construction will be sponsored or financed by the State of Nevada must be designated as a demonstration project and be equivalent to a LEED Silver or higher certification, or an equivalent standard. The bill also provides tax abatements for property which has an eligible LEED Silver building and tax exemptions for products or materials used in the construction of a LEED Silver building.

Name of State	Date (update)	Causes (Type)	Content
New Jersey	January 13, 2008 (2/15/2008)	Statute/Ordinance	Governor Corzine signed Senate Bill 843 into law, requiring all new state-owned buildings of 15,000 square feet or greater to earn LEED Silver certification or equivalent as determined by state authorities.
Pennsylvania	July 2005 (3/14/2008)	Statute/Ordinance	The Pennsylvania legislature passed House Bill 628, amending the Public School Code to provide a financial incentive to public school districts that achieve LEED Silver certification. On April 25, 2006, school districts in Allegheny, Montgomery, Perry, Philadelphia, Westmoreland, Erie and Delaware counties were awarded a grant as part of the Green Schools Grant Program. School construction projects must achieve at least a LEED Silver certification. Buildings currently under construction on behalf of the Department of Environmental Protection and the Department of Conservation and Natural Resources are seeking LEED Silver certification. Four state funds including the $20 million Sustainable Energy Fund provide grants, loans and "near-equity" investments in energy efficiency and renewable energy projects in Pennsylvania.
South Carolina	Jun 20 2007 (11/7/2007)	Statute/Ordinance	The South Carolina legislature passed H3034 requiring that all state-owned and state-funded construction greater than 10,000 ft2 and any major renovation projects of greater than fifty percent of total building space or value achieve LEED-NC Silver certification or comparable standard. With a focus on energy efficiency, the legislation specifically requires a minimum of four credits earned in Energy & Atmosphere Credit 1, “Optimize Energy Performance.”

Name of State	Date (update)	Causes (Type)	Content
South Dakota	Mar 17, 2008 (4/17/2008)	Statute/Ordinance	Governor Rounds signed into law SB 188, establishing leadership in public buildings by requiring all new construction and major renovations of state-owned buildings costing at least $500K and greater than 5,000 square feet to earn LEED Silver, two Green Globes or a comparable standard.
Virginia	Mar 04, 2008 (4/17/2008)	Statute/Ordinance	Governor Kaine signed into law HB 239, amending and reenacting Section 58.1-3221.2 of the Code of Virginia thus declaring energy efficient buildings to be a separate class of taxation from other real property. The amended code provides for localities in the Commonwealth to levy equal or lesser taxes on energy efficient buildings, as defined in the code as meeting the performance standards of LEED, Energy Star, Green Globes or EarthCraft.

Name of State	Date (update)	Causes (Type)	Content
Washington	April 08, 2005 (12/12/2007)		Governor Gregoire approved Chapter 39.35D of the Revised Code of Washington, “High-Performance Public Buildings,” requiring all projects over 5,000 square feet receiving capital funds after July 1, 2006 to be certified to the LEED Silver standard. The code also requires that all K-12 schools be certified to the LEED Silver standard or built to comply with the Washington Sustainable Schools Protocol as of July 1, 2007. In addition, the code required all affordable homes receiving money from the state's Housing Trust Fund after July 1, 2008, to be built in compliance with the Evergreen Standard for Affordable Housing. By 2009, all new construction projects and major renovations receiving Washington State funds will be built to a green standard. The Dept. of Corrections has made LEED Silver a requirement and certification is also required for buildings larger than 5,000 sq ft. Community Colleges, Dept. of General Administration, The Evergreen State College, and several other smaller agencies have made LEED Silver the standard for design and construction, however certification is not required. New Energy Life Cycle Cost Analysis Guidelines (ELCCA) went into effect January 2005 requiring that all new and remodeled public projects over 25,000 square feet in Washington State to submit a completed scorecard reflecting an attempt at LEED Silver. Project teams are permitted to submit an alternative means for scoring their efforts in sustainable building as approved by WA State Dept. of General Administration.

Policy Path: Executive

Name of State	Date (update)	Causes (Type)	Content
Arizona	2/11/2005 (11/26/2007)	Executive Order	Governor Janet Napolitano signed Executive Order #2005-05 requiring all state funded buildings to achieve LEED Silver certification. The Executive Order also requires newly constructed state-funded buildings to incorporate renewable energy. This makes the state the first governmental entity in Arizona to adopt a mandatory green building standard.
Colorado	7/15/2005 (11/26/2007)	Executive Order	Governor Owens signed Executive Order # D005 05 adopting LEED for Existing Buildings and incorporating LEED for New Construction practices for all state buildings. The order also creates a Colorado Greening Government Coordinating Council to develop and implement conservation policies.
Florida	7/13/2007 (11/26/2007)	Executive Order	Governor Crist issued Executive Order #07-126 adopting LEED-NC for any new building constructed for or by the State. New construction projects must strive for Platinum certification, the highest level possible. The Executive Order also required the Department of Management Services to implement LEED-EB across all buildings currently owned and operated by the department on behalf of client agencies. In addition, agencies and departments were instructed to only enter into new leasing agreements for office space that meets Energy Star building standards, unless no other viable alternative exists.
Maine	1/1/0001 (11/26/2007)	Executive Order	Governor John Baldacci issued an Executive Order in November 2003 directing all new or expanding state buildings to incorporate LEED guidelines provided that standards can be met on a cost-effective basis.

Name of State	Date (update)	Causes (Type)	Content
Massachusetts	Apr 18, 2007 (5/9/2008)	Executive Order	Governor Deval Patrick signed Executive Order 484, “Leading by Example – Clean Energy and Efficient Buildings.” The order instructed all agencies involved in the construction and major renovation projects of over 20,000 square feet to meet LEED certification as well as energy performance 20% better than the Massachusetts Energy Code, independent third- party commissioning, and outdoor water reduction requirements.
Michigan	4/22/2005 (11/26/2007)	Executive Order	Governor Granholm signed Executive Order #2005-4 requiring that all state-funded new construction and major renovation projects over $1,000,000 be built in accordance with LEED guidelines.
New Jersey	July 29, 2002 (3/14/2008)	Executive Order	Governor James E. McGreevey signed Executive Order #24 in July 2002 requiring all new school designs to incorporate LEED guidelines. The New Jersey Economic Schools Construction Corporation is encouraging the use of LEED but not requiring certification of new projects built under its $12 billion public school construction program.
New Mexico	1/16/2006 (11/26/2007)	Executive Order	Governor Bill Richardson signed Executive Order #06-001 requiring all public buildings over 15,000 ft2 to be LEED Silver certified.

Name of State	Date (update)	Causes (Type)	Content
New York	6/10/2001 (11/26/2007)	Executive Order	Governor Pataki issued Executive Order #111 in June 2001 encouraging but not requiring state projects to incorporate LEED Criteria and seek LEED Certification where possible. New York State Energy Research and Development Authority (NYSERDA) award incentives and technical assistance to help state agencies achieve the Executive Order objective. NYSERDA also offers incentives for owners and design teams of any privately owned and operated buildings in the state for energy efficiency measures and whole buildings that achieve a LEED rating with at least two points in Energy and Atmosphere Credit 1, Optimizing Energy Performance. NYSERDA's New Construction and Green Buildings Program offers a 10% increase on incentives for energy efficiency measures that reduce the use of electricity if the building achieves LEED plus 2 points in Energy and Atmosphere Credit 1 and a 25% increase in incentives if the building achieves 4 points in Energy and Atmosphere Credit 1. NYSERDA program funds up to $800,000 per building in Upstate New York and up to $1.5 million per project in New York City. NYSERDA will also buy down the interest rate on loans (4% below market rate) for energy efficiency measures and measures that assist in attaining a LEED credit. A low-interest loan may cover up to $1.5 million in energy and green measures.
Rhode Island	8/22/2005 (11/26/2007)	Executive Order	Governor Donald Carcieri signed Executive Order # 05-14 requiring all new constructions and renovations of public buildings to meet LEED Silver certification or higher.

Name of State	Date (update)	Causes (Type)	Content
Virginia	4/5/2007 (11/26/2007)	Executive Order	Gov. Tim Kaine signed Executive Order 48, "Energy Efficiency in State Government," which set out to reduce non-renewable energy purchases and increase overall energy savings. As part of instituting the energy saving goals, the order instructs all state agencies and institutions constructing state-owned facilities over 5,000 gross square feet in size, and renovations of such buildings valued at 50% of the assessed building value, shall be designed and constructed consistent with the energy performance standards at least as stringent as LEED or EPA's Energy Star rating. In addition, the order instructs the Commonwealth to encourage the private sector to adopt energy-efficient building standards by giving preference when leasing facilities for state use to facilities meeting LEED or Energy Star.
Wisconsin	4/11/2006 (11/26/2007)	Executive Order	Governor Jim Doyle signed Executive Order 145 Relating to Conserve Wisconsin and the Creation of High Performance Green Building Standards and Energy Conservation for State Facilities and Operations. The Executive Order directs the Department of Administration to establish and adopt guidelines based on LEED for New Construction and LEED for Existing Buildings within 6 months. Any project that requests LEED certification as part of the initial project request will be supported by Department of Administration.

Appendix D:

Green Building Strategies and Technologies

#	**Green Building Strategies and Technologies**
1	Additional lighting power reduction
2	Adhesives and Sealants must comply with SCAQMD (South Coast Air Quality Management District)
3	Adjustable blinds
4	Adjustable task lighting
5	Air barrier construction
6	Air barrier performance
7	Alternative-fuel fueling station
8	Architectural shading system
9	Automated faucet sensor
10	Automated time sweepers
11	Below-grade exterior insulation
12	Bicycle racks/ storage and shower rooms
13	Biofuel- Agricultural crops and waste
14	Biofuel- Animal waste and other organic waste
15	Biofuel- Landfill gas
16	Biofuel- Untreated wood waste, including mill residue
17	Bioreactors
18	Carbon dioxide sensors
19	Carpets and carpet cushions meeting the requirement of Carpet and Rug Institute Green Label Plus program
20	Carpool and vanpool preferred parking
21	Certified wood materials
22	Clerestory window
23	Cogeneration
24	Composite wood & Agrifiber products
25	Computer simulated model for energy
26	Computer simulation for lighting
27	Construction IAQ Management Plan
28	Containment and disposal of hazardous waste
29	Continuous metering equipment, electricity
30	Continuous metering equipment, electricity
31	Cost premium captured by GUC
32	Courtyard
33	Daylight dimming systems
34	Daylighting enhancement
35	Dedicated mechanical systems
36	Demand control ventilation
37	Disconnection of impervious areas

38	Domestic hot water efficiency
39	Earth dike
40	Efficient building envelope
41	Electronic blackout glazing
42	Energy net metering
43	Energy recovery units
44	Enhanced building systems commissioning
45	Enhanced building systems commissioning
46	Exhaust sufficiently where hazardous gases stored, creating negative pressure to adjacent rooms
47	Exterior fins
48	Fault detection and diagnostics
49	Fenestration performance
50	Fire suppression systems- Should not contain ozone depleting substances
51	Fritted glazing
52	Fundamental building systems commissioning
53	Fundamental building systems commissioning
54	Fundamental economizer performance
55	Geothermal electric system
56	Geothermal heating system
57	Hard surface flooring complaint with floor score standard- Ceramic flooring
58	Hard surface flooring complaint with floor score standard- Laminate flooring
59	Hard surface flooring complaint with Floor Score Standard- Linoleum flooring
60	Hard surface flooring complaint with Floor Score Standard- Rubber flooring
61	Hard surface flooring complaint with Floor Score Standard- Vinyl flooring
62	Hard surface flooring complaint with Floor Score Standard- Wall base
63	Hard surface flooring complaint with Floor Score Standard- Wood flooring
64	Heat recovery system
65	High albedo material
66	High efficiency chillers
67	Highly reflective energy star roof material
68	Improved design reducing heat islands
69	Improved design reducing light pollution
70	Increased landscape area
71	Increased vegetation- Large trees
72	Increased vegetation- Small trees, shrubs and non-invasive vines
73	Indirect evaporative cooling
74	Innovative wastewater technologies
75	In-situ remediation
76	Landscape- Drip irrigation system
77	Landscape- Moisture sensors
78	Landscape- Native drought resistant plants
79	Landscape- Native drought resistant plants
80	Landscape- Practical turf areas

81	Landscape- Xeriscaping
82	Light Pollution Reducing fixtures
83	Light shelves
84	Lighting controls
85	Lighting power density
86	Louvers
87	Low flow plumbing fixtures
88	Low-emitting and Fuel-efficient vehicles
89	Low-emitting and Fuel-efficient vehicles parking
90	Low-impact hydroelectric power systems
91	Manhole treatment device
92	Materials manufactured regionally
93	Materials with recycled content
94	Measurement and Verification- Corrective action, if desired results not achieved
95	Measurement and Verification plan
96	Mechanical equipment efficiency requirements
97	MERV of 13 or higher filters
98	MERV of 8 at each return air grill if permanent air handlers used during construction
99	Minimum Indoor Air Quality performance
100	Modulating condensing boilers
101	Mulching
102	Non-water fixture
103	Occupancy sensor controls
104	Opaque envelope performance
105	Operable windows
106	Optimize building form
107	Optimize building orientation
108	Paints and coating applied on interior must comply with Green Seal Standards (GS-11 and GC-03) and SCAQMD
109	Permanent entryway system
110	Permanent seeding
111	Pervious surfaces
112	Photo-responsive electric controls
113	Photovoltaic
114	Plug loads, appliance efficiency
115	Pre-Construction planning and construction management for lower impacts on site.
116	Premium economizer performance
117	Premium efficiency motors
118	Pre-Occupancy IAQ Management plan
119	Programmed master lighting control panel
120	Protect on-site absorptive material from moisture
121	Pump-and-treat
122	Rain garden
123	Rain water harvesting for reuse in irrigation

