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Diffusion of Energy Efficient Technology in Commercial Buildings: An Analysis of the Commercial Building Partnerships Program

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Diffusion of Energy Efficient Technology in Commercial Buildings:

An Analysis of the Commercial Building Partnerships Program

by

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Master of Urban Studies

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Abstract

This study presents findings from survey and interview data investigating replication of green building measures by Commercial Building Partnership (CBP) partners that worked directly with the Pacific Northwest National Laboratory (PNNL). PNNL partnered directly with 12 organizations on new and retrofit construction projects, which represented approximately 28 percent of the entire U.S. Department of Energy (DOE) CBP program. Through a feedback survey mechanism, along with personal interviews, quantitative and qualitative data were gathered relating to replication efforts by each organization. These data were analyzed to provide insight into two primary research areas: 1) CBP partners' replication efforts of green building approaches used in the CBP project to the rest of the organization's building portfolio, and, 2) the market potential for technology diffusion into the total U.S. commercial building stock, as a direct result of the CBP program. The first area of this research focused specifically on replication efforts underway or planned by each CBP program participant. The second area of this research develops a diffusion of innovations model to analyze potential broad market impacts of the CBP program on the commercial building industry in the United States.

Findings from this study provided insight into motivations and objectives CBP partners had for program participation. Factors that impact replication include motivation, organizational structure and objectives firms have for implementation of energy efficient technologies. Comparing these factors between different CBP partners revealed patterns in motivation for constructing energy efficient buildings, along with better insight into market trends for green building practices. The optimized approach to the CBP program allows partners to develop green building parameters that fit the specific uses of their building, resulting in greater motivation for replication. In addition, the diffusion model developed for this analysis indicates that this method of market prediction may be used to adequately capture cumulative construction metrics for a whole-building analysis as opposed to individual energy efficiency measures used in green building.

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Chapter 1. Introduction

In 2010, the U.S. consumed 97 quadrillion BTUs of energy, spending approximately $1.2 billion, or roughly 8.3% of total GDP for the country (EIA, 2012). In 2011, U.S. energy consumption resulted in approximately 5.5 million metric tons of carbon dioxide emitted into the atmosphere (EIA, 2012). U.S. energy consumption equals approximately 19% of global consumption; a close second only to China which consumes 20% of global totals (DOE, 2012a). While energy production and consumption is essential for U.S. economic interests, the negative environmental externalities pose threats to the environment, national security and stress on the overall economy.

Of the overall energy footprint in the U.S., approximately 40% of total primary energy is consumed by the buildings sector, almost half of which is attributed to commercial buildings (DOE, 2012a). Furthermore, building codes, which mandate benchmark safety and building procedures, did not include energy savings considerations before 1979. According to the most recent Commercial Building Energy Consumption Survey (CBECS), there were approximately 4.9 million commercial buildings in the U.S. in 2003, 2.8 million of which were built prior to 1979, when the first energy codes were enacted (EIA, 2008). Building energy codes help address energy losses through prescriptive requirements for envelope, mechanical and electrical system efficiencies, thus promoting efficient systems and lowering the overall footprint of the building.

The United States has ambitious goals for increasing efficiency of the nation's building stock and lowering the energy footprint of both residential and commercial buildings. The U.S. Department of Energy (DOE) has commercial building reduction goals of 20% by 2020, supported by programs through Energy Efficiency and Renewable Energy's (EERE) Building Technologies Office (BTO). By 2030, all federal buildings are required to meet a 30% reduction in energy intensity based on 2003 levels (EISA, 2007; DOE, 2011a). To promote energy efficiency in the buildings sector, EERE utilizes a multi-pronged effort that includes research to develop new energy efficient building technologies, regulatory efforts to enforce greater efficiency for new buildings and equipment, and deployment programs that seek to promote adoption of energy efficient technologies in new and existing buildings. The Commercial Building Partnerships (CBP), one example of a DOE program, is a public/private cost-share program addressing new and existing commercial buildings with the aim of dramatic energy reductions in new construction and existing buildings (DOE, 2011b). Replication of building measures utilized in the CBP program could have significant market transformation potential for the commercial building sector in the U.S in terms of energy savings and promotion of green building initiatives.

This research focuses on better understanding the CBP program impacts including investigating how program participants are applying technologies used in their one building project (replication efforts) into other buildings. Analysis of these replication efforts can provide information about energy savings efforts of individual partners along with potential market impacts if outcomes of the program are propagated into the entire commercial building sector.

The Commercial Building Partnerships Program

The CBP program is a limited duration DOE initiative, initially funded in 2008 (CBP I), with a second funding opportunity presented in 2010 (CBP II) through the American Recovery and Reinvestment Act (ARRA). Selection process for these projects was competitive, with strict energy savings requirements mandated by DOE. Once selected, each partner committed to savings goals that were at least 50% greater than ANSI/ASHRAE/IESNA Standard 90.1-2004 or 2007 for new construction projects, and retrofit projects were designed to consume at least 30% less energy than either Standard 90.1-2004 or baseline building consumption (DOE, 2011b).

The CBP program includes partnerships of commercial companies, with engineers and scientists from national laboratories and other energy efficiency experts designing, implementing and monitoring energy efficient measures for building construction and/or retrofits (usually one or two building projects per partner). National lab partners include the Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Argonne National Laboratory (ANL) and the Pacific Northwest National Laboratory (PNNL). Energy efficiency measures (EEMs) include a broad array of technologies and applications to the building envelope, mechanical systems, electrical systems and approaches to operations and maintenance (O&M). The national laboratories provided modeling and design assistance to each partner. A package of EEMs was developed for each project based on business criteria provided by each partner, along with measurement and verification (M&V) methods in order to design protocols for development.

To date, CBP has partnered with 42 entities on 54 specific new construction and retrofit projects, addressing 8.3 million square feet of commercial building space (DOE 2011b). Total square footage of commercial building floor area held in these portfolios equals about 4 billion square feet, approximately 6% of the total commercial building stock in the U.S. (DOE, 2011b; EIA, 2008). While the CBP program only addresses one or two buildings within an organization's entire building portfolio, replication of CBP program measures to all buildings could result in significant energy and cost savings. Figure1 below provides a list of all companies chosen by DOE to participate in the CBP program. Green building initiatives strive to promote a "win-win" concept to building owners and operators by promoting diffusion of technologies that save energy expenditures, enhance occupant comfort and reduce environmental impacts.

Commercial Building Energy Alliances

Commercial Building Partnerships: Partners and Projects

Bank of America
- Punta Gorda, FL
- Multiple Locations

Best Buy Co., Inc.
- Lakewood, CO
- To Be Determined

CB Richard Ellis Group, Inc. / Fitzmartin Consulting
- Denver, CO

Clark Atlanta University
- Center for Alternative, Renewable Energy, Technology and Training

Defense Commissary Agency (DeCA)
- Lackland Air Force Base

Forest City Enterprises, Inc.
- Forest City—Richmond, VA

Grand Valley State University
- Library
- Seidman Center

Hines (Morgan Stanley property owner)
- Data Center—Somerset, NJ
- Office—New York, NY