124	Rain water harvesting for reuse in sewage conveyance.
125	Rainwater cisterns
126	Rapidly renewable material- Bamboo flooring
127	Rapidly renewable material- Bamboo plywood
128	Rapidly renewable material- Bio-based paints
129	Rapidly renewable material- Cork flooring
130	Rapidly renewable material- Cotton batt insulation
131	Rapidly renewable material- Geotextile fabrics
132	Rapidly renewable material- Linoleum flooring
133	Rapidly renewable material- Soy-based form release agent
134	Rapidly renewable material- Soy-based insulation
135	Rapidly renewable material- Straw bales
136	Rapidly renewable material- Sunflower seed board panels
137	Rapidly renewable material- Wheatboard cabinetry
138	Rapidly renewable material- Wool carpeting
139	Recyclable material collection & storage
140	Reducing internal loads
141	Reflective Surfaces in interior
142	Refrigerant- Equipment having less than 0.5 pounds of refrigerant allowed.
143	Refrigerant- Free of CFC, has no or small ODP values, and small or no GWP values. (Natural refrigerants)
144	Refrigerant- Free of CFC, has Short environmental lifetimes, small ODP values, and small GWP values. For HVAC and fire suppression systems.
145	Refrigerant- Minimize leakage
146	Refrigerant- No use
147	Renewable energy certificate
148	Renewable energy power program
149	Renewable energy purchase
150	Retention ponds
151	Reuse of demolished building components (Non-Structural)
152	Reuse of demolished building components (Structural)
153	Roof- White PVC roof
154	Salvaged, refurbished, and reused materials
155	Sediment basin
156	Sediment trap
157	Shielding the exterior glass façade to reduce indoor light transmittance to the exterior
158	Shifting load to off-peak period
159	Silt fence
160	Skylight
161	Smoking allowed within building, but only at designated places with dedicated ventilation
162	Smoking prohibited within 25 feet of points of air exchange
163	Smoking prohibited within the building
164	Solar heating

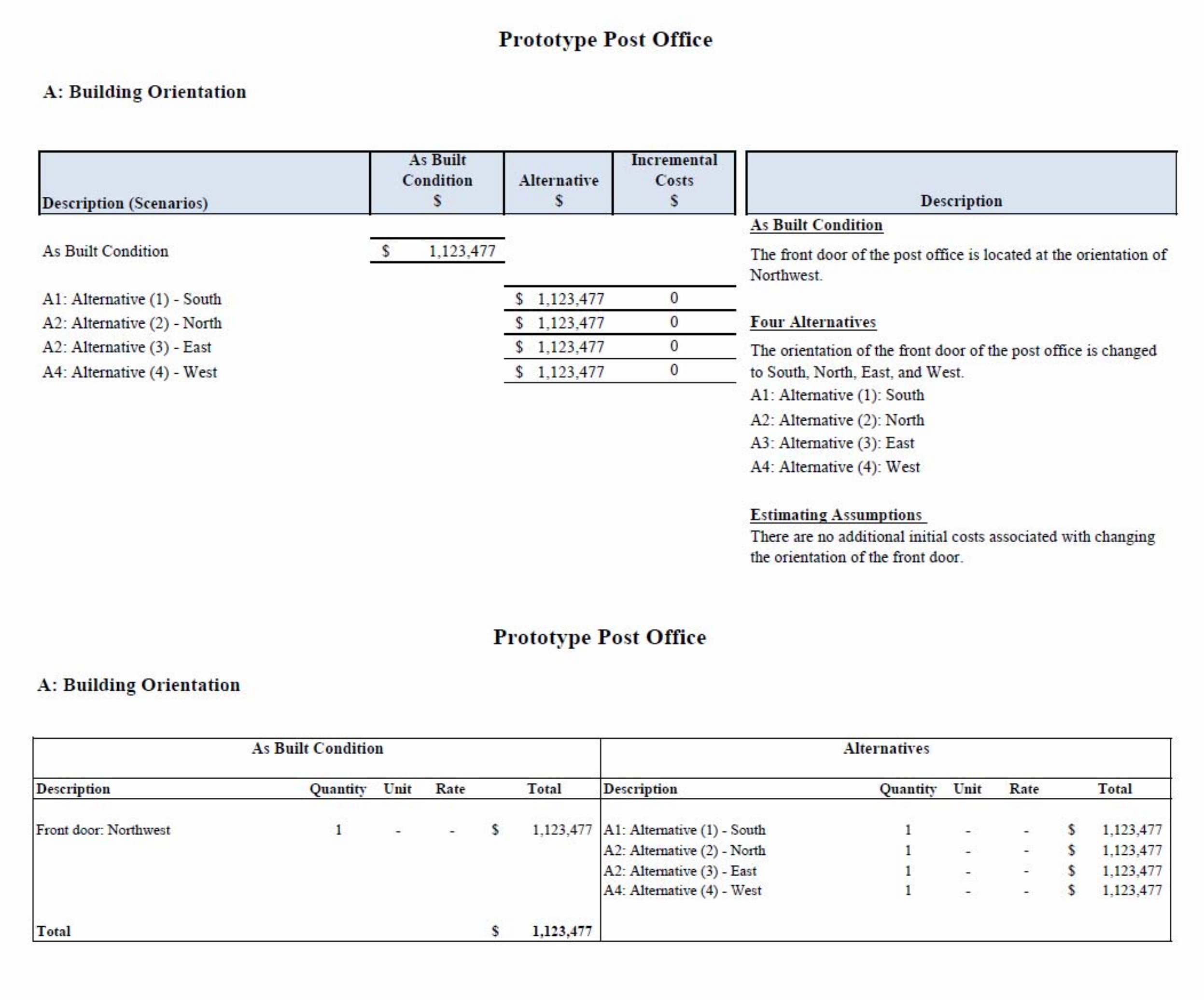
165	Solar hot water- Domestic
166	Solar power
167	Subsurface sand filter system
168	Supply air temperature reset (VAV)
169	Sustainable design strategies: Low impact development
170	Swales
171	Temporary seeding
172	Thermal and Humidity monitoring systems
173	Thermal comfort survey and corrective action
174	Transportation management plan
175	Use temporary ventilation units
176	Variable frequency drive cooling tower fans
177	Variable speed control
178	Vegetated filter strips
179	Vegetated roofs
180	Vegetated roofs- Ecologically diverse
181	Vehicle tracking
182	Ventilation- Mechanical ventilation meet requirements of section 4-7 of ASHRAE standard 62.1-2007
183	Ventilation- Mixed mode ventilation meets requirements of ASHRAE standard 62.1-2007
184	Ventilation- Naturally ventilated whole building as per ASHRAE standard 62.1-2007
185	Waste management plan
186	Water meter for irrigation
187	Water metering controls for use in house
188	Wave and tidal power system
189	Wetland
190	Wind energy

Source: (Pearce et al. 2009)

Appendix E:

Detail Estimating of Alternatives

Appendix E1: Orientation



Prototype Post Office

A: Building Orientation

Description (Scenarios)	As Built Condition $	Alternative $	Incremental Costs $
As Built Condition	$ 1,123,477		
A1: Alternative (1) - South		$ 1,123,477	0
A2: Alternative (2) - North		$ 1,123,477	0
A2: Alternative (3) - East		$ 1,123,477	0
A4: Alternative (4) - West		$ 1,123,477	0

Description

As Built Condition

The front door of the post office is located at the orientation of Northwest.

Four Alternatives

The orientation of the front door of the post office is changed to South, North, East, and West.

A1: Alternative (1): South

A2: Alternative (2): North

A3: Alternative (3): East

A4: Alternative (4): West

Estimating Assumptions

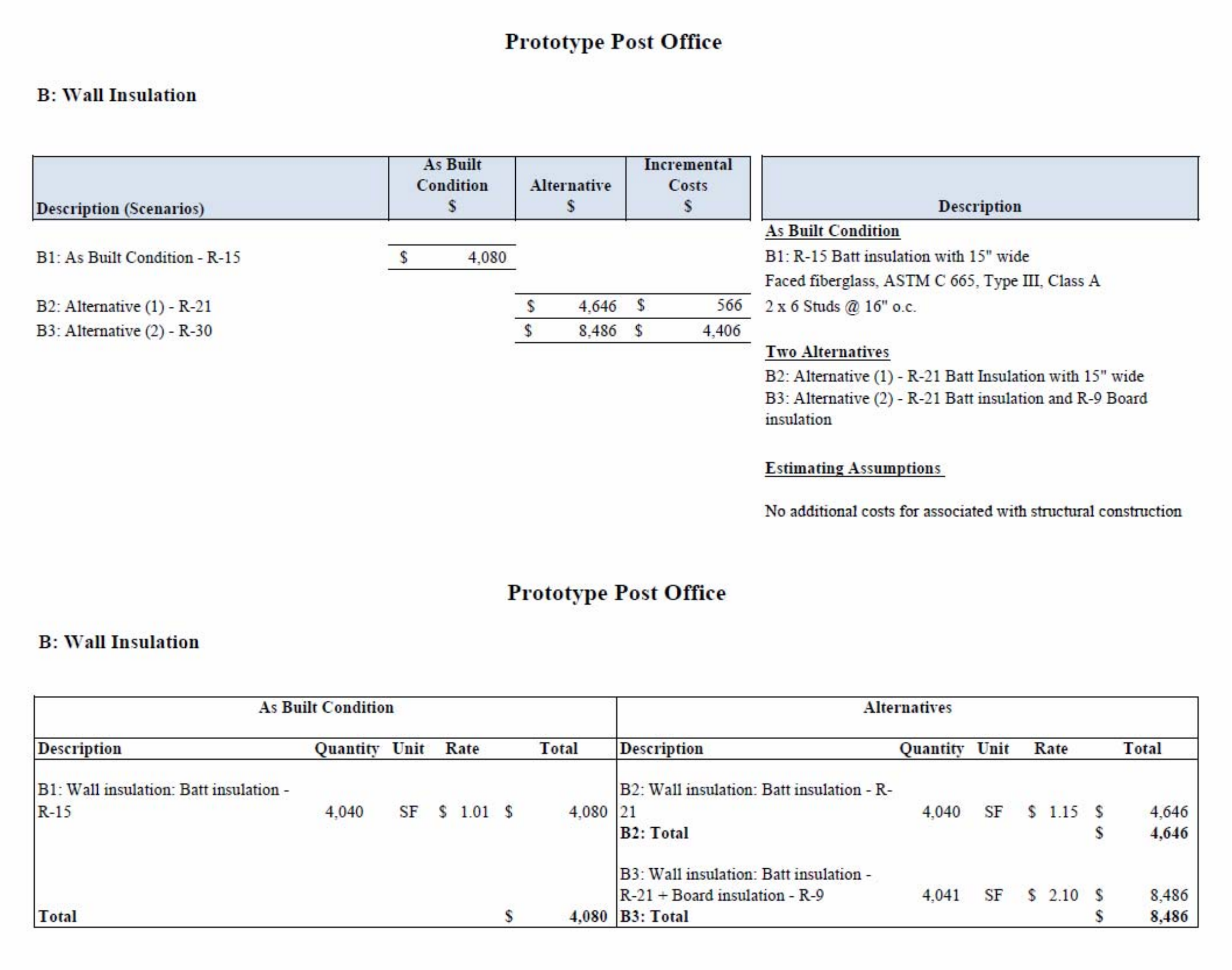
There are no additional initial costs associated with changing the orientation of the front door.

Prototype Post Office

A: Building Orientation

As Built Condition					Alternatives				
Description	**Quantity**	**Unit**	**Rate**	**Total**	**Description**	**Quantity**	**Unit**	**Rate**	**Total**
Front door: Northwest	1	-	-	$ 1,123,477	A1: Alternative (1) - South	1	-	-	$ 1,123,477
					A2: Alternative (2) - North	1	-	-	$ 1,123,477
					A2: Alternative (3) - East	1	-	-	$ 1,123,477
					A4: Alternative (4) - West	1	-	-	$ 1,123,477
Total				**$ 1,123,477**					

Appendix E2: Wall Insulation



Prototype Post Office

B: Wall Insulation

Description (Scenarios)	As Built Condition $	Alternative $	Incremental Costs $
B1: As Built Condition - R-15	$ 4,080		
B2: Alternative (1) - R-21		$ 4,646	$ 566
B3: Alternative (2) - R-30		$ 8,486	$ 4,406

Description

As Built Condition

B1: R-15 Batt insulation with 15" wide
Faced fiberglass, ASTM C 665, Type III, Class A
2 x 6 Studs @ 16" o.c.