InterContinental Hotels Group
- Crowne Plaza Hotel (BF Saul Franchise)
- Holiday Inn (JVD Enterprise Franchise)

jcpenney
- Colonial Heights, VA
- Dallas, TX

Job Corps
- Cafeteria—Reno, NV

John Deere
- Sales and Service Center—Des Moines, IA

Kohl's Department Stores
- To Be Determined
- Warren, OH

Living City Block
- Denver, CO

Long Beach Gas and Oil
- Office—Long Beach, CA

Loyola University
- Dumbach Hall

Massachusetts Institute of Technology
- MIT Data and Stata Center

Mesa Lane Partners, LLC
- The LOOP—Santa Barbara, CA

NASA
- Ames Research Center

New York Times Company
- New York Times Building

Oregon BEST
- Environmental & Sustainable Technologies Center

Prologis
- Warehouse—Olive Branch, MS

Regency Centers Corp.
- Mall—Granada Hills, CA

Shy Brothers Farm
- Dairy and Creamery—Westport, MA

SUPERVALU INC.
- Washington, DC
- Chestnut Hill, MA

Target Corp.
- Brookfield, WI
- Thornton, CO

The Bullitt Foundation
- Cascadia Center—Seattle, WA

The Home Depot, Inc.
- Lodi, CA

The PNC Financial Services Group, Inc.
- Riviera Beach, FL
- Ft. Lauderdale, FL

The Westfield Group
- Solano Mall—Fairfield, CA

Twentieth Century Fox Film Corp.
- Twentieth Century Fox Studios

U.S. Army
- Fort Bragg, NC

U.S. Department of Energy
- NREL Research Support Facility—Golden, CO

U.S. General Services Administration
- Region 1, Pease Building—Portsmouth, NH
- Lighting Portfolio—San Francisco, CA
- Region 9, Multiple Locations
  - Los Angeles, CA
  - Oakland, CA
  - Sacramento, CA
  - San Francisco, CA

University of California
- Merced, CA

University of Hawaii at Manoa
- Kuykendall Hall—Honolulu, HI

University of South Carolina
- Columbia, SC

University of Utah
- College of Architecture + Planning

Walmart Stores, Inc.
- Royse City, TX
- Centennial, CO

Whole Foods Market, Inc.
- Raleigh, NC
- Edgewater, NJ

August 1, 2011

Commercial Building Energy Alliances

Figure 1. Commercial Building Partners and Projects

This study presents findings from survey and interview data investigating replication efforts of each CBP partner that worked directly with the Pacific Northwest National Laboratory (PNNL). PNNL partnered directly with 12 organizations on new and retrofit construction projects, which represented approximately 28 percent of the entire CBP program. Through a feedback survey mechanism, along with personal interviews, quantitative and qualitative data were gathered relating to replication efforts by each organization. These data were analyzed to provide insight into two primary research areas: 1) CBP partners' replication efforts of technologies and approaches used in the CBP project to the rest of the organization's building portfolio (including replication verification), and, 2) the market potential for technology diffusion into the total U.S. commercial building stock, as a direct result of the CBP program.

Chapter 2. Green Building

As energy intensities and natural resource consumption continues to grow in the built environment, principles of green building have become more widely adopted throughout the world. In the United States, buildings account for approximately 41% of total primary energy consumption, resulting in 2,268 million metric tons of carbon dioxide emissions (DOE, 2012c). Of total carbon emissions in the United States, the buildings sector is responsible for 40% of total emissions, consuming approximately 44% more primary energy than the transportation sector (DOE 2012c). Reducing building sector energy consumption is a pillar of the nation’s overall plans to decrease greenhouse gas emissions.

Green building is the process of integrating a variety of technologies into a building project aimed at increasing the efficiency, health and safety of the project, along with reducing the overall environmental footprint of the building. No concrete definition of green building exists, but measures often include site considerations such as location and orientation, envelope treatments, mechanical system enhancements, materials selection, water consumption, construction methods and economic considerations (Retzlaff, 2009). Green building measures that increase energy efficiency have been cited by many as an efficient way to decrease energy consumption by targeting “low hanging fruit” before other, more expensive measures such as onsite renewable energy generation systems (Harmelink et al., 2008; ürge-Vorsatz et al., 2007; Sachs et al., 2004; Reinhardt, 2000). This premise, along with federal and state incentives, has helped advance the green building industry over the past couple of decades.

Energy efficiency measures implemented in green building practices include envelope treatments such as insulation, air sealing, installation of advanced windows and roofing materials. Mechanical system improvements include Heating, Ventilation, & Air Conditioning (HVAC) system size optimization and programmable thermostats or other whole-building intelligent software. Electrical systems include lighting retrofits and installation of energy-saving lighting technologies such as compact florescent or light emitting diode (LED) lighting. In addition, architectural design applications such as building orientation, site evaluation, daylighting and other structural considerations can help increase the efficiency of buildings (Wilson, 1998; Melton, 2012, Kebert, 1999). The goal of optimizing these building systems is to promote the most efficient operation of the structure, reducing the environmental footprint as much as possible.

In addition to envelope, mechanical, electrical and structural components, renewable energy systems are increasingly being used to offset the overall footprint and energy consumption of buildings. Solar photovoltaic, various thermal systems, small wind and other renewable energy technologies help buildings decrease their overall footprint, with some achieving zero net energy. Zero net energy buildings combine efficiency gains with onsite production of renewable energy with the goal of producing as much annual energy as they consume (Marszal et al., 2011; Torcellini et al., 2006). Many developers and energy efficiency programs have eventual goals of achieving zero net energy within the built environment.

Not only do green building approaches apply to specific buildings, but increasing attention to sustainable community and urban development incorporates green building perspectives to the overall infrastructure of the built environment. Planners, city officials, developers and academics are investigating the role that green building technology advancement plays in developing sustainable communities (Getter and Rowe, 2006; Ding, 2008). Advancement of green building initiatives helps lay stronger foundations for future sustainable city and urban development.

Regulatory Perspectives on Energy Efficiency in Buildings

The primary regulatory mechanism for energy efficiency in buildings is promoted by building energy codes, which now exist in almost every state for the construction of new buildings (DSIRE, 2012). Building energy codes are adopted on a state or local level based on the International Energy Conservation Code (IECC) for residential buildings, and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 90.1 for Commercial Buildings (ICC, 2012; ASHRAE, 2010). Building energy codes provide a benchmark for systems within a building that includes both prescriptive and performance options for compliance. Codes vary by state, city and county in some cases, and are based both on the efficiencies outlined by ASHRAE 90.1

and the International Energy Code Council (IECC) 2003 to 2012 editions. Figure 2 provides a synopsis of the state of energy codes across the nation as of October, 2013.

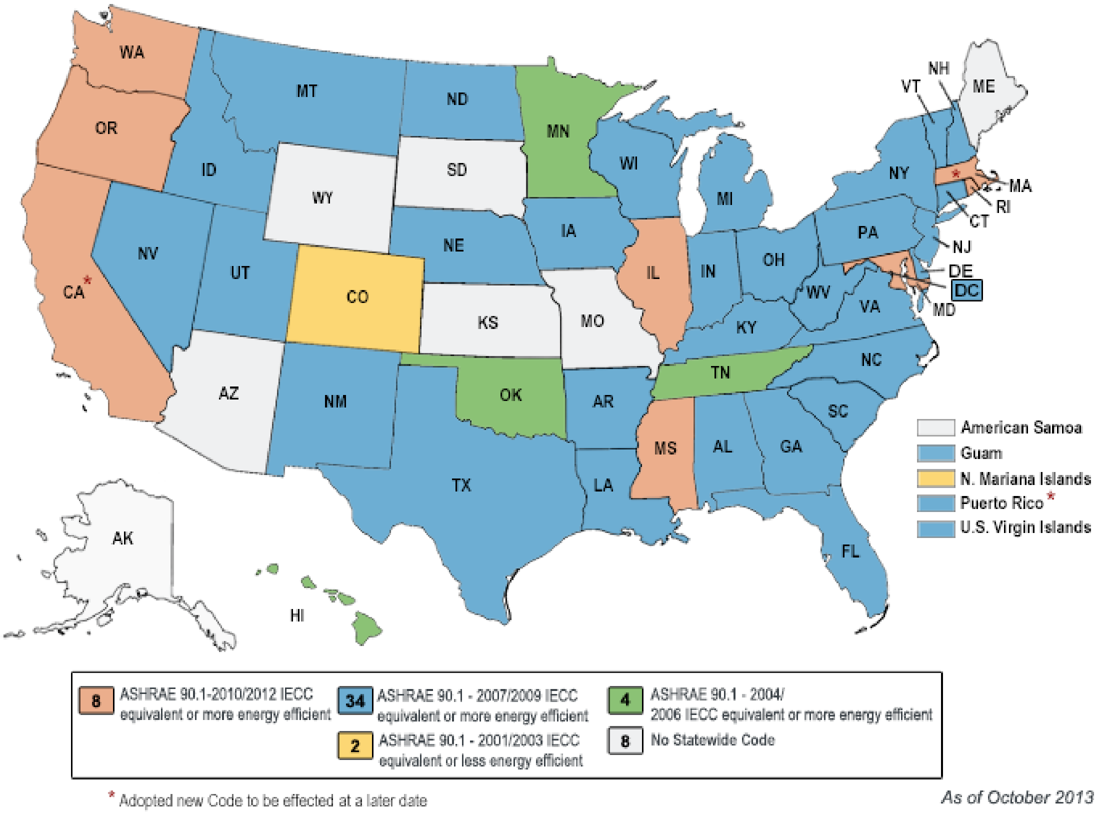

Figure 2. Current Commercial Building Energy Code Adoption Status (DOE, 2013)

While codes are effective measures for promoting energy standards, they do have barriers for implementation. Not only are they not adopted in every state (see Figure 2), but there are issues with code official training, lax updating schedules, poor industry communication and demonstration of cost effectiveness (Levine et al., 2012). Such barriers further hinder the advancement of green buildings and technologies across the nation.

In addition to building energy codes, the U.S. Department of Energy (DOE) has commercial building reduction goals of 20% by 2020, supported by programs through Energy Efficiency and Renewable Energy's (EERE) Building Technologies Office (BTO). By 2030, all federal buildings are required to meet a 30% reduction in energy intensity based on 2003 levels, per EISA 2007 (DOE, 2011a). To promote energy efficiency in the buildings sector, EERE utilizes a multi-pronged effort that includes research to develop new energy efficient building technologies, regulatory efforts to enforce greater efficiency for new buildings and equipment, and deployment programs that seek to promote adoption of energy efficient technologies in new and existing buildings. The CBP program, part of this outreach approach to the private sector, optimizes new buildings to achieve 50% greater energy savings over ASHRAE Standard 90.1 (2004 version) and retrofits 30% savings over ASHRAE Standard 90.1 or current consumption levels determined through building energy modeling software (DOE, 2011b).

The CBP program is one example of a voluntary program for green building. Outside of building codes, voluntary programs are another effective driver for energy efficient buildings, by providing a prescriptive and/or performance approach to energy efficiency and promoting environmentally conscious building science. Voluntary building energy and environmental labeling programs can achieve great energy reductions (often far more than prescriptive codes) and further promote green development. It has been noted that the most effective way to promote green infrastructure is to combine regulatory mechanisms such as codes with voluntary labeling programs and financial incentives (Levine et al., 2012). The following section discusses some of these approaches.

Green Building Programs

Another driver for energy efficiency in buildings includes voluntary labeling mechanisms designed to distinguish efficient buildings from non-efficient ones. Such programs include the U.S. Green Building Council’s Leadership in Energy & Environmental Design (LEED) program, which certifies buildings in one of four competitive levels: certified, silver, gold and platinum (USGBC, 2012). The Better Buildings Initiative, initially funded by Recovery Act dollars, was expanded by President Obama in 2011 to increase commercial and industrial buildings efficiency 20% by 2020 (DOE, 2012b). These programs, along with many others, are designed to transform the energy efficiency market, spurring increased private investment in energy efficiency technologies and aiding market development; the CBP program can be seen as another example of such programs. Participation in voluntary programs, such as LEED or ENERGY STAR provides whole-building packages that optimize energy efficiency from a building science perspective (DOE 2012a).

While the federal government has established programs for energy efficiency, there are many other models that have been developed by utilities, non-governmental organizations and local governments. Because of this, efficiency programs tend to be fragmented (Blumstein et al., 2005). One result is that replication and direct influences on market transformation is not well understood.

Leadership in Energy and Environmental Design (LEED)

One of the most widely adopted green building programs in the U.S. is the USGBC's LEED program. Currently, there are nine different rating systems that award different points for various green attributes within the building project. Levels of LEED certification include LEED Certified (40-49 points), LEED Silver (50-59 points), LEED Gold (60-69 points) and LEED Platinum (> 80 points) (USGBC, 2013). Unlike some of the state and federal programs, participants pay for certification.

LEED scoring systems cover broad categories of green building attributes including sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design and regional priority (USGBC, 2013). Although successful, LEED has been criticized in recent years with many questioning the measured and verified energy savings within the scoring mechanism of the program. Some analyses have determined that LEED certified buildings do not have guaranteed superior energy performance compared to non-LEED certified buildings (Levine et al., 2012). Regardless, with over 55,000 buildings certified across the country, LEED does represent the greatest set of voluntarily certified green buildings in the U.S. As such, this study leveraged LEED data for calibration of the diffusion model used to address the second part of the research question (see Chapter 5, Methodology).

ENERGY STAR Buildings

The ENERGY STAR Buildings Labeling program began in 1999 and is a voluntary building design and labeling system for commercial buildings. The program provides two scoring mechanisms, the first being to design a prototype building to perform better than the median performance of buildings in the nation. The second scoring mechanism is a 1-100 ENERGY STAR score, requiring a score of 75 in order to meet certification standards. The score is based on the building's estimated energy use relative to similar buildings nationwide. On average, these buildings consume 35% less energy than other similar buildings across the country (EPA, 2013). Other similar buildings are not measured based on energy code, but instead use site consumption metrics as a means for comparison. This approach to consumption metrics is an effort to control for varying codes and standards throughout the U.S.

Unlike LEED, the ENERGY STAR program includes a measurement and verification period for one year after the building is constructed, that monitors performance once the building is occupied. The tool, called the Portfolio Manager is designed to help ensure that building goals are met, and energy performance is maintained over a period of time. To date, ENERGY STAR has partnered with over 5,000 organizations that represent 35% of the Fortune 500 companies, including major league sports teams, small businesses, colleges/universities, and cities/towns working on sustainable urban infrastructure or large development projects (EPA, 2013).

Net Zero Energy Building Certification

The Net Zero Energy Building Certification program is part of the International Living Future Institute, based on the Living Building Challenge. In order to qualify for certification, a building must meet actual performance standards, as opposed to modeled or anticipated energy performance (International Living Future Institute, 2012). In addition, the building must be constructed to incorporate renewable energy systems along with waste processing systems, making it more aggressive than LEED or ENERGY STAR. The program also has an equity and design component as well as requirements on how the building interacts with the surrounding habitat (International Living Future Institute, 2012). The Net Zero Energy Building Certification program strives to integrate architectural design, art, landscape and green building.

The program is new and only began certifying residential and commercial buildings in 2010, with 11 buildings being certified as of September, 2013. Although there are only a few number of total certifications, the program is more rigorous than other green building programs, providing a platform for advancement of net zero building approaches.