Two Alternatives

B2: Alternative (1) - R-21 Batt Insulation with 15" wide
B3: Alternative (2) - R-21 Batt insulation and R-9 Board insulation

Estimating Assumptions

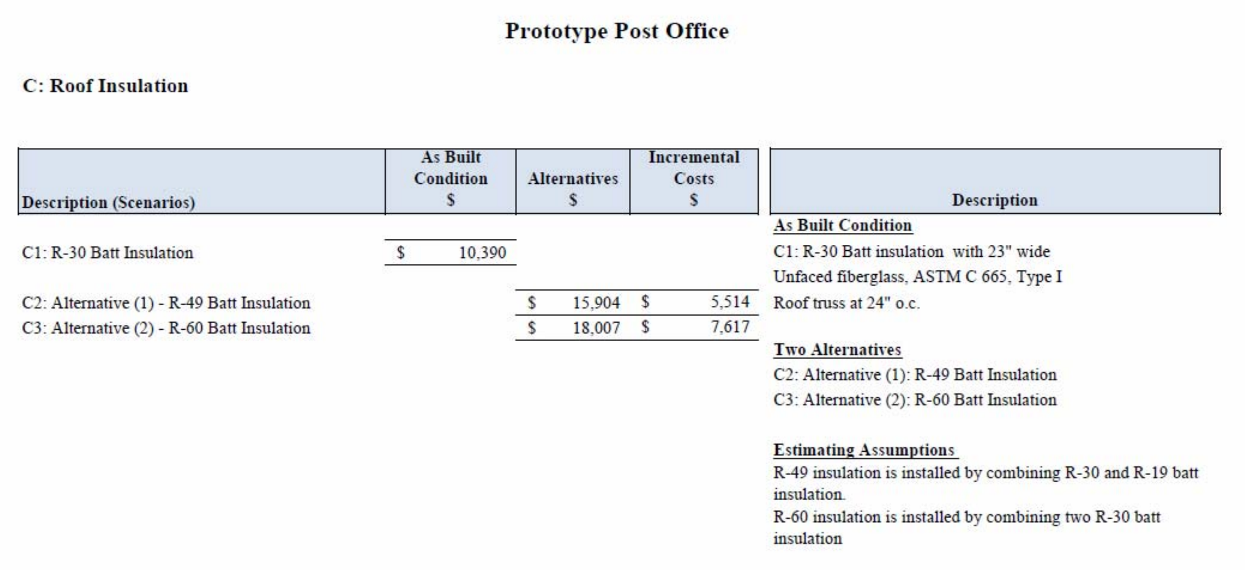
No additional costs for associated with structural construction

Prototype Post Office

B: Wall Insulation

As Built Condition					Alternatives				
Description	**Quantity**	**Unit**	**Rate**	**Total**	**Description**	**Quantity**	**Unit**	**Rate**	**Total**
B1: Wall insulation: Batt insulation - R-15	4,040	SF	$ 1.01	$ 4,080	B2: Wall insulation: Batt insulation - R-21	4,040	SF	$ 1.15	$ 4,646
					B2: Total				$ **4,646**
					B3: Wall insulation: Batt insulation - R-21 + Board insulation - R-9	4,041	SF	$ 2.10	$ 8,486
Total				$ **4,080**	**B3: Total**				$ **8,486**

Appendix E3: Roof Insulation



Prototype Post Office

C: Roof Insulation

Description (Scenarios)	As Built Condition $	Alternatives $	Incremental Costs $
C1: R-30 Batt Insulation	$ 10,390		
C2: Alternative (1) - R-49 Batt Insulation		$ 15,904	$ 5,514
C3: Alternative (2) - R-60 Batt Insulation		$ 18,007	$ 7,617

Description

As Built Condition

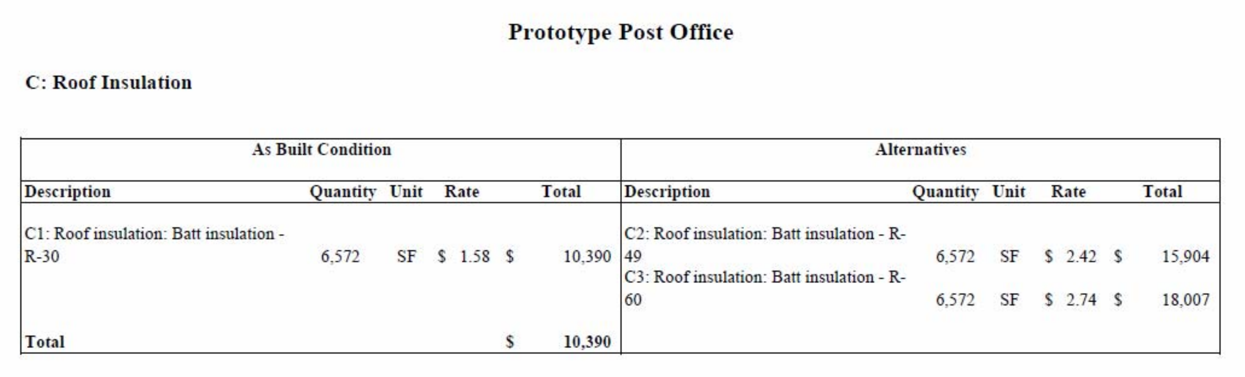
C1: R-30 Batt insulation with 23" wide Unfaced fiberglass, ASTM C 665, Type I Roof truss at 24" o.c.

Two Alternatives

C2: Alternative (1): R-49 Batt Insulation
C3: Alternative (2): R-60 Batt Insulation

Estimating Assumptions

R-49 insulation is installed by combining R-30 and R-19 batt insulation.
R-60 insulation is installed by combining two R-30 batt insulation

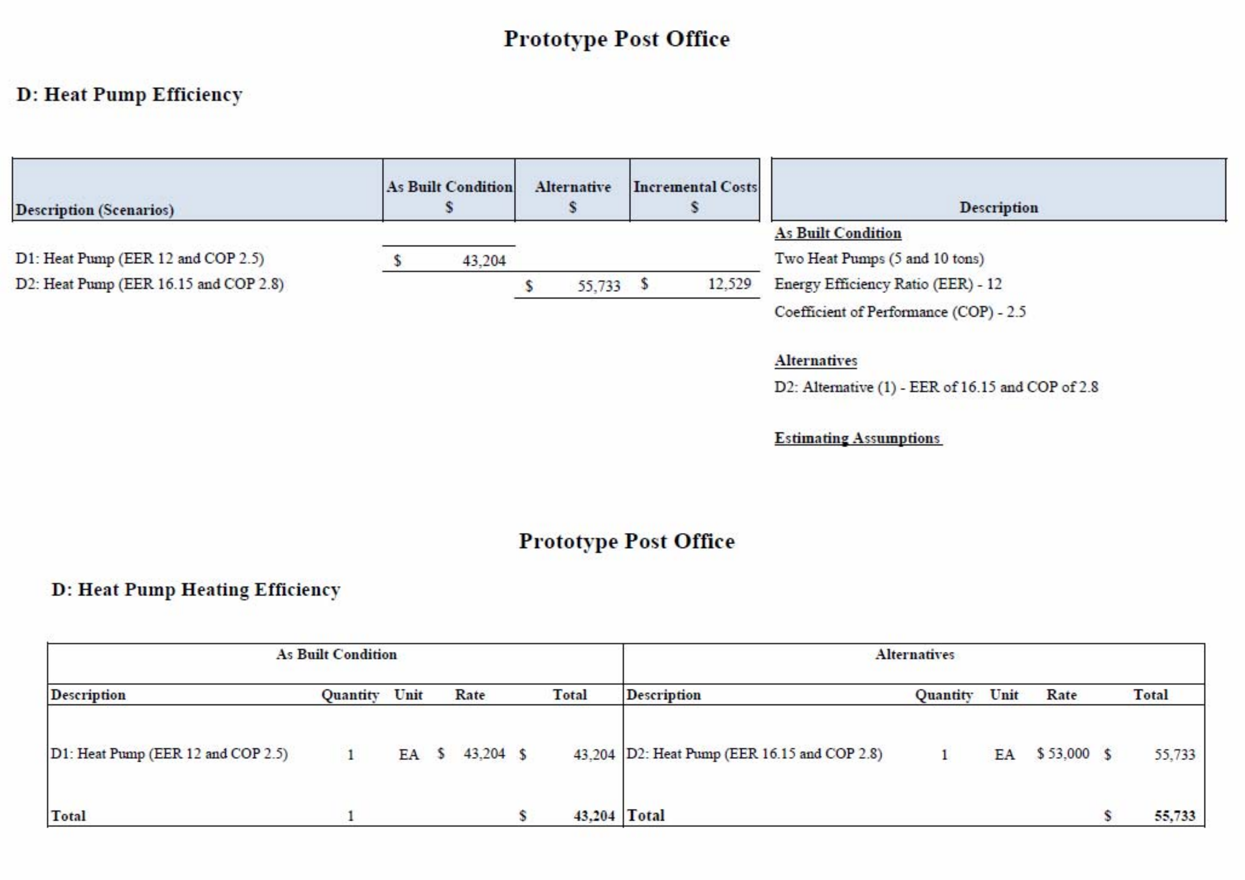


Prototype Post Office

C: Roof Insulation

As Built Condition					Alternatives				
Description	Quantity	Unit	Rate	Total	Description	Quantity	Unit	Rate	Total
C1: Roof insulation: Batt insulation - R-30	6,572	SF	$ 1.58	$ 10,390	C2: Roof insulation: Batt insulation - R-49	6,572	SF	$ 2.42	$ 15,904
					C3: Roof insulation: Batt insulation - R-60	6,572	SF	$ 2.74	$ 18,007
Total				**$ 10,390**					

Appendix E4: Efficiency of HVAC systems



Prototype Post Office

D: Heat Pump Efficiency

Description (Scenarios)	As Built Condition $	Alternative $	Incremental Costs $
D1: Heat Pump (EER 12 and COP 2.5)	$ 43,204		
D2: Heat Pump (EER 16.15 and COP 2.8)		$ 55,733	$ 12,529

Description

As Built Condition

Two Heat Pumps (5 and 10 tons)
Energy Efficiency Ratio (EER) - 12
Coefficient of Performance (COP) - 2.5

Alternatives

D2: Alternative (1) - EER of 16.15 and COP of 2.8

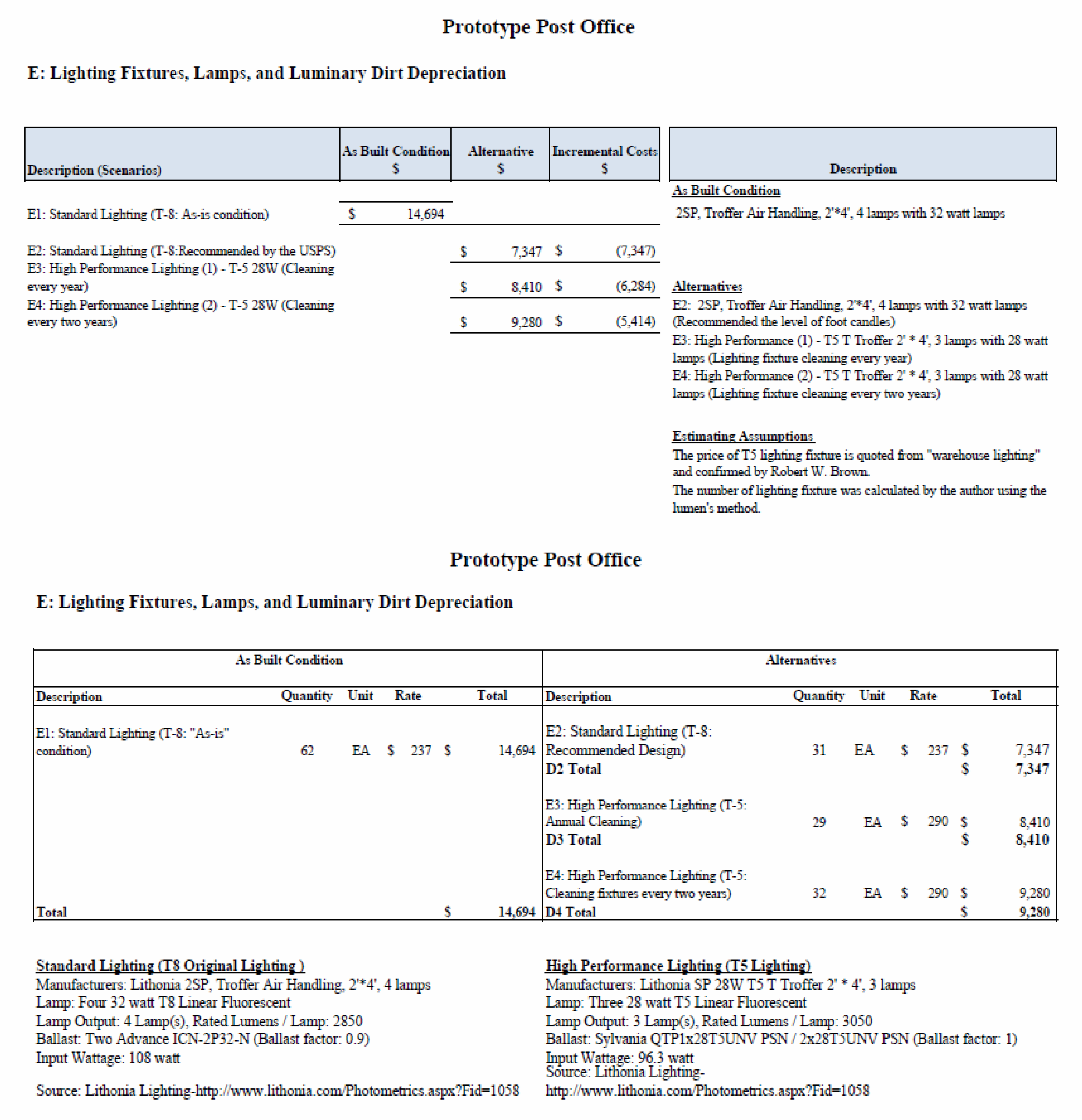
Estimating Assumptions

Prototype Post Office

D: Heat Pump Heating Efficiency

As Built Condition					Alternatives				
Description	**Quantity**	**Unit**	**Rate**	**Total**	**Description**	**Quantity**	**Unit**	**Rate**	**Total**
D1: Heat Pump (EER 12 and COP 2.5)	1	EA	$ 43,204	$ 43,204	D2: Heat Pump (EER 16.15 and COP 2.8)	1	EA	$ 53,000	$ 55,733
Total	1			$ **43,204**	**Total**				$ **55,733**

Appendix E5: Lighting types and maintenance



Prototype Post Office

E: Lighting Fixtures, Lamps, and Luminary Dirt Depreciation

Description (Scenarios)	As Built Condition $	Alternative $	Incremental Costs $
E1: Standard Lighting (T-8: As-is condition)	$ 14,694		
E2: Standard Lighting (T-8:Recommended by the USPS)		$ 7,347	$ (7,347)
E3: High Performance Lighting (1) - T-5 28W (Cleaning every year)		$ 8,410	$ (6,284)
E4: High Performance Lighting (2) - T-5 28W (Cleaning every two years)		$ 9,280	$ (5,414)

Description

As Built Condition

2SP, Troffer Air Handling, 2'*4', 4 lamps with 32 watt lamps

Alternatives

E2: 2SP, Troffer Air Handling, 2'*4', 4 lamps with 32 watt lamps (Recommended the level of foot candles)

E3: High Performance (1) - T5 T Troffer 2' * 4', 3 lamps with 28 watt lamps (Lighting fixture cleaning every year)

E4: High Performance (2) - T5 T Troffer 2' * 4', 3 lamps with 28 watt lamps (Lighting fixture cleaning every two years)

Estimating Assumptions

The price of T5 lighting fixture is quoted from "warehouse lighting" and confirmed by Robert W. Brown.