Chapter 3. Literature Review

Literature review for this research focused on three primary areas. The first area explores classic diffusion of innovations theory, which provides the theoretical background for analyzing potential market impacts of the CBP program. The second area focuses on corporate social responsibility, organizational theory, and environmental management, which provides foundations for organizations' motivations for implementing sustainability protocols and energy efficient technologies. The third body of literature explored focuses more specifically on the economics of energy efficiency and related policy, including the energy paradox which provides a behavioral perspective to efficiency gains. Focus on economics provides additional background motivations for organizations' participation in green building programs and was cited by survey and interview respondents as the primary motivation for participating in the CBP program.

Diffusion of Innovations Theory

The discussion of diffusion theory explores two primary areas. First, the historical significance of diffusion of innovations theory is discussed, including modeling techniques used by various industries. Second, literature pertaining specifically to energy efficient technologies and green building is presented, utilizing the diffusion of innovations theoretical framework.

Historical Perspectives of the Diffusion on Innovations Theory

New innovations have been introduced into society for as long as humans have developed communities. At its core, innovation diffusion occurs due to social interactions, but has more traditionally been measured by other economic indicators such as capital accumulation (Fagerbert, 2003). One of the first social scientists to study innovation diffusion was Joseph Schumpter, who in the 1930’s analyzed the role of innovation in economic and social change (Schumpter, 1949). Schumpter first defined innovation as “new combinations” of existing resources that became a driver for economic development, and that these activities were spurred by entrepreneurs (Fagerbert, 2003). While Shumpter’s focus was more on the innovation process, his insight provided foundations for analyzing market penetration of new products. Later work by many scholars and academics further explored innovations, defining product and process innovations separately, which is not discussed here since it is out of scope for this research.

The diffusion of innovations theory also has a spatial component, especially in the context of urban studies. Different areas, with varying resource availability will innovate and adopt new technologies based on regional perspectives. City-system development is dependent on the organizational structure and resource availability of an area, which requires diffusion studies to take into account the spatial structure of these organizations (Pred, 1974; Pred, 1975). This organizational structure spurs urban growth and regional economic development in measurable ways. The first way urban advancement is diffused is through contagious spread of “clustered growth” which is a result of concentrated advancement from a central area (Hudson, 1969). This idea originated from Torsten Hägerstrand, who also noted that diffusion occurs concentrically, with through a central location, known as the “initial frontier” (Hägerstrand, 1965).

From an analytical perspective, diffusion of innovations theory (pertaining to technology transfer) was developed in the 1960’s by Everett Rogers as a means to describe the process of technical change and advancement of innovation within a culture over time (Rogers, 1995). Rogers has been cited as providing the technical outline for most energy efficiency diffusion analysis (Shove, 1998). Mathematically, the primary model used to measure diffusion in markets, per Roger’s theory, was developed by Frank Bass in 1969. This model was used in this research and is discussed in detail in the Methodology chapter of this thesis.

Technology diffusion happens over five primary “adopter” categories, resulting in an S curve when analyzed over time, as presented in figure 3 below. New ideas developed by innovators are introduced into the market with very little penetration and are first accepted by early adopters. The next adopter categories are the early and late majorities, and eventually the laggards (Rogers, 1995). The result is a description of the process, based largely on communication channels, in which new products become adopted by a population or society.

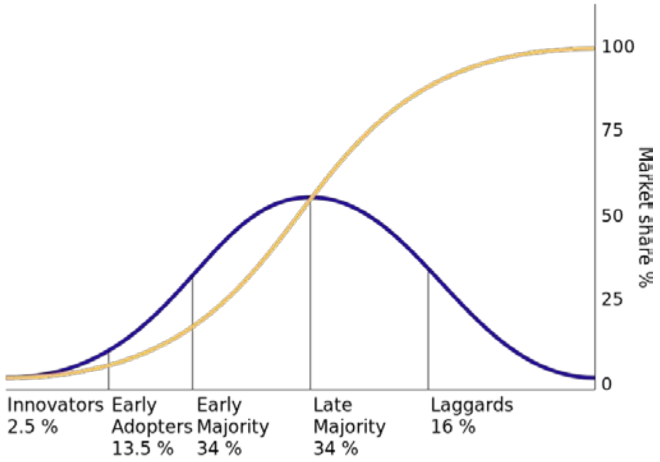

Figure 3. Adopter Categories and Market Penetration of the Diffusion of Innovations Theory (Rogers, 1995)

The period of time between when the innovation is developed and eventually saturated into the market can vary greatly. This can be due to lags in commercialization, lack of adequate materials, or general lack of a well-defined product/idea (Fagerbert, 2003; Kline and Rosenberg, 1986; Rogers, 1995). Analysts tasked with exploring technology diffusion develop coefficients or other assumptions to control for these varying factors that impact the diffusion process within different markets or technology sectors.

Finally, another approach to diffusion theory is to model technology adoption and substitution of products. The traditional approach for this type of analysis is coined the Fisher-Pry model, developed in the 1970's (Fisher and Pry, 1971). The model has been used to explore the number, order of magnitude and pace of new technology adoption in society (Norton and Bass, 1987). The model assumes a 50% substitution rate for technology adoption, and note “many technological advances can be considered as competitive substitutions of one method of satisfying a need for another” (Fisher and Pry, 1971). The 50% technology substitution assumption is built into the equation, making it more difficult to adapt to a broad range of market analyses.

Diffusion of Innovations Theory and Energy Efficiency

The energy efficiency technology and green building industries have seen tremendous innovation and growth in recent decades. Market analysis of technology innovations and effectiveness of technology transfer has been studied utilizing the diffusion of innovations theory and modeling. On an international scale, one recent study found that distance plays a large role in dissemination of energy efficient knowledge; countries far from innovators are less likely to obtain knowledge related to energy efficiency (Verdolini and Galeotti 2010). In addition, higher rates of diffusion of energy efficiency technologies have been associated with greater technological learning and information availability (Weiss et al., 2010; Claudy et al., 2011).

The literature relating to diffusion modeling being used specifically for green building applications is more sparse. There are studies, but most focus on specific technologies, not the entire energy efficient building as the product diffused. This research aims to add to the literature, providing an analytical method for energy efficiency diffusion on a whole-building scale. Yudelson (2005) used a diffusion model to predict market penetration of USGBC LEED buildings. In his analysis, he utilized a Fisher-Pry model for technology substitution in order to predict the future diffusion of LEED buildings in the commercial sector (Yudelson, 2005). Thus one weakness of using the diffusion of innovations for this study could be that there are not many proven analytical methods to reference and use in building the CBP model. However, the strengths of the model, including diffusion models' potential accuracy in predicting market penetration of energy efficiency may be a useful tool for analyzing green building programs.

Different versions of the Bass model have been used to predict energy efficiency technology diffusion in the building sector by several authors. The work of Elliott et al. (2004) used a modified version for specific building technologies including condensing furnaces, compact fluorescent lights, and low-emissivity windows. The authors determined coefficients (*p* and *q*) and market potential for each individual building technology or energy measure separately. Andrews and Krogmann (2009) compared 1992 and 2003 CBECS data to explore key technology diffusion trajectories and energy intensities over time. In more recent work, Kok et al. (2011) analyzed green building diffusion in U.S. property markets, estimating that 30% of commercial office space in large metropolitan areas is ENERGY STAR certified, and 11% LEED certified. This research expands on the diffusion modeling literature by providing a method for analyzing diffusion potential of energy efficient commercial buildings on the whole-building scale.

A related perspective to technology diffusion is energy efficiency market transformation. Market transformation occurs in the later phases of innovation, once a particular idea has significantly penetrated the market. Research has shown that for the commercial building energy efficiency industry, process change should occur in three levels: 1) making energy efficiency relevant, 2) encouraging demand and institutionalizing energy efficiency in the market place, and 3) standardization within the development/design process (Lutzenhiser et al., 2001). These principles speak to the importance of program development and administration.