The number of lighting fixture was calculated by the author using the lumen's method.

Prototype Post Office

E: Lighting Fixtures, Lamps, and Luminary Dirt Depreciation

As Built Condition					Alternatives				
Description	**Quantity**	**Unit**	**Rate**	**Total**	**Description**	**Quantity**	**Unit**	**Rate**	**Total**
E1: Standard Lighting (T-8: "As-is" condition)	62	EA	$ 237	$ 14,694	E2: Standard Lighting (T-8: Recommended Design)	31	EA	$ 237	$ 7,347
					D2 Total				**$ 7,347**
					E3: High Performance Lighting (T-5: Annual Cleaning)	29	EA	$ 290	$ 8,410
					D3 Total				**$ 8,410**
					E4: High Performance Lighting (T-5: Cleaning fixtures every two years)	32	EA	$ 290	$ 9,280
Total				$ 14,694	**D4 Total**				$ 9,280

Standard Lighting (T8 Original Lighting)
Manufacturers: Lithonia 2SP, Troffer Air Handling, 2'*4', 4 lamps
Lamp: Four 32 watt T8 Linear Fluorescent
Lamp Output: 4 Lamp(s), Rated Lumens / Lamp: 2850
Ballast: Two Advance ICN-2P32-N (Ballast factor: 0.9)
Input Wattage: 108 watt

Source: Lithonia Lighting-http://www.lithonia.com/Photometrics.aspx?Fid=1058

High Performance Lighting (T5 Lighting)
Manufacturers: Lithonia SP 28W T5 T Troffer 2' * 4', 3 lamps
Lamp: Three 28 watt T5 Linear Fluorescent
Lamp Output: 3 Lamp(s), Rated Lumens / Lamp: 3050
Ballast: Sylvania QTP1x28T5UNV PSN / 2x28T5UNV PSN (Ballast factor: 1)
Input Wattage: 96.3 watt
Source: Lithonia Lighting-
http://www.lithonia.com/Photometrics.aspx?Fid=1058

Appendix F:

Scenarios, Initial Cost Premiums, Maintenance Costs, Annual Energy Consumption, Annual Energy Costs, and Repair and Replacement Costs

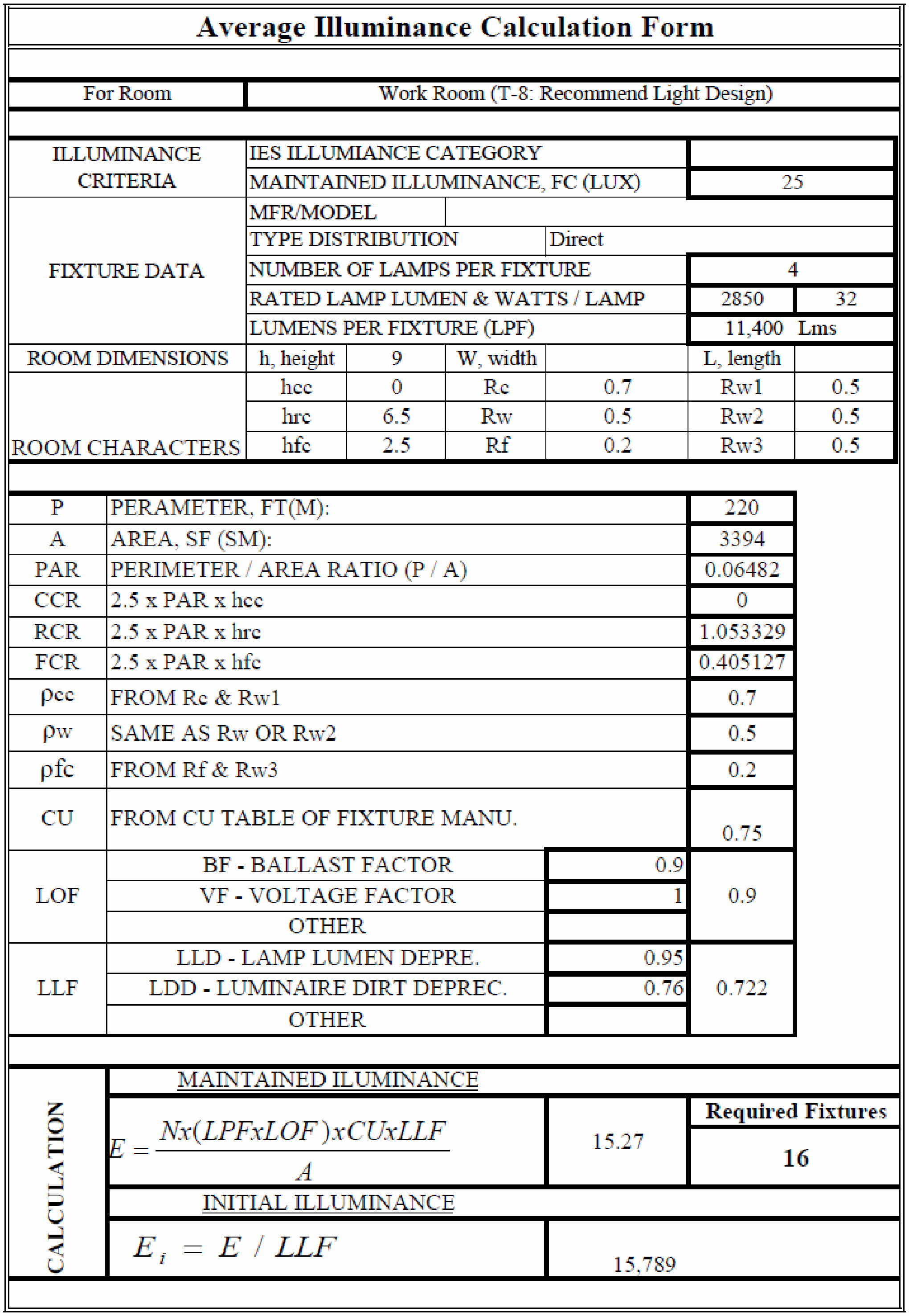
ID	Orientation	Wall Insulation	Roof Insulation	Efficiency of Heat Pump Systems	Initial Cost Premiums	Incremental Unit Costs	Maintenance Costs	Annual Energy Consumption KWh * 1000	Annual Energy Costs	Annual Energy Savings	Repair and Replacement Costs
1	South	R - 15	R - 30	Heat Pump A	$ -	$ -	$ 654	121.030	$ 13,313	$ -	$ 5,368
2	South	R - 15	R - 30	Heat Pump B	$ 12,529	$ 2.03	$ 654	114.610	$ 12,607	$ 706	$ 5,904
3	South	R - 15	R - 49	Heat Pump A	$ 5,514	$ 0.90	$ 654	120.740	$ 13,281	$ 32	$ 5,368
4	South	R - 15	R - 49	Heat Pump B	$ 18,043	$ 2.93	$ 654	114.310	$ 12,574	$ 739	$ 5,904
5	South	R - 15	R - 60	Heat Pump A	$ 7,617	$ 1.24	$ 654	120.620	$ 13,268	$ 45	$ 5,368
6	South	R - 15	R - 60	Heat Pump B	$ 20,146	$ 3.27	$ 654	114.190	$ 12,561	$ 752	$ 5,904
7	South	R - 21	R - 30	Heat Pump A	$ 566	$ 0.09	$ 654	120.280	$ 13,231	$ 82	$ 5,368
8	South	R - 21	R - 30	Heat Pump B	$ 13,095	$ 2.13	$ 654	113.870	$ 12,526	$ 788	$ 5,904
9	South	R - 21	R - 49	Heat Pump A	$ 6,080	$ 0.99	$ 654	119.990	$ 13,199	$ 114	$ 5,368
10	South	R - 21	R - 49	Heat Pump B	$ 18,609	$ 3.02	$ 654	113.570	$ 12,493	$ 821	$ 5,904
11	South	R - 21	R - 60	Heat Pump A	$ 8,183	$ 1.33	$ 654	119.870	$ 13,186	$ 128	$ 5,368
12	South	R - 21	R - 60	Heat Pump B	$ 20,712	$ 3.36	$ 654	113.440	$ 12,478	$ 835	$ 5,904
13	South	R - 30	R - 30	Heat Pump A	$ 4,406	$ 0.72	$ 654	118.960	$ 13,086	$ 228	$ 5,368
14	South	R - 30	R - 30	Heat Pump B	$ 16,935	$ 2.75	$ 654	112.560	$ 12,382	$ 932	$ 5,904
15	South	R - 30	R - 49	Heat Pump A	$ 9,920	$ 1.61	$ 654	118.670	$ 13,054	$ 260	$ 5,368
16	South	R - 30	R - 49	Heat Pump B	$ 22,449	$ 3.64	$ 654	112.250	$ 12,348	$ 966	$ 5,904
17	South	R - 30	R - 60	Heat Pump A	$ 12,023	$ 1.95	$ 654	118.540	$ 13,039	$ 274	$ 5,368
18	South	R - 30	R - 60	Heat Pump B	$ 24,552	$ 3.99	$ 654	112.130	$ 12,334	$ 979	$ 5,904
19	North	R - 15	R - 30	Heat Pump A	$ -	$ -	$ 654	121.890	$ 13,408	$ (95)	$ 5,368
20	North	R - 15	R - 30	Heat Pump B	$ 12,529	$ 2.03	$ 654	115.940	$ 12,753	$ 560	$ 5,904
21	North	R - 15	R - 49	Heat Pump A	$ 5,514	$ 0.90	$ 654	121.600	$ 13,376	$ (63)	$ 5,368
22	North	R - 15	R - 49	Heat Pump B	$ 18,043	$ 2.93	$ 654	115.640	$ 12,720	$ 593	$ 5,904
23	North	R - 15	R - 60	Heat Pump A	$ 7,617	$ 1.24	$ 654	121.470	$ 13,362	$ (48)	$ 5,368
24	North	R - 15	R - 60	Heat Pump B	$ 20,146	$ 3.27	$ 654	115.510	$ 12,706	$ 607	$ 5,904
25	North	R - 21	R - 30	Heat Pump A	$ 566	$ 0.09	$ 654	121.160	$ 13,328	$ (14)	$ 5,368
26	North	R - 21	R - 30	Heat Pump B	$ 13,095	$ 2.13	$ 654	115.210	$ 12,673	$ 640	$ 5,904
27	North	R - 21	R - 49	Heat Pump A	$ 6,080	$ 0.99	$ 654	120.860	$ 13,295	$ 19	$ 5,368
28	North	R - 21	R - 49	Heat Pump B	$ 18,609	$ 3.02	$ 654	114.910	$ 12,640	$ 673	$ 5,904
29	North	R - 21	R - 60	Heat Pump A	$ 8,183	$ 1.33	$ 654	120.740	$ 13,281	$ 32	$ 5,368
30	North	R - 21	R - 60	Heat Pump B	$ 20,712	$ 3.36	$ 654	114.780	$ 12,626	$ 688	$ 5,904
31	North	R - 30	R - 30	Heat Pump A	$ 4,406	$ 0.72	$ 654	119.880	$ 13,187	$ 127	$ 5,368
32	North	R - 30	R - 30	Heat Pump B	$ 16,935	$ 2.75	$ 654	113.930	$ 12,532	$ 781	$ 5,904

ID	Orientation	Wall Insulation	Roof Insulation	Efficiency of Heat Pump Systems	Initial Cost Premiums	Incremental Unit Costs	Maintenance Costs	Annual Energy Consumption KWh * 1000	Annual Energy Costs	Annual Energy Savings	Repair and Replacement Costs
33	North	R - 30	R - 49	Heat Pump A	$ 9,920	$ 1.61	$ 654	119.580	$ 13,154	$ 159	$ 5,368
34	North	R - 30	R - 49	Heat Pump B	$ 22,449	$ 3.64	$ 654	113.620	$ 12,498	$ 815	$ 5,904
35	North	R - 30	R - 60	Heat Pump A	$ 12,023	$ 1.95	$ 654	119.450	$ 13,140	$ 174	$ 5,368
36	North	R - 30	R - 60	Heat Pump B	$ 24,552	$ 3.99	$ 654	113.490	$ 12,484	$ 829	$ 5,904
37	West	R - 15	R - 30	Heat Pump A	$ -	$ -	$ 654	121.560	$ 13,372	$ (58)	$ 5,368
38	West	R - 15	R - 30	Heat Pump B	$ 12,529	$ 2.03	$ 654	115.230	$ 12,675	$ 638	$ 5,904
39	West	R - 15	R - 49	Heat Pump A	$ 5,514	$ 0.90	$ 654	121.260	$ 13,339	$ (25)	$ 5,368
40	West	R - 15	R - 49	Heat Pump B	$ 18,043	$ 2.93	$ 654	114.930	$ 12,642	$ 671	$ 5,904
41	West	R - 15	R - 60	Heat Pump A	$ 7,617	$ 1.24	$ 654	120.140	$ 13,215	$ 98	$ 5,368
42	West	R - 15	R - 60	Heat Pump B	$ 20,146	$ 3.27	$ 654	114.810	$ 12,629	$ 684	$ 5,904
43	West	R - 21	R - 30	Heat Pump A	$ 566	$ 0.09	$ 654	120.850	$ 13,294	$ 20	$ 5,368
44	West	R - 21	R - 30	Heat Pump B	$ 13,095	$ 2.13	$ 654	114.520	$ 12,597	$ 716	$ 5,904
45	West	R - 21	R - 49	Heat Pump A	$ 6,080	$ 0.99	$ 654	120.550	$ 13,261	$ 53	$ 5,368
46	West	R - 21	R - 49	Heat Pump B	$ 18,609	$ 3.02	$ 654	114.220	$ 12,564	$ 749	$ 5,904
47	West	R - 21	R - 60	Heat Pump A	$ 8,183	$ 1.33	$ 654	120.430	$ 13,247	$ 66	$ 5,368
48	West	R - 21	R - 60	Heat Pump B	$ 20,712	$ 3.36	$ 654	114.100	$ 12,551	$ 762	$ 5,904
49	West	R - 30	R - 30	Heat Pump A	$ 4,406	$ 0.72	$ 654	119.610	$ 13,157	$ 156	$ 5,368
50	West	R - 30	R - 30	Heat Pump B	$ 16,935	$ 2.75	$ 654	113.280	$ 12,461	$ 852	$ 5,904
51	West	R - 30	R - 49	Heat Pump A	$ 9,920	$ 1.61	$ 654	119.310	$ 13,124	$ 189	$ 5,368
52	West	R - 30	R - 49	Heat Pump B	$ 22,449	$ 3.64	$ 654	112.980	$ 12,428	$ 885	$ 5,904
53	West	R - 30	R - 60	Heat Pump A	$ 12,023	$ 1.95	$ 654	119.190	$ 13,111	$ 202	$ 5,368
54	West	R - 30	R - 60	Heat Pump B	$ 24,552	$ 3.99	$ 654	112.850	$ 12,414	$ 900	$ 5,904
55	East	R - 15	R - 30	Heat Pump A	$ -	$ -	$ 654	121.07	$ 13,318	$ (4)	$ 5,368
56	East	R - 15	R - 30	Heat Pump B	$ 12,529	$ 2.03	$ 654	114.990	$ 12,649	$ 664	$ 5,904
57	East	R - 15	R - 49	Heat Pump A	$ 5,514	$ 0.90	$ 654	120.77	$ 13,285	$ 29	$ 5,368
58	East	R - 15	R - 49	Heat Pump B	$ 18,043	$ 2.93	$ 654	114.680	$ 12,615	$ 698	$ 5,904
59	East	R - 15	R - 60	Heat Pump A	$ 7,617	$ 1.24	$ 654	120.65	$ 13,272	$ 42	$ 5,368
60	East	R - 15	R - 60	Heat Pump B	$ 20,146	$ 3.27	$ 654	114.550	$ 12,601	$ 713	$ 5,904
61	East	R - 21	R - 30	Heat Pump A	$ 566	$ 0.09	$ 654	120.33	$ 13,236	$ 77	$ 5,368
62	East	R - 21	R - 30	Heat Pump B	$ 13,095	$ 2.13	$ 654	114.250	$ 12,568	$ 746	$ 5,904
63	East	R - 21	R - 49	Heat Pump A	$ 6,080	$ 0.99	$ 654	120.03	$ 13,203	$ 110	$ 5,368
64	East	R - 21	R - 49	Heat Pump B	$ 18,609	$ 3.02	$ 654	113.940	$ 12,533	$ 780	$ 5,904

ID	Orientation	Wall Insulation	Roof Insulation	Efficiency of Heat Pump Systems	Initial Cost Premiums	Incremental Unit Costs	Maintenance Costs	Annual Energy Consumption KWh * 1000	Annual Energy Costs	Annual Energy Savings	Repair and Replacement Costs
65	East	R - 21	R - 60	Heat Pump A	$ 8,183	$ 1.33	$ 654	119.91	$ 13,190	$ 123	$ 5,368
66	East	R - 21	R - 60	Heat Pump B	$ 20,712	$ 3.36	$ 654	113.810	$ 12,519	$ 794	$ 5,904
67	East	R - 30	R - 30	Heat Pump A	$ 4,406	$ 0.72	$ 654	119.03	$ 13,093	$ 220	$ 5,368
68	East	R - 30	R - 30	Heat Pump B	$ 16,935	$ 2.75	$ 654	112.950	$ 12,425	$ 889	$ 5,904
69	East	R - 30	R - 49	Heat Pump A	$ 9,920	$ 1.61	$ 654	118.73	$ 13,060	$ 253	$ 5,368
70	East	R - 30	R - 49	Heat Pump B	$ 22,449	$ 3.64	$ 654	113.640	$ 12,500	$ 813	$ 5,904
71	East	R - 30	R - 60	Heat Pump A	$ 12,023	$ 1.95	$ 654	118.61	$ 13,047	$ 266	$ 5,368
72	East	R - 30	R - 60	Heat Pump B	$ 24,552	$ 3.99	$ 654	112.510	$ 12,376	$ 937	$ 5,904

Appendix G:

Illumination Calculation for Spaces



Average Illuminance Calculation Form

For Room	Work Room (T-8: Recommend Light Design)					
ILLUMINANCE CRITERIA	IES ILLUMIANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				25	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION		Direct			
	NUMBER OF LAMPS PER FIXTURE				4	
	RATED LAMP LUMEN & WATTS / LAMP				2850	32
	LUMENS PER FIXTURE (LPF)				11,400 Lms	
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		220
A	AREA, SF (SM):		3394
PAR	PERIMETER / AREA RATIO (P / A)		0.06482
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		1.053329
FCR	2.5 x PAR x hfc		0.405127
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.75
LOF	BF - BALLAST FACTOR	0.9	0.9
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.722
	LDD - LUMINAIRE DIRT DEPREC.	0.76	
	OTHER		

CALCULATION

MAINTAINED ILUMINANCE

$$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$$

15.27

Required Fixtures

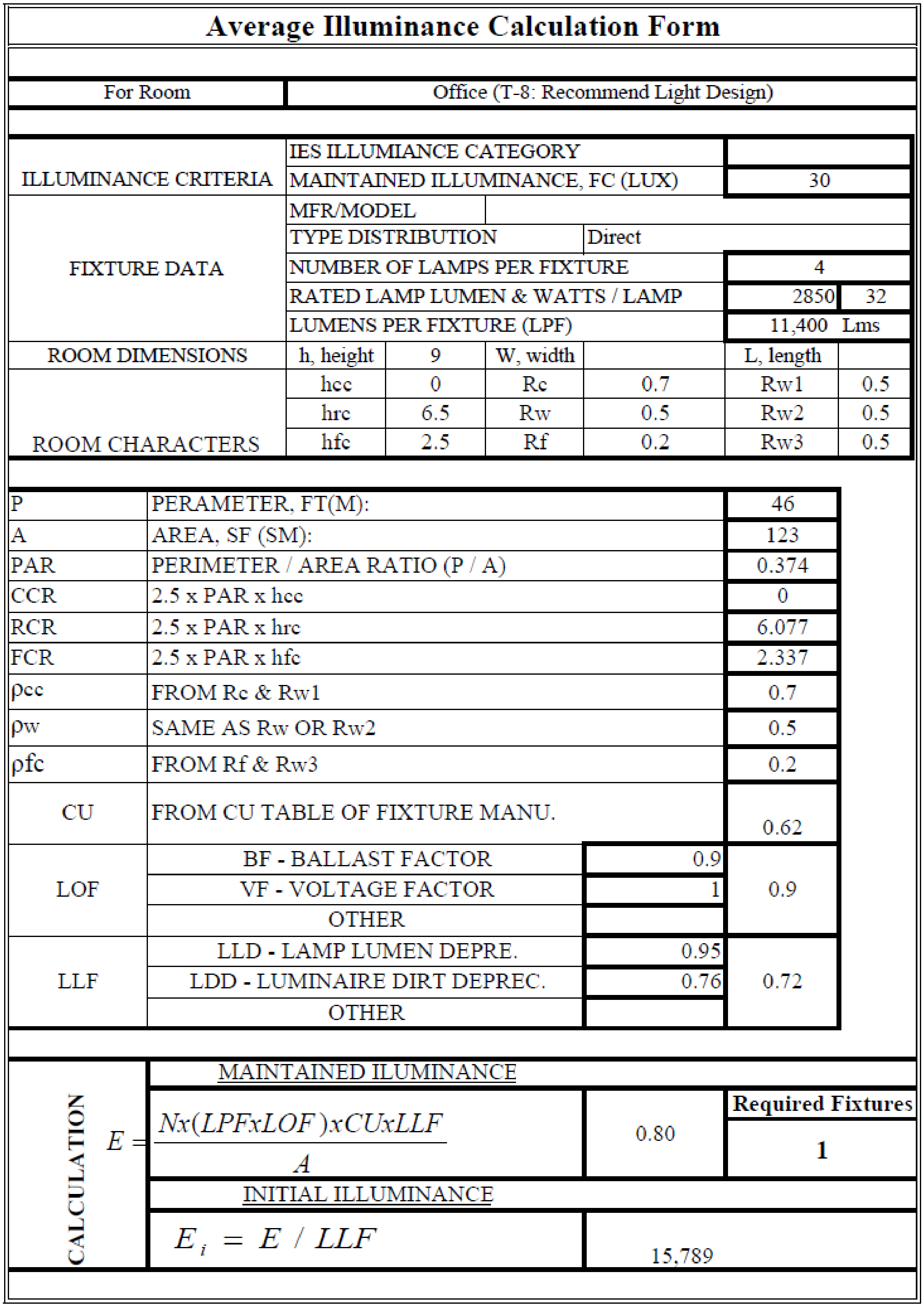
16

INITIAL ILLUMINANCE

$$E_i = E / LLF$$

15,789

Appendix G1 Illuminance calculation for work room (T-8: recommended light design)



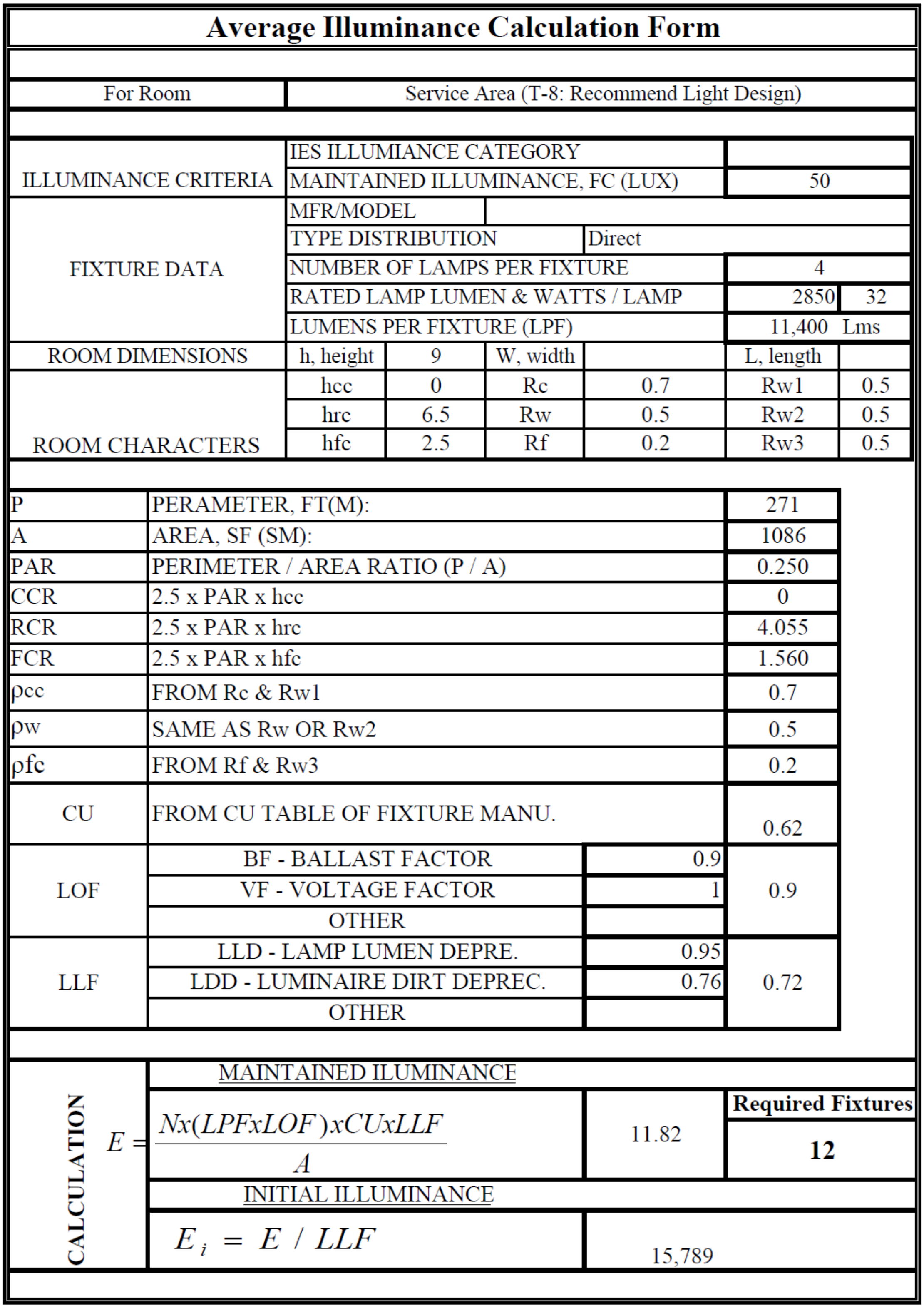
Average Illuminance Calculation Form

For Room	Office (T-8: Recommend Light Design)					
ILLUMINANCE CRITERIA	IES ILLUMIANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				30	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION			Direct		
	NUMBER OF LAMPS PER FIXTURE				4	
	RATED LAMP LUMEN & WATTS / LAMP				2850	32
	LUMENS PER FIXTURE (LPF)				11,400 Lms	
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		46
A	AREA, SF (SM):		123
PAR	PERIMETER / AREA RATIO (P / A)		0.374
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		6.077
FCR	2.5 x PAR x hfc		2.337
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.62
LOF	BF - BALLAST FACTOR	0.9	0.9
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.72
	LDD - LUMINAIRE DIRT DEPREC.	0.76	
	OTHER		