Institutional Theory, Corporate Social Responsibility and Business Environmental Management

There is a wide body of literature existing that explores traditional institutional and organizational theory. Most relevant to this research is neoinstitutuional theory which includes neoclassical economic notions such as optimization, marginality and equilibrium (Scott, 2008). Institutional theory research investigates both internal and external influences on firms that motivate them to adopt values, policies and procedures to minimalize risk. Such pressures have been identified as coercive, normative and mimetic pressure (DiMaggio and Powell, 1991; Scott, 2008). Much focus has been paid to understanding firm motivations to adopt environmental management practices. In general, organizational structure and management institutional pressures contribute greatly to the environmental management program instituted by a firm. Non-market pressures (customers, stakeholders etc.) tend to be business drivers and support enhanced voluntary environmental management to elevate the company. Such measures are supported by marketing departments. In contrast, market pressures are handled through the legal department of a firm and are seen as risk mitigation for future regulations (Delmas and Toeffel, 2008; Alberini and Segerson, 2002).

Whether an organization decides to purchase or introduce energy efficiency measures, originally installed during their participation process of the CBP program depends on economics of the project (as discussed in the findings chapter), and organizational structure or behavior. A growing literature is focusing on the behavioral sciences to investigate non-monetary motivations for increased energy efficiency (Allcot and Mullainathan, 2010). This section explores organizational motivations for replication by CBP partners, outside of cost savings. In an effort to measure CBP partner motivations to replicate energy efficiency measures into other buildings, a portion of the survey and interview was dedicated to non-monetary motivations.

Corporate social responsibility (CSR) initiatives are becoming mainstream in most markets today. Environmental corporate social responsibility is a loosely defined term pertaining to the role of self-regulation within private corporations regarding environmental protection (Portney, 2005; Lyon and Maxwell, 2008). From a market perspective, CSR is promoted by both demand and supply side forces. On the demand side, the largest factors are the level of competition of firms, investor influences and labor retention through CSR practices. On the supply side, efficiency can be enhanced by reducing waste and streamlining the production process; often this can present a cost effective approach to abating the “low hanging fruit,” so to speak (Lyon and Maxwell, 2008; Reinhardt, 2000). Market forces also are at play in the international arena; firms with production facilities in countries with lax or nonexistent laws, transfer their CSR practices to their facilities overseas, thus promoting a higher level of environmental protections in countries that otherwise have little or none (Portney, 2005).

There are many political forces that support CSR programs. Voluntary pollution prevention programs are supported by industries primarily due to their cost effectiveness. The CBP program is an example of a voluntary program aimed at reducing the building environmental footprint. In many cases, the cost of voluntarily lowering toxic chemical use (for example) is significantly less than the costs associated with complying with a federal regulation mandating abatement. In other words, it often makes economic sense to voluntarily institute environmental measures as opposed to waiting for regulations to be enacted. Blackman (2010) supports this notion by identifying a firm’s cost-maximizing potential by balancing the expected marginal penalty with the marginal abatement costs. Regulations to control pollution will shift either curve (supply or demand), causing the equilibrium to shift down, thus reducing profits. Voluntary practices to reduce emissions can help keep profits maximized, typically because the private sector can lose profits in order to comply with new standards (Porter and Van der Linde, 1995). While economic in nature, these are some of the underlying principles of CSR and business environmental management.

Another motivating factor besides cost and energy reduction, impacting the willingness of companies to engage in increased energy efficiency or other sustainable building programs is overall organization culture. Organizations that encourage CSR programs or are environmentally minded tend to be more willing to invest in technologies or applications that improve building or operational efficiency (Kahanna et al., 2007). Likewise, companies with socially conscious CEOs or upper management are also more likely to have voluntary environmental programs (Delmas and Toffel, 2008; Ervin et al., undated; Martin et al., 2012). In terms of CBP partners, all participants interviewed for this study indicated that CSR, company culture, and sustainability initiatives played a part in the organization's willingness to participate in the CBP program and invest the upfront capital necessary for efficiency upgrades in new or existing building. One respondent identified that the CBP program was an opportunity to increase education, awareness and competency for sustainable operations. However, all respondents indicated that cost savings was their primary motivation.

Economics of Energy Efficiency

The previous section discusses corporate social responsibility and the economics of motivating businesses to participate in business environmental management programs as an underlying motivator for companies. While also exploring economic considerations, this section focuses specifically on the economics of energy efficiency, namely in the built environment.

In addition to realizing increased efficiency, installation of energy efficient technologies has been determined by many to provide economic gains. Overall building design can help achieve energy and cost savings. For example, design solutions for existing commercial buildings based on climate zone in which the building is located has been estimated to have a cost savings potential of 10—20% (Belzer, 2009). Other studies point to economic gains from lower operation costs of HVAC systems due to increased envelope efficiencies (Kneifel, 2010; Howarth, 2010). Analysis of the CBP program will provide further insight into the possible savings associated with energy efficiency installments.

The terms “triple bottom line” and “win-win-win” are used to describe firms who are trying to maximize profits, reduce costs and protect the environment. In an effort to achieve this, many companies aim for product differentiation and profit maximizing potential (Reinhardt, 2000; Blackman, 2010; Lyon and Maxwell, 2008). They are also motivated as a way to abate future costs associated with complying with regulations. Voluntary pollution prevention programs are supported by industries primarily due to their cost effectiveness.

Interestingly, Lyon and Maxwell (2008) note that there is little measureable societal benefit from such programs. This could be a foreseen conclusion, since it aligns with some of the open-access theories of environmental economics. If CSR methods do not optimize environmental protections, then they must act as a profit maximization tool for corporations. While CSR should be promoted, it will not alone act to optimize the net benefits to society of environmental protection. This is because of the open-access issue associated with many public goods. Firms do not have incentive to stop consuming at the point that rents are maximized; instead they will consume (or degrade the environment) until their total cost curve crosses their total benefit curve. This naturally results in overconsumption since the profit maximizing point is well beyond the rent maximizing point of consumption.

The literature supporting both efficiency and economic gains varies greatly. Some economists argue that although analysis of potential savings is positive, behavior patterns have yet to support development of efficiency markets (Gillingham et al., 2009). Others assert that cost-saving strategies such as efficient lighting systems or ENERGY STAR electronics increase when firms participate in public programs, but only because the firm did not have the information prior to participating in the program (Howarth et al., 2000). In other words, companies are always as efficient as possible and once they know that installation of efficient lighting systems will reduce operation costs, the will not hesitate to install these measures. This represents full market penetration, in terms of adoption trends of the diffusion of innovations theory.

The Energy Paradox

Many argue that market penetration of energy efficient technologies is much lower than the potential savings of those technologies, a term dubbed the “energy gap” or “energy paradox” (Jaffe and Stavins, 1994; Alcott and Mullainathan, 2010; Klemich, 2013). The goal of this research is to add to the literature and support methods for better understanding energy efficiency program replication over time, through analysis of a well-established public-private energy efficiency program. One aspect of energy efficiency programs that is greatly criticized is the fact that buildings are designed from model outputs that do not account for human behavior, representing investment barriers (DeCanio, 1993; Deuble and de Dear, 2012). This issue is recognized by many green building programs and efforts to remedy this issue by promoting longer-term measurement and verification periods are being taken.

Market barriers for energy efficiency have been a focus of the current administration and continue to be focused on by scholars (Charles, 2009; Hoffman and Henn, 2008). Diffusion of advanced technologies tends to be gradual (Jaffe and Stavins, 1994). Some technologies analyzed in the CBP program are new technologies that have not been on the market long, so it is likely those technologies in stand-alone analysis will penetrate the market rather slowly. However some technologies, especially those with short payback such as LED lighting are being replicated by all partners and will likely diffuse into the market more quickly than preceding technologies, such as CFL lamps.