CALCULATION	MAINTAINED ILUMINANCE		
	$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$	0.80	**Required Fixtures** **1**
	INITIAL ILLUMINANCE		
	$E_i = E / LLF$	15,789	

Appendix G2 Illuminance calculation for office (T-8: recommended light design)



Average Illuminance Calculation Form

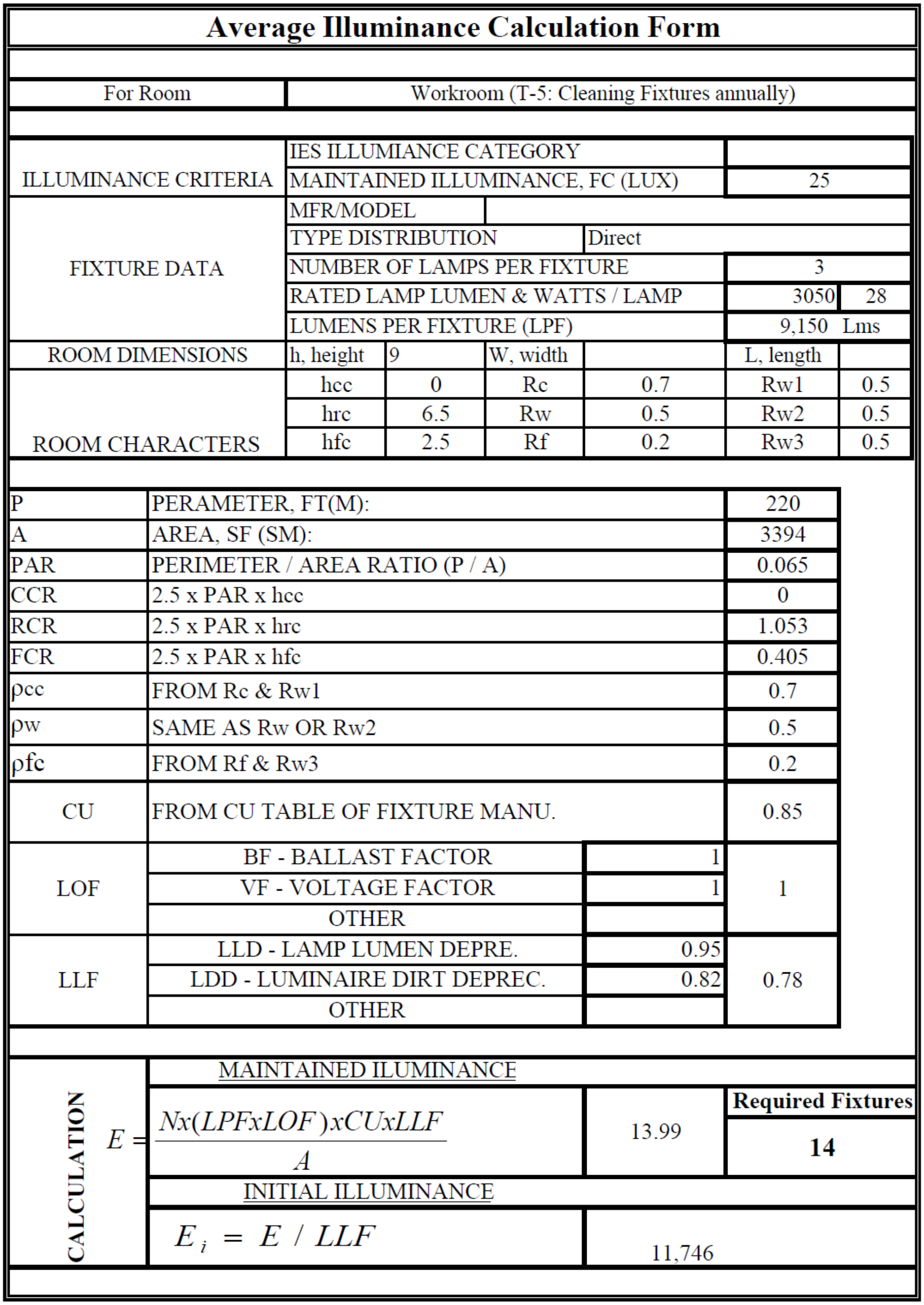
For Room	Service Area (T-8: Recommend Light Design)

ILLUMINANCE CRITERIA	IES ILLUMIANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				50	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION		Direct			
	NUMBER OF LAMPS PER FIXTURE				4	
	RATED LAMP LUMEN & WATTS / LAMP				2850	32
	LUMENS PER FIXTURE (LPF)				11,400	Lms
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		271
A	AREA, SF (SM):		1086
PAR	PERIMETER / AREA RATIO (P / A)		0.250
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		4.055
FCR	2.5 x PAR x hfc		1.560
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.62
LOF	BF - BALLAST FACTOR	0.9	0.9
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.72
	LDD - LUMINAIRE DIRT DEPREC.	0.76	
	OTHER		

CALCULATION	MAINTAINED ILUMINANCE		
	$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$	11.82	**Required Fixtures** **12**
	INITIAL ILLUMINANCE		
	$E_i = E / LLF$	15,789	

Appendix G3 Illuminance calculation for service area (T-8: recommended light design)



Average Illuminance Calculation Form

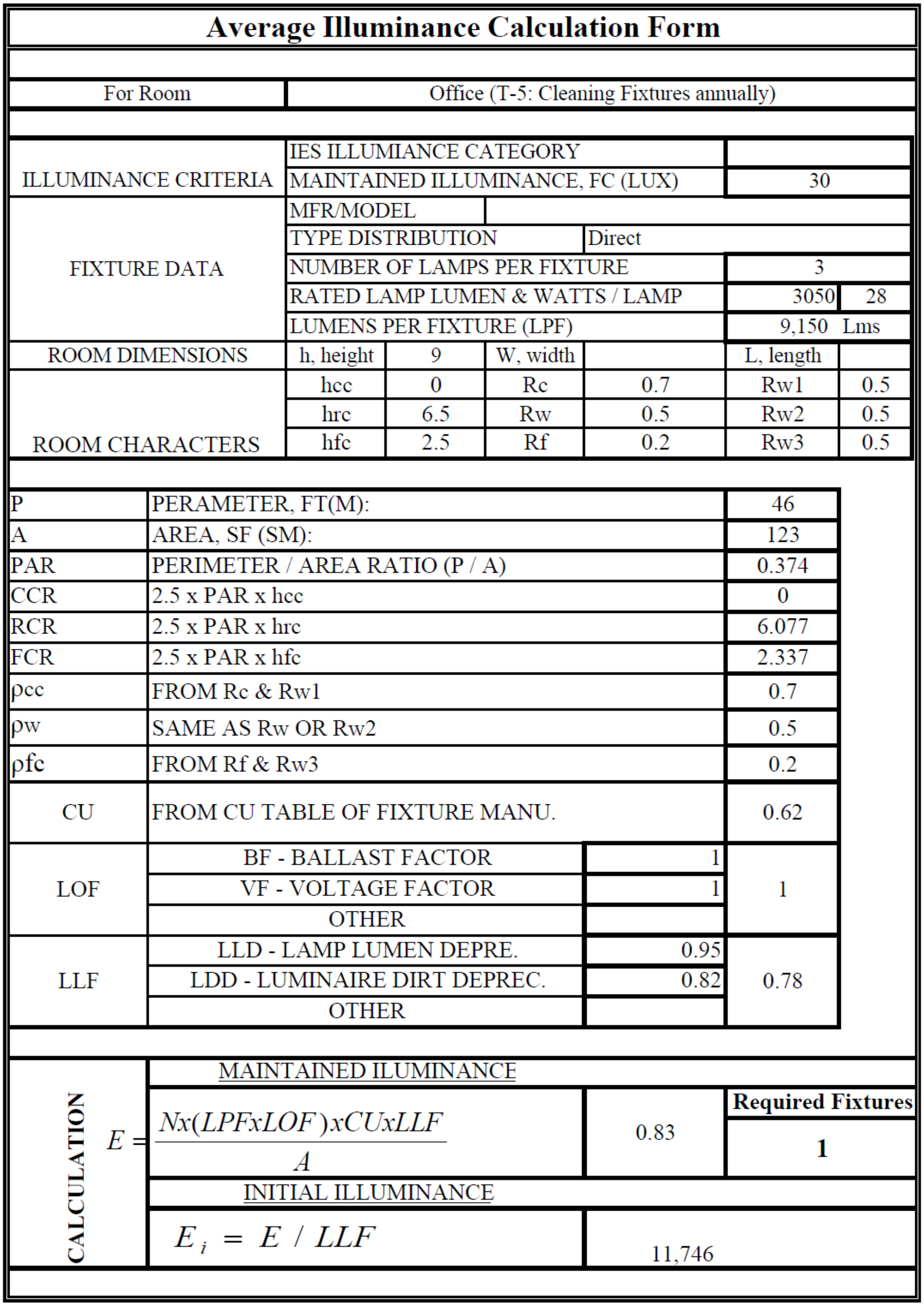
For Room	Workroom (T-5: Cleaning Fixtures annually)					
ILLUMINANCE CRITERIA	IES ILLUMIANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				25	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION		Direct			
	NUMBER OF LAMPS PER FIXTURE				3	
	RATED LAMP LUMEN & WATTS / LAMP				3050	28
	LUMENS PER FIXTURE (LPF)				9,150 Lms	
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		220
A	AREA, SF (SM):		3394
PAR	PERIMETER / AREA RATIO (P / A)		0.065
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		1.053
FCR	2.5 x PAR x hfc		0.405
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.85
LOF	BF - BALLAST FACTOR	1	1
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.78
	LDD - LUMINAIRE DIRT DEPREC.	0.82	
	OTHER		

CALCULATION

MAINTAINED ILUMINANCE			
$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$	13.99	**Required Fixtures**	**14**
INITIAL ILLUMINANCE			
$E_i = E / LLF$	11,746		

Appendix G4 Illuminance calculation for work area (T-5: Cleaning fixtures annually)



Average Illuminance Calculation Form

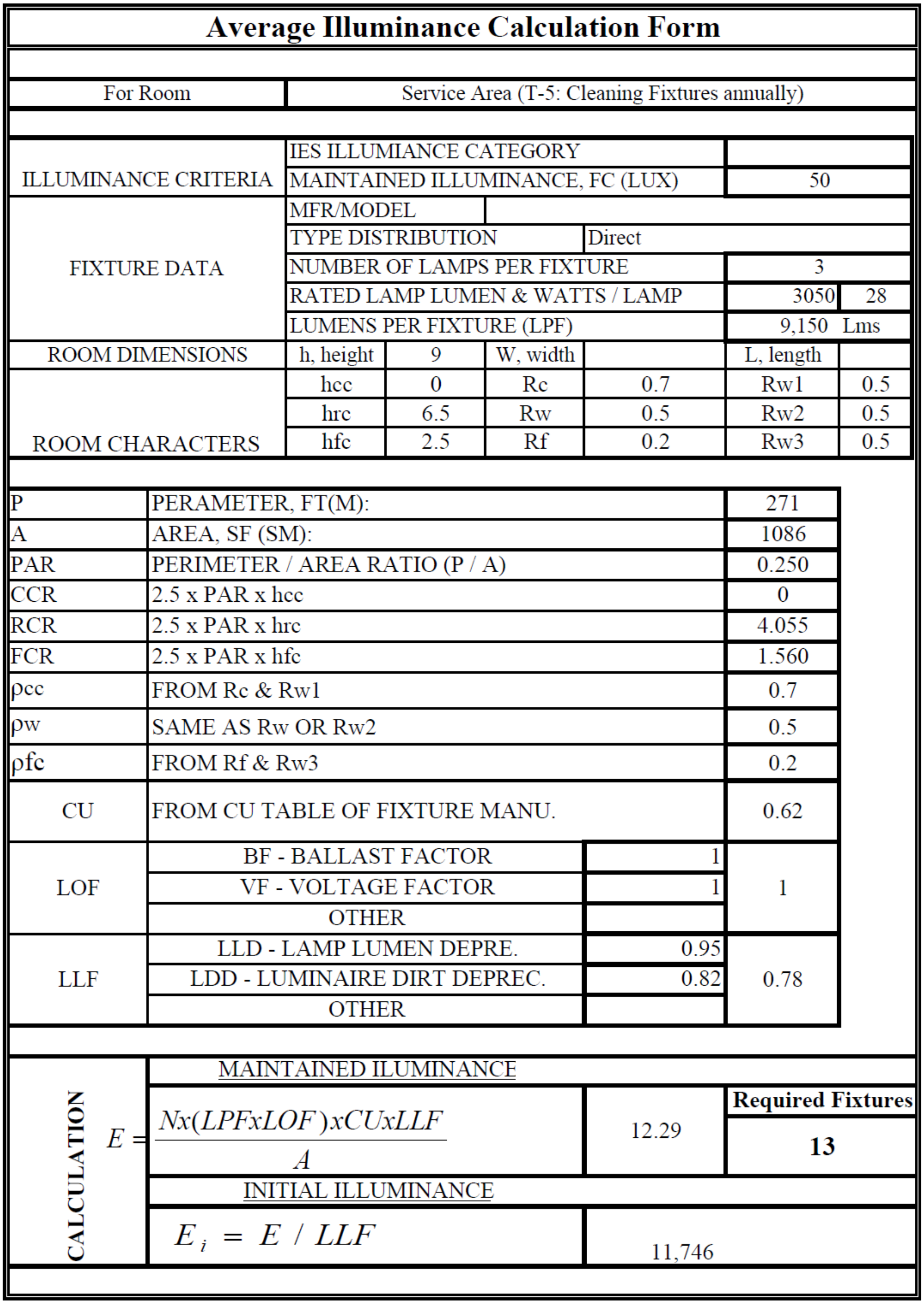
For Room	Office (T-5: Cleaning Fixtures annually)