Chapter 4. Theoretical Framework

Diffusion theory provides the background for the theoretical framework of this research. Traditional innovation or technology diffusion theory was developed in the 1960's by Everett Rogers as a means to describe the process of technical change and advancement of innovation within a culture over time (Rogers, 1995). Technology diffusion happens over five primary "adopter" categories, resulting in an S curve when analyzed over time. New ideas developed by innovators are introduced into the market by early adopters, then through the early and late majorities, and eventually the laggards (Rogers, 1995). The result is a description of the process, based largely on communication channels, in which new products become adopted by a population or society.

This research uses diffusion theory to explore potential outcomes of building programs and partnerships on energy intensities in the commercial building industry. While Rogers' diffusion of innovations theory has been widely used in market research for technology adoption, application of this theory to commercial building energy efficiency is relatively new in terms of a whole-building approach to energy savings. Figure 4 is a representation of Rogers technology adoption curve, representing each phase of market transformation.

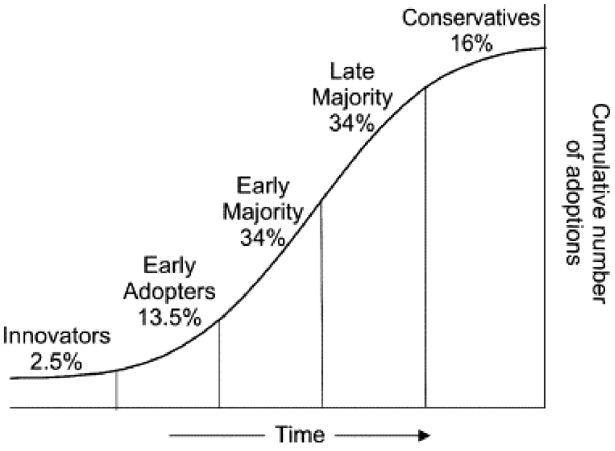

Figure 4. Traditional Diffusion Curve (Patenaude, 2011)

The proposed theoretical framework for this study builds off of Bass and Rogers diffusion of innovations S-curve, applying the diffusion theory to the CBP program, and beyond. CBP participants, although motivated by cost savings, represent early adopters within the curve, expanding to partner portfolios, and the entire stock of commercial building square footage in the United States. As the suite of measures included in the CBP program is replicated, the potential for market transformation through technology diffusion is realized.

Figure 5 below represents the proposed framework and model for this study based on the diffusion of innovations theory. Instead of the S-curve illustrated in Figure 4 above, this framework displays market diffusion from the innovators represented in the smallest circle, out to full market penetration, represented by the largest circle. The gradual evolution of the energy efficiency market within the commercial sector begins with the innovators and ends with laggards. The CBP program is identified as an innovator because it promotes an optimized approach to designing a suite of energy efficient approaches that optimize energy performance of the building. This is different from other programs that require a checkbox-style approach to green building.

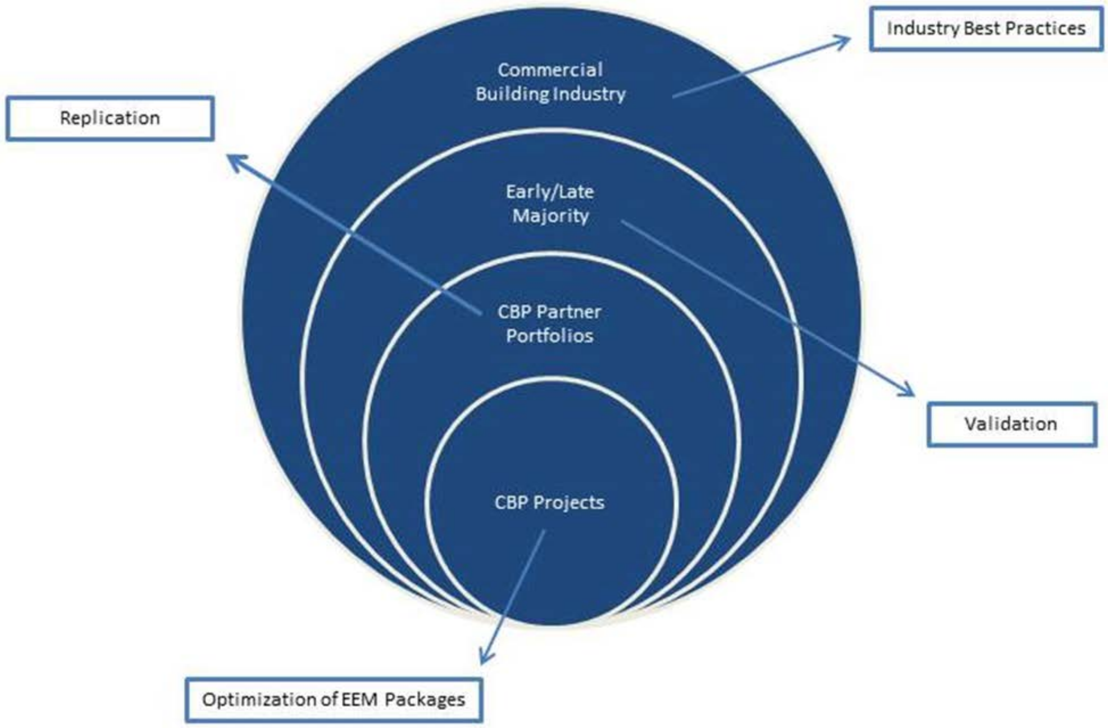

Figure 5. Theoretical Framework

Each level of adopters represented within the circles of the conceptual framework is a result of a primary outcome of their market experience. For the CBP partner specific projects, a package of energy efficiency measures (EEM's) were optimized based on building use, cost and energy savings then implemented into the building project. The second circle, “CBP Partner Portfolios”, represents the replication efforts of each partner based on their optimized EEM package. The third circle, “Early/Late Majority,” represent broader market adoption and validation of EEM packages. Finally, “Commercial Building Industry,” is characterized by what Rogers refers to as “laggards,” the final saturation level realized after industry best practices have been identified and documented. In the case of commercial building energy efficiency, market saturation or transformation would occur when price and energy savings packages are maximized.

Chapter 5. Methodology

This research utilized two approaches to understand specific CBP partner program experience, and potential market impacts for full CBP deployment within the commercial building industry in the United States. This section discusses the specific research question and research design for this effort.

Research Question

The broad goal of this investigation is to analyze the CBP program critically in an effort to better understand the impacts of public/private partnership energy efficiency, including overall energy savings, cost-effectiveness and behavioral changes. More specifically, this study aims to analyze direct impacts of the CBP program on the building portfolios of participants in an effort to determine the overall influence the program has had on the larger building portfolios of CBP partners.

The focus of this study addresses two primary research questions:

1. How are CBP partners replicating specific measures, treatments and processes throughout their building portfolios? How are these efforts verified?
2. How are efforts undertaken through the CBP program diffusing into the overall commercial building industry?

By exploring these questions, this study aims to provide insight into how firms replicate the measures of one building project, and their participation in the CBP program, into the rest of their building portfolios. Additionally, a better understanding of CBP program replication can help correlate the design of public/private partnerships for buildings energy efficiency. This includes analysis of the program structure, individual results and how those results translate into the remaining building stock held by the owner/operator.

What is Replication?

For this study, replication refers to the implementation of building science measures, such as envelope, HVAC and lighting treatments into other buildings owned by a company. Specifically, this refers to transferring EEMs from the CBP building project into the rest of the company's building portfolio. Factors that impact replication include motivation, organizational structure and objectives firms have for implementation of energy efficient technologies. Comparing these factors between different CBP partners may reveal patterns in motivation for constructing energy efficient buildings, along with better insight into corporate environmental management.

Research Design

In order to study replication of the CBP program, this study surveyed program participants regarding their participation in the CBP, including motivations, desired outcomes and continuing efforts. The survey was created, distributed in May, 2013, and followed up with personal interviews with each participant. While the CBP program represents a significant amount of commercial building space in the United States, the total number of participants is relatively small. There are a total of 42 CBP partners, whose building portfolios amount to approximately 3.6 billion square feet of commercial building space (DOE 2013). The survey instrument was distributed to 11 individual partners (12 projects), representing 858 million square feet of commercial building space, about 1% of all commercial square footage in the United States, and 28% of all CBP participant building portfolios.

Because this research is focused on impacts of a specific program, the sample analyzed was not chosen at random, and pretests were not utilized to enhance the survey mechanism. In its entirety, the CBP program is consulted by four national laboratories: Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Argonne National Laboratory (ANL) and the Pacific Northwest National Laboratory (PNNL). Data was gathered through the specific partners of the PNNL. Due to confidentiality protocols, specific partner names are not used in this analysis, however, a full list of CBP partners is available from the U.S. Department of Energy (DOE, 2013).

Selection of each CBP participant was a competitive process through DOE (DOE, 2013). Once selected, each participant was partnered with one of the three national labs to act as building consultants. This partnership resulted in a design-build process to carry out the construction or retrofit project based on modeling results, company objectives and program requirements. The consulting teams from each lab were comprised of people with similar backgrounds and education including engineers, building scientists, energy analysts and program managers. As such, this study makes the assumption that NREL, LBNL, ANL and PNNL's approach to optimizing EEM packages for their CBP partners are alike. That is to say that the same project conducted by any of the three labs would result in nearly identical approaches to energy and cost savings.

Protocol development for this study was aimed to ensure that data gathered from each participant was collected using a systematic approach and set of questions, providing both quantitative (survey) and qualitative (interview) data. There were two formats of questions:

1. A feedback survey mechanism, distributed through Survey Monkey, with scaled, yes/no, multiple choice, multi-select, and open-ended questions. The feedback survey was completed by CBP partners in May, 2013.
2. A personal telephone interview with follow-up questions, open-ended in nature, designed to give further insight into replication efforts. Follow-up interviews with CBP partners were completed in June, 2013.

The Survey Instrument

The feedback survey was sent via Survey Monkey, a website that provides surveying services with various features for developing surveys, collecting, and analyzing responses. The Survey Monkey site allows the user to develop and monitor surveys and responses, conduct basis analysis and download, track and manage respondent answers. Prior to completing the survey, respondents were sent a letter explaining the intension of the survey, the format and process and procedures for completion. Respondents were asked to access and complete the survey within two weeks of receiving the Survey Monkey link, which was sent to their email. The complete introductory letter can be accessed in Appendix A. The feedback survey was sent to participants on May 10, 2013. Appendix B contains the full survey in the format sent to respondents. Each respondent was given two weeks to complete and resubmit the survey. During this time, respondents were sent reminder emails twice to encourage survey participation.

The feedback survey contained three primary categories with a total of 37 questions on a variety of subjects relating to their organization’s participation in the CBP program. The first section focused on CBP partner structure, motivations and objectives for implementing CBP measures, along with organizational demographic information. The second section was focused on specific replication strategies and outcomes of replicating CBP measures. The final section was intended to provide information about outcomes of replication, documentation processes and long term monitoring of CBP measures.

The questions in the feedback survey were presented in various formats. The first format provided fixed-alternative questions with one answer, such as “yes-no” questions. The second question format was a 3-point scale where multiple options could be selected by participants. The third format was a ranking system, allowing the user to rank the importance of various types of green building motivations.

Follow-Up Interviews

Once the survey instruments were completed, follow-up interviews were scheduled and conducted to gain further qualitative insight into CBP partner participation and experiences. The interviews were scheduled on the week of May 24, 2013, and conducted throughout the month of June. The interviewee and survey respondent from each organization was the same person, and interviews were focused on expanding survey responses. Each interview was conducted over the telephone, and lasted anywhere between 20—45 minutes, depending on the preference of the interviewee.

The format of the interview, specific interview structure and questions can be found in Appendix C. Although the interviews were structured, many respondents discussed specific interests, opinions and feedback that was unstructured in nature.

Data Analysis

Data analysis for this study is broken out into two primary efforts. The first focuses on the primary data gathered through the survey and interview mechanisms. These data provided insight into specific experiences of each CBP partner. Additionally, a diffusion model was developed utilizing data from each CBP partner. The model was calibrated using commercial green building data that were obtained through the United States Green Building Council (USGBC). Thus, the second portion of this effort resulted in two analyses.

Data for both efforts was analyzed using The R Project for Statistical Computing (R), an open source software program providing a language environment for data analysis, calculations and graphic development (The R Project for Statistical Computing, 2013). R was developed in 1997, and is currently managed by the R Foundation, a non-profit entity which maintains R statistical computing software. R is open-source, and available to the public at no cost. R was chosen for this analysis because I am familiar with using this platform for analysis, and believe it creates superior visual graphs compared to Microsoft Excel or SPSS. Additionally, a colleague of mine assisted with the script writing for developing the diffusion model, also utilizing R.

CBP Partner Data Analysis

After the survey and interviews were complete in June, 2013, the data were gathered and uploaded into a spreadsheet. Because the survey data were sparse, they did not warrant advanced statistical analysis. Instead, these data were used to provide descriptive statistics of respondent answers and insights, along with qualitative interview answers providing further insight into motivations, experience and replication efforts.

The survey response was a total of 9 CBP partners, representing 11 projects, from a total of 10 possible respondents, and 12 projects, overseen directly by PNNL. While the total response number is low, it represents 28% of the entire CBP program, and over 1.4 million square feet of commercial building space. Total square footage of these 11 partners building portfolios is close to 1.9 billion square feet of U.S. commercial building space. Figure 6 below presents CBP partner profiles by industry, for the group analyzed in this study. There was an even split between education, finance & financial services, government, and retail & consumer durables (22%). The commercial real estate industry was also represented at 11%.

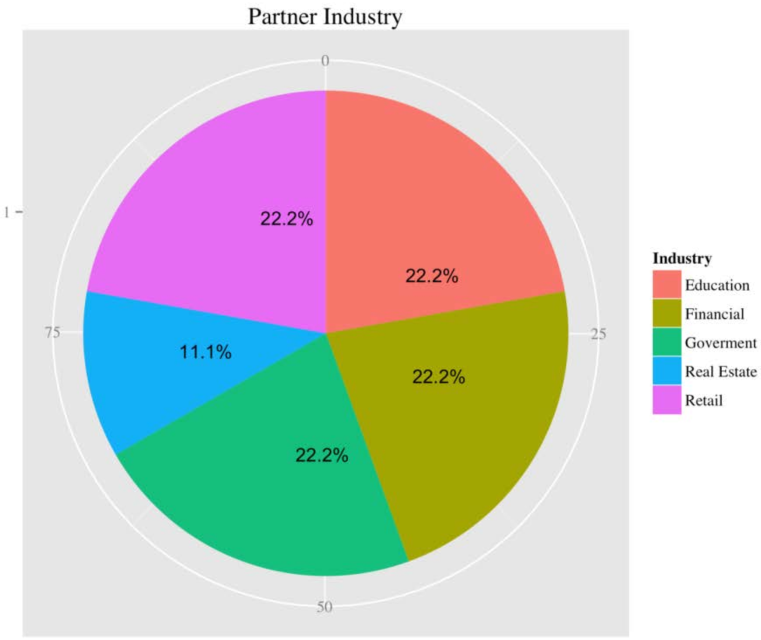

Figure 6. CBP Partner Participation by Industry as Reported by Survey Respondents

As shown in Figure 7 below, the majority (56%) of projects were new construction. Retrofit construction totaled 11%, and three partners (33%) worked on a new and retrofit project simultaneously. Several of the CBP partners had multiple buildings in the program that included one new construction and one existing building project.