ILLUMINANCE CRITERIA	IES ILLUMIANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				30	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION		Direct			
	NUMBER OF LAMPS PER FIXTURE				3	
	RATED LAMP LUMEN & WATTS / LAMP				3050	28
	LUMENS PER FIXTURE (LPF)				9,150	Lms
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		46
A	AREA, SF (SM):		123
PAR	PERIMETER / AREA RATIO (P / A)		0.374
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		6.077
FCR	2.5 x PAR x hfc		2.337
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.62
LOF	BF - BALLAST FACTOR	1	1
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.78
	LDD - LUMINAIRE DIRT DEPREC.	0.82	
	OTHER		

CALCULATION	MAINTAINED ILUMINANCE		
	$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$	0.83	**Required Fixtures** **1**
	INITIAL ILLUMINANCE		
	$E_i = E / LLF$	11,746	

Appendix G5 Illuminance calculation for office (T-5: Cleaning fixtures annually)



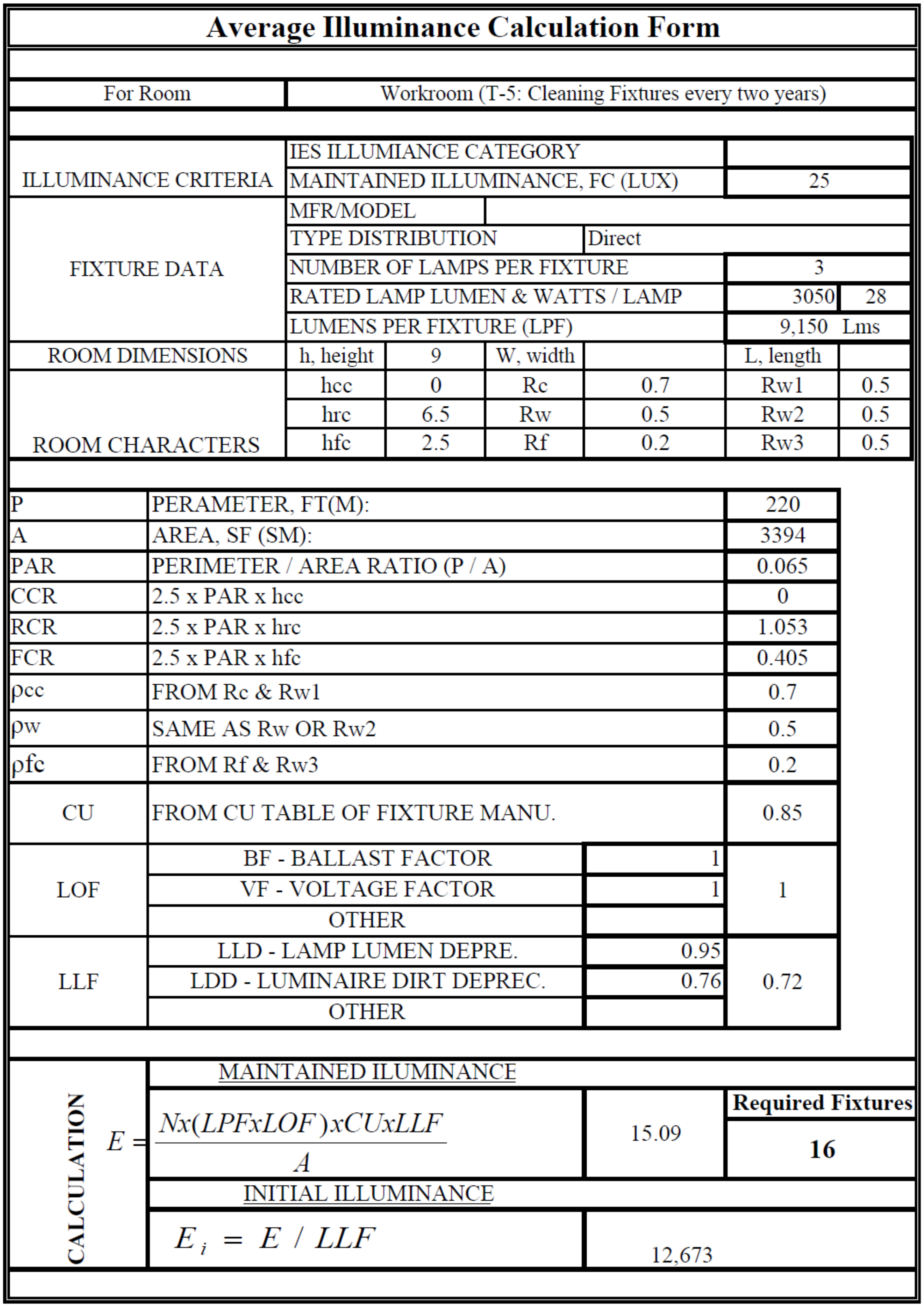
Average Illuminance Calculation Form

For Room	Service Area (T-5: Cleaning Fixtures annually)					
ILLUMINANCE CRITERIA	IES ILLUMIANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				50	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION		Direct			
	NUMBER OF LAMPS PER FIXTURE				3	
	RATED LAMP LUMEN & WATTS / LAMP				3050	28
	LUMENS PER FIXTURE (LPF)				9,150	Lms
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		271
A	AREA, SF (SM):		1086
PAR	PERIMETER / AREA RATIO (P / A)		0.250
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		4.055
FCR	2.5 x PAR x hfc		1.560
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.62
LOF	BF - BALLAST FACTOR	1	1
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.78
	LDD - LUMINAIRE DIRT DEPREC.	0.82	
	OTHER		

CALCULATION	MAINTAINED ILUMINANCE		
	$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$	12.29	**Required Fixtures** **13**
	INITIAL ILLUMINANCE		
	$E_i = E / LLF$	11,746	

Appendix G6 Illuminance calculation for office (T-5: Cleaning fixtures annually)



Average Illuminance Calculation Form

For Room	Workroom (T-5: Cleaning Fixtures every two years)					
ILLUMINANCE CRITERIA	IES ILLUMIANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				25	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION			Direct		
	NUMBER OF LAMPS PER FIXTURE				3	
	RATED LAMP LUMEN & WATTS / LAMP				3050	28
	LUMENS PER FIXTURE (LPF)				9,150 Lms	
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		220
A	AREA, SF (SM):		3394
PAR	PERIMETER / AREA RATIO (P / A)		0.065
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		1.053
FCR	2.5 x PAR x hfc		0.405
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.85
LOF	BF - BALLAST FACTOR	1	1
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.72
	LDD - LUMINAIRE DIRT DEPREC.	0.76	
	OTHER		

CALCULATION	MAINTAINED ILUMINANCE		
	$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$	15.09	**Required Fixtures** **16**
	INITIAL ILLUMINANCE		
	$E_i = E / LLF$	12,673	

Appendix G7 Illuminance calculation for workarea (T-5: Cleaning fixtures every two years)

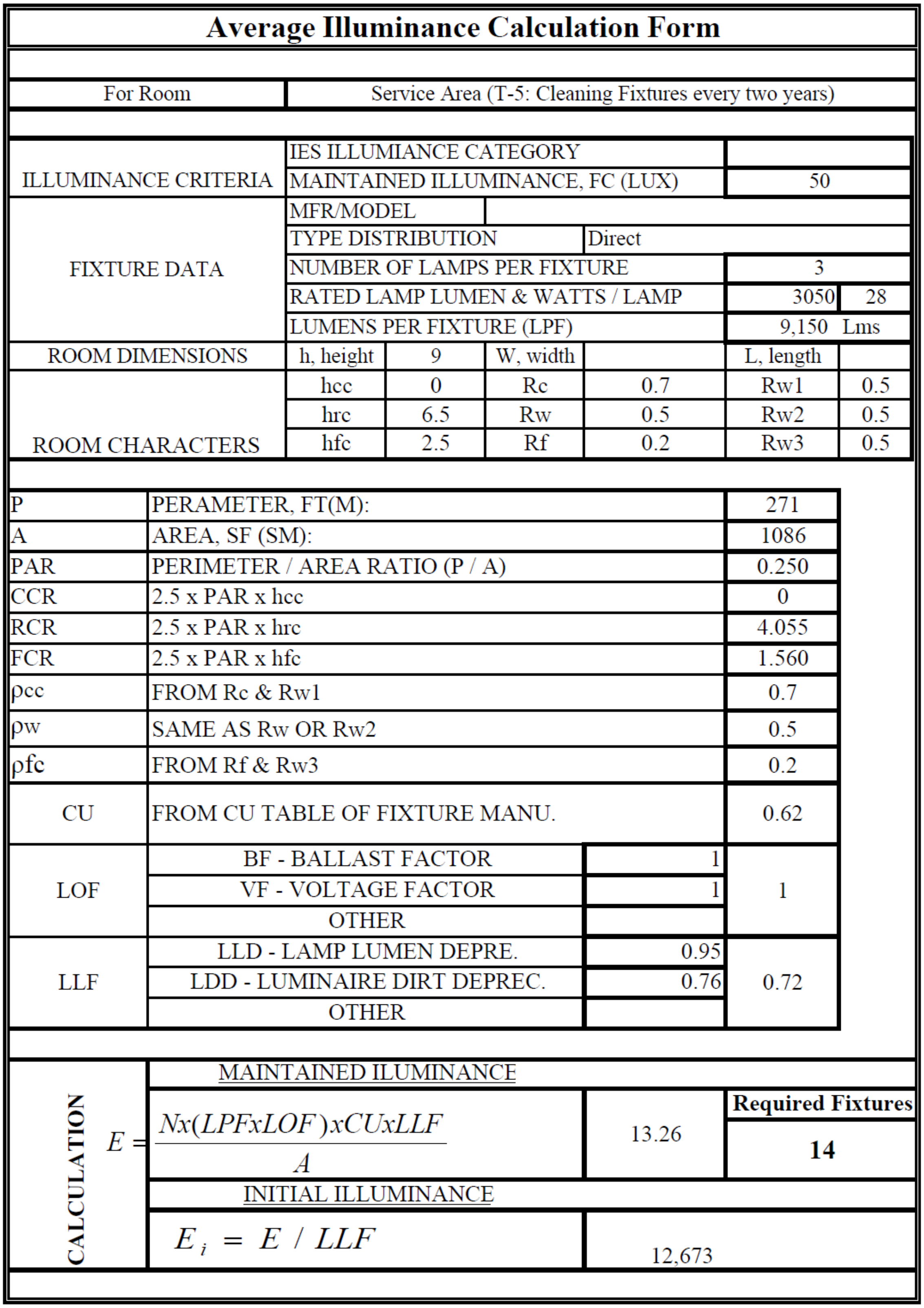
Average Illuminance Calculation Form

For Room	Office (T-5: Cleaning Fixtures every two years)					
ILLUMINANCE CRITERIA	IES ILLUMINANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				30	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION		Direct			
	NUMBER OF LAMPS PER FIXTURE				3	
	RATED LAMP LUMEN & WATTS / LAMP				3050	28
	LUMENS PER FIXTURE (LPF)				9,150	Lms
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		46
A	AREA, SF (SM):		123
PAR	PERIMETER / AREA RATIO (P / A)		0.374
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		6.077
FCR	2.5 x PAR x hfc		2.337
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.62
LOF	BF - BALLAST FACTOR	1	1
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.72
	LDD - LUMINAIRE DIRT DEPREC.	0.76	
	OTHER		

CALCULATION	MAINTAINED ILUMINANCE		
	$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$	0.90	**Required Fixtures**
			1
	INITIAL ILLUMINANCE		
	$E_i = E / LLF$	12,673	

Appendix G7 Illuminance calculation for office (T-5: Cleaning fixtures every two years)



Average Illuminance Calculation Form

For Room	Service Area (T-5: Cleaning Fixtures every two years)

ILLUMINANCE CRITERIA	IES ILLUMIANCE CATEGORY					
	MAINTAINED ILLUMINANCE, FC (LUX)				50	
FIXTURE DATA	MFR/MODEL					
	TYPE DISTRIBUTION		Direct			
	NUMBER OF LAMPS PER FIXTURE				3	
	RATED LAMP LUMEN & WATTS / LAMP				3050	28
	LUMENS PER FIXTURE (LPF)				9,150	Lms
ROOM DIMENSIONS	h, height	9	W, width		L, length	
ROOM CHARACTERS	hcc	0	Rc	0.7	Rw1	0.5
	hrc	6.5	Rw	0.5	Rw2	0.5
	hfc	2.5	Rf	0.2	Rw3	0.5

P	PERAMETER, FT(M):		271
A	AREA, SF (SM):		1086
PAR	PERIMETER / AREA RATIO (P / A)		0.250
CCR	2.5 x PAR x hcc		0
RCR	2.5 x PAR x hrc		4.055
FCR	2.5 x PAR x hfc		1.560
ρcc	FROM Rc & Rw1		0.7
ρw	SAME AS Rw OR Rw2		0.5
ρfc	FROM Rf & Rw3		0.2
CU	FROM CU TABLE OF FIXTURE MANU.		0.62
LOF	BF - BALLAST FACTOR	1	1
	VF - VOLTAGE FACTOR	1	
	OTHER		
LLF	LLD - LAMP LUMEN DEPRE.	0.95	0.72
	LDD - LUMINAIRE DIRT DEPREC.	0.76	
	OTHER		

CALCULATION

MAINTAINED ILUMINANCE

$$E = \frac{Nx(LPFxLOF)xCUxLLF}{A}$$

13.26

Required Fixtures

14

INITIAL ILLUMINANCE

$$E_i = E / LLF$$

12,673

Appendix G7 Illuminance calculation for service area (T-5: Cleaning fixtures every two years)

Appendix H:

First Costs and Life Cycle Costs of Scenarios

Sen.	Initial Cost Premiums	Life Cycle Costs										
		Discount Rate								Electricity Price		
		0.00%	2.00%	3.00%	4.00%	5.00%	7.00%	9.00%	11.00%	Real	High	Linear
1	$ -	$ 277,253	$ 226,172	$ 205,563	$187,580	$171,833	$ 145,789	$ 125,397	$109,213	$ 205,562	$ 212,367	$245,888
2	$ 12,529	$ 276,593	$ 227,947	$ 208,317	$191,187	$176,186	$ 151,372	$ 131,939	$116,515	$ 208,317	$ 214,761	$246,504
3	$ 5,514	$ 282,145	$ 231,179	$ 210,615	$192,673	$176,962	$ 150,976	$ 130,629	$114,481	$ 210,615	$ 217,404	$250,844
4	$ 18,043	$ 281,466	$ 232,938	$ 213,355	$196,267	$181,302	$ 156,548	$ 137,163	$121,776	$ 213,355	$ 219,783	$251,442
5	$ 7,617	$ 283,995	$ 233,076	$ 212,531	$194,605	$178,908	$ 152,946	$ 132,618	$116,484	$ 212,531	$ 219,313	$252,720
6	$ 20,146	$ 283,316	$ 234,835	$ 215,271	$198,199	$183,249	$ 158,518	$ 139,151	$123,779	$ 215,271	$ 221,692	$253,318
7	$ 566	$ 276,225	$ 225,438	$ 204,947	$187,068	$171,411	$ 145,517	$ 125,241	$109,150	$ 204,946	$ 211,710	$245,024
8	$ 13,095	$ 275,584	$ 227,229	$ 207,716	$190,688	$175,776	$ 151,109	$ 131,792	$116,460	$ 207,715	$ 214,118	$245,657
9	$ 6,080	$ 281,117	$ 230,445	$ 210,000	$192,161	$176,540	$ 150,704	$ 130,474	$114,418	$ 209,999	$ 216,746	$249,980
10	$ 18,609	$ 280,457	$ 232,220	$ 212,754	$195,768	$180,892	$ 156,286	$ 137,016	$121,721	$ 212,754	$ 219,140	$250,596
11	$ 8,183	$ 282,967	$ 232,342	$ 211,915	$194,093	$178,486	$ 152,674	$ 132,462	$116,421	$ 211,915	$ 218,655	$251,856
12	$ 20,712	$ 282,268	$ 234,085	$ 214,641	$197,674	$182,815	$ 158,236	$ 138,987	$123,709	$ 214,641	$ 221,019	$252,437
13	$ 4,406	$ 277,246	$ 226,979	$ 206,697	$189,001	$173,504	$ 147,874	$ 127,805	$111,877	$ 206,697	$ 213,386	$246,335
14	$ 16,935	$ 276,625	$ 228,786	$ 209,481	$192,635	$177,881	$ 153,477	$ 134,365	$119,195	$ 209,480	$ 215,810	$246,986
15	$ 9,920	$ 282,138	$ 231,986	$ 211,750	$194,094	$178,633	$ 153,061	$ 133,038	$117,146	$ 211,750	$ 218,423	$251,291
16	$ 22,449	$ 281,478	$ 233,761	$ 214,505	$197,702	$182,985	$ 158,643	$ 139,580	$124,449	$ 214,504	$ 220,816	$251,907
17	$ 12,023	$ 283,949	$ 233,851	$ 213,637	$196,000	$180,555	$ 155,011	$ 135,009	$119,134	$ 213,637	$ 220,302	$253,132
18	$ 24,552	$ 283,309	$ 235,642	$ 216,406	$199,620	$184,920	$ 160,603	$ 141,560	$126,444	$ 216,406	$ 222,711	$253,766
19	$ -	$ 279,100	$ 227,678	$ 206,931	$188,829	$172,978	$ 146,761	$ 126,233	$109,941	$ 206,931	$ 213,785	$247,544
20	$ 12,529	$ 279,431	$ 230,262	$ 210,421	$193,107	$177,945	$ 152,865	$ 133,224	$117,635	$ 210,420	$ 216,939	$249,050
21	$ 5,514	$ 283,991	$ 232,685	$ 211,984	$193,923	$178,106	$ 151,948	$ 131,465	$115,210	$ 211,984	$ 218,821	$252,500
22	$ 18,043	$ 284,304	$ 235,253	$ 215,459	$198,187	$183,061	$ 158,041	$ 138,448	$122,896	$ 215,459	$ 221,961	$253,988
23	$ 7,617	$ 285,822	$ 234,566	$ 213,886	$195,841	$180,040	$ 153,907	$ 133,445	$117,205	$ 213,885	$ 220,716	$254,359
24	$ 20,146	$ 286,135	$ 237,134	$ 217,361	$200,106	$184,995	$ 160,001	$ 140,427	$124,892	$ 217,360	$ 223,855	$255,847
25	$ 566	$ 278,110	$ 226,976	$ 206,345	$188,343	$172,580	$ 146,509	$ 126,095	$109,894	$ 206,344	$ 213,157	$246,715
26	$ 13,095	$ 278,442	$ 229,560	$ 209,834	$192,621	$177,547	$ 152,612	$ 133,086	$117,587	$ 209,834	$ 216,312	$248,221
27	$ 6,080	$ 282,983	$ 231,967	$ 211,383	$193,423	$177,696	$ 151,685	$ 131,318	$115,155	$ 211,383	$ 218,179	$251,654
28	$ 18,609	$ 283,315	$ 234,551	$ 214,873	$197,701	$182,663	$ 157,789	$ 138,310	$122,848	$ 214,872	$ 221,333	$253,159
29	$ 8,183	$ 284,814	$ 233,848	$ 213,284	$195,342	$179,631	$ 153,645	$ 133,298	$117,150	$ 213,284	$ 220,073	$253,513
30	$ 20,712	$ 285,145	$ 236,432	$ 216,774	$199,620	$184,598	$ 159,749	$ 140,289	$124,844	$ 216,773	$ 223,227	$255,018
31	$ 4,406	$ 279,209	$ 228,580	$ 208,153	$190,329	$174,721	$ 148,907	$ 128,694	$112,652	$ 208,152	$ 214,893	$248,096
32	$ 16,935	$ 279,541	$ 231,164	$ 211,642	$194,607	$179,688	$ 155,011	$ 135,685	$120,346	$ 211,642	$ 218,048	$249,602
33	$ 9,920	$ 284,082	$ 233,571	$ 213,191	$195,409	$179,838	$ 154,083	$ 133,918	$117,913	$ 213,191	$ 219,915	$253,035
34	$ 22,449	$ 284,374	$ 236,119	$ 216,646	$199,654	$184,773	$ 160,157	$ 140,880	$125,579	$ 216,646	$ 223,035	$254,503
35	$ 12,023	$ 285,913	$ 235,452	$ 215,093	$197,328	$181,772	$ 156,043	$ 135,897	$119,909	$ 215,092	$ 221,809	$254,894
36	$ 24,552	$ 286,225	$ 238,020	$ 218,568	$201,593	$186,727	$ 162,137	$ 142,880	$127,595	$ 218,567	$ 224,949	$256,382
37	$ -	$ 278,400	$ 227,108	$ 206,413	$188,356	$172,544	$ 146,393	$ 125,916	$109,665	$ 206,412	$ 213,248	$246,916
38	$ 12,529	$ 277,915	$ 229,026	$ 209,297	$192,082	$177,005	$ 152,067	$ 132,538	$117,037	$ 209,296	$ 215,776	$247,689
39	$ 5,514	$ 283,272	$ 232,098	$ 211,451	$193,436	$177,660	$ 151,569	$ 131,140	$114,926	$ 211,451	$ 218,269	$251,855
40	$ 18,043	$ 282,787	$ 234,016	$ 214,335	$197,162	$182,121	$ 157,243	$ 137,761	$122,298	$ 214,335	$ 220,797	$252,628
41	$ 7,617	$ 282,965	$ 232,235	$ 211,767	$193,908	$178,269	$ 152,404	$ 132,151	$116,078	$ 211,767	$ 218,522	$251,796
42	$ 20,146	$ 284,638	$ 235,913	$ 216,251	$199,094	$184,068	$ 159,214	$ 139,750	$124,301	$ 216,251	$ 222,706	$254,504
43	$ 566	$ 277,449	$ 226,437	$ 205,855	$187,896	$172,170	$ 146,161	$ 125,796	$109,633	$ 205,854	$ 212,650	$246,122
44	$ 13,095	$ 276,965	$ 228,355	$ 208,739	$191,622	$176,631	$ 151,835	$ 132,417	$117,004	$ 208,738	$ 215,178	$246,895
45	$ 6,080	$ 282,322	$ 231,428	$ 210,893	$192,976	$177,287	$ 151,338	$ 131,019	$114,894	$ 210,893	$ 217,671	$251,061
46	$ 18,609	$ 281,837	$ 233,346	$ 213,777	$196,702	$181,748	$ 157,012	$ 137,641	$122,265	$ 213,777	$ 220,199	$251,834
47	$ 8,183	$ 284,153	$ 233,309	$ 212,794	$194,895	$179,221	$ 153,297	$ 132,999	$116,889	$ 212,794	$ 219,566	$252,920
48	$ 20,712	$ 283,687	$ 235,243	$ 215,693	$198,634	$183,694	$ 158,982	$ 139,629	$124,269	$ 215,693	$ 222,108	$253,710
49	$ 4,406	$ 278,626	$ 228,105	$ 207,721	$189,935	$174,360	$ 148,600	$ 128,430	$112,422	$ 207,720	$ 214,446	$247,573
50	$ 16,935	$ 278,161	$ 230,039	$ 210,619	$193,673	$178,833	$ 154,285	$ 135,060	$119,801	$ 210,619	$ 216,989	$248,363
51	$ 9,920	$ 283,499	$ 233,096	$ 212,759	$195,015	$179,476	$ 153,777	$ 133,654	$117,683	$ 212,759	$ 219,467	$252,512
52	$ 22,449	$ 283,033	$ 235,029	$ 215,658	$198,754	$183,949	$ 159,461	$ 140,284	$125,062	$ 215,657	$ 222,010	$253,302
53	$ 12,023	$ 285,349	$ 234,993	$ 214,675	$196,947	$181,423	$ 155,747	$ 135,642	$119,686	$ 214,674	$ 221,376	$254,388
54	$ 24,552	$ 284,864	$ 236,910	$ 217,559	$200,672	$185,884	$ 161,421	$ 142,264	$127,058	$ 217,558	$ 223,904	$255,161
55	$ -	$ 277,350	$ 226,251	$ 205,635	$187,646	$171,893	$ 145,840	$ 125,441	$109,251	$ 205,634	$ 212,442	$245,975
56	$ 12,529	$ 277,410	$ 228,613	$ 208,922	$191,740	$176,692	$ 151,801	$ 132,309	$116,837	$ 208,922	$ 215,388	$247,236

57	$ 5,514	$ 282,222	$ 231,242	$ 210,673	$192,726	$177,010	$ 151,017	$ 130,664	$114,512	$ 210,673	$ 217,464	$250,913
58	$ 18,043	$ 282,263	$ 233,588	$ 213,946	$196,807	$181,796	$ 156,967	$ 137,524	$122,091	$ 213,946	$ 220,394	$252,157
59	$ 7,617	$ 284,073	$ 233,139	$ 212,589	$194,658	$178,956	$ 152,987	$ 132,653	$116,515	$ 212,588	$ 219,373	$252,790
60	$ 20,146	$ 284,093	$ 235,469	$ 215,848	$198,725	$183,730	$ 158,927	$ 139,503	$124,086	$ 215,847	$ 222,288	$254,016
61	$ 566	$ 276,322	$ 225,517	$ 205,019	$187,134	$171,471	$ 145,568	$ 125,285	$109,188	$ 205,018	$ 211,784	$245,111
62	$ 13,095	$ 276,401	$ 227,895	$ 208,321	$191,241	$176,282	$ 151,539	$ 132,162	$116,782	$ 208,321	$ 214,745	$246,389
63	$ 6,080	$ 281,194	$ 230,508	$ 210,057	$192,214	$176,588	$ 150,745	$ 130,509	$114,449	$ 210,057	$ 216,806	$250,049
64	$ 18,609	$ 281,235	$ 232,854	$ 213,331	$196,294	$181,374	$ 156,695	$ 137,368	$122,028	$ 213,330	$ 219,737	$251,293
65	$ 8,183	$ 283,045	$ 232,405	$ 211,973	$194,146	$178,534	$ 152,715	$ 132,497	$116,452	$ 211,973	$ 218,715	$251,926
66	$ 20,712	$ 283,065	$ 234,735	$ 215,232	$198,213	$183,309	$ 158,655	$ 139,348	$124,023	$ 215,231	$ 221,631	$253,152
67	$ 4,406	$ 277,382	$ 227,090	$ 206,798	$189,093	$173,589	$ 147,946	$ 127,867	$111,931	$ 206,798	$ 213,491	$246,457
68	$ 16,935	$ 277,461	$ 229,468	$ 210,100	$193,200	$178,399	$ 153,917	$ 134,744	$119,525	$ 210,100	$ 216,451	$247,736
69	$ 9,920	$ 282,254	$ 232,081	$ 211,837	$194,173	$178,705	$ 153,122	$ 133,090	$117,192	$ 211,836	$ 218,512	$251,396
70	$ 22,449	$ 284,413	$ 236,151	$ 216,675	$199,680	$184,797	$ 160,177	$ 140,898	$125,594	$ 216,675	$ 223,064	$254,538
71	$ 12,023	$ 284,105	$ 233,978	$ 213,753	$196,105	$180,652	$ 155,092	$ 135,079	$119,195	$ 213,752	$ 220,421	$253,272
72	$ 24,552	$ 284,125	$ 236,308	$ 217,011	$200,173	$185,426	$ 161,033	$ 141,929	$126,766	$ 217,011	$ 223,337	$254,498