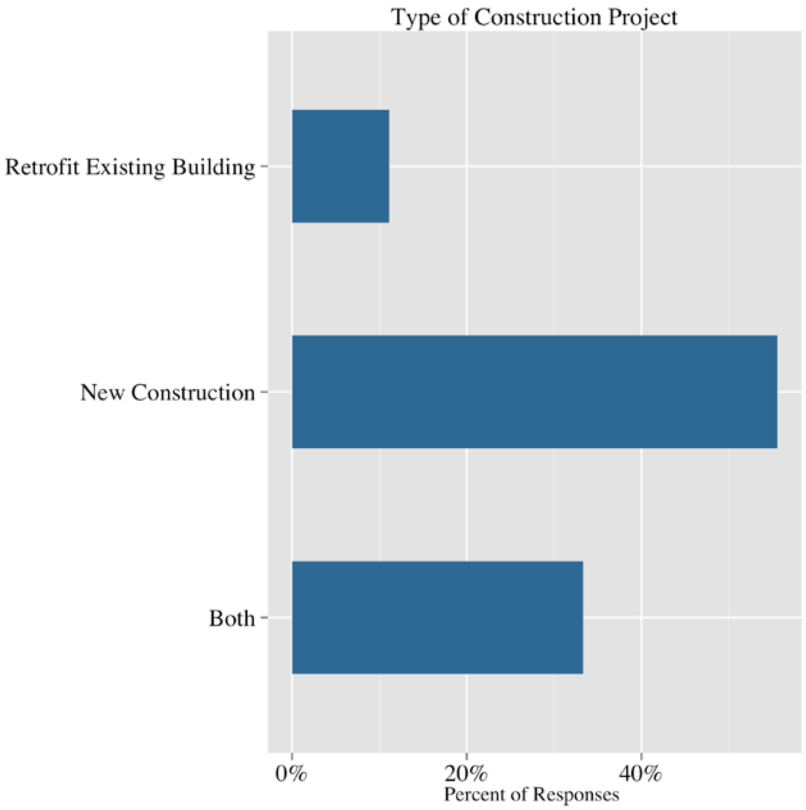

Figure 7. Percentage of CBP Projects by Building Type

The majority of CBP partners that participated in this study have already finished construction and are occupying their new building or retrofit construction project (67%). Figure 8 below presents the design phase of all partners surveyed and interviewed for this study, as of June 2013.

Figure 8. Current Phase of Construction for Each CBP Partner

Diffusion Model Development and Analysis

Another primary objective of this study aimed to gain a better understanding of replication efforts underway by partners, taking EEMs from their specific projects into the rest of their building portfolios. Analysis of these efforts provides foundations for broader market analysis of the potential of the CBP program on total commercial building sector energy consumption and cost savings. Broader market impacts were calculated using data collected from interviews, survey answers and metadata of each CBP partner building portfolios. This analysis used the diffusion of innovations theory to explore possible market impacts of the CBP program throughout the commercial building sector in the United States.

Different versions of a diffusion model have been used to predict energy efficiency technology diffusion in the building sector by several authors, as discussed in detail in the Literature Review chapter of this thesis. For technologies relating to green building, two primary models have been used by researchers; the Bass Model and the Fisher-Pry Model. Mathematically, the first widely adopted quantitative model describing the new product or technology diffusion process was developed by Frank Bass in 1969. In the Bass diffusion model, the formulation is based upon a differential equation representing the number or market share of innovation adopters over a period of time, incorporating both internal and external influences (Bass, 2004). Internal influences are impacts of media, government and other broad adoption efforts, and external influences involve social interaction (Bass, 2004). Both are represented as coefficients (q and p) and are key factors in the modeling technique.

The work of Fisher and Pry (Fisher and Pry, 1971) is similar to the work of Bass, but differs in the initial conditions used to solve the equation. The Fisher-Pry model for technology diffusion has an assumption of 50% market penetration (or substitution), a rate which is built into the model. The Bass diffusion model avoids this issue and is considered more appropriate for this study. Yudelson (Yudelson, 2007) used the Fisher-

Pry model to estimate the market penetration of green buildings as the technology diffused rather than individual energy efficient technologies such as lighting or HVAC systems, which is also the aim of this analysis. So, a process for developing a diffusion model that avoids the 50% market penetration assumption but also analyzes the entire building as the technology diffused had to be created. In order to measure the CBP program on a whole building scale, development of a Bass Model with appropriate values for *q* and *p* were imperative.

Diffusion models are widely used in many industries as a means of forecasting market penetration of new technologies. The general form of the Bass model is given in Equation 1, where:

N(t) is the cumulative number of adoptions at time *(t)*
M is the market potential, a constant
p is the coefficient of innovation
q is the coefficient of imitation or internal influence (Bass, 1969).

$$\frac{dN(t)}{dt} = \left(p + \frac{q}{M} \cdot N(t)\right) \cdot \big(M - N(t)\big)$$

The Bass model may be solved explicitly for the fraction of the market penetrated, *F(t)*, by assuming the initial number of adopters at *t*=0 is 0. This results in a formula that may be used to estimate the cumulative adoptions as a function of *q* (coefficient of imitation) and p (coefficient of innovation). These coefficients describe the curve of the output, speaking to the rate of diffusion within a market.

$$F(t) = \frac{1 - exp(-(p+q)t)}{1 + \left(\frac{q}{p}\right) exp(-(p+q)t)}$$

The diffusion model in this study has been used to estimate the long-term impact of the CBP efforts (within partner portfolios and the broader market) by modeling replication of the CBP program approach over time. The most challenging part of developing the model was identifying the correct values of q and p. The general approach consisted of calibrating the Bass model for a specific application, in this case commercial buildings on a whole-building scale, not individual EEMs within it. Because the only other study analyzing green building on a whole-building scale utilized the Fisher-Pry model, a method for calibrating it to the Bass model was necessary. To calibrate the Bass model, a larger whole-building data set was needed so the USGC certification database was considered.

For application to CBP buildings, this study adopted the diffusion process based on the model developed by Bass (Bass, 1969) but treats the entire energy-efficient building as the technology to be diffused rather than a specific EEM. One of the most important factors in Bass model development is the correct identification of the primary coefficients, q (coefficient of imitation) and p (coefficient of innovation). To determine the appropriate coefficients for this model, the market penetration of green buildings was examined using the methodology of Yudelson. Specifically, the empirical modeling was based on the market data available for LEED certification.

The current study is not focused on the validity of the USGBC system, and considered it only as an energy efficiency program that operates at the whole-building level in a manner comparable to the CBP program. The USGBC dataset has a much larger number of data points than CBP; roughly 15,500 certified buildings are included in the dataset at the time of this study (USGBC, 2013).

The data set was downloaded from the USGBC website and the Yudelson estimate was compared to actual LEED certifications as shown in Figure 9 below. The red data represents actual USGBC data (USGBC, 2013), and the blue line is the Yudelson estimated (modeled) diffusion profile presented in his 2005 analysis. No modeling work was done to these data, only comparison between actual buildings constructed, and Yudelson’s predictions using the Fisher Pry diffusion model developed for that study.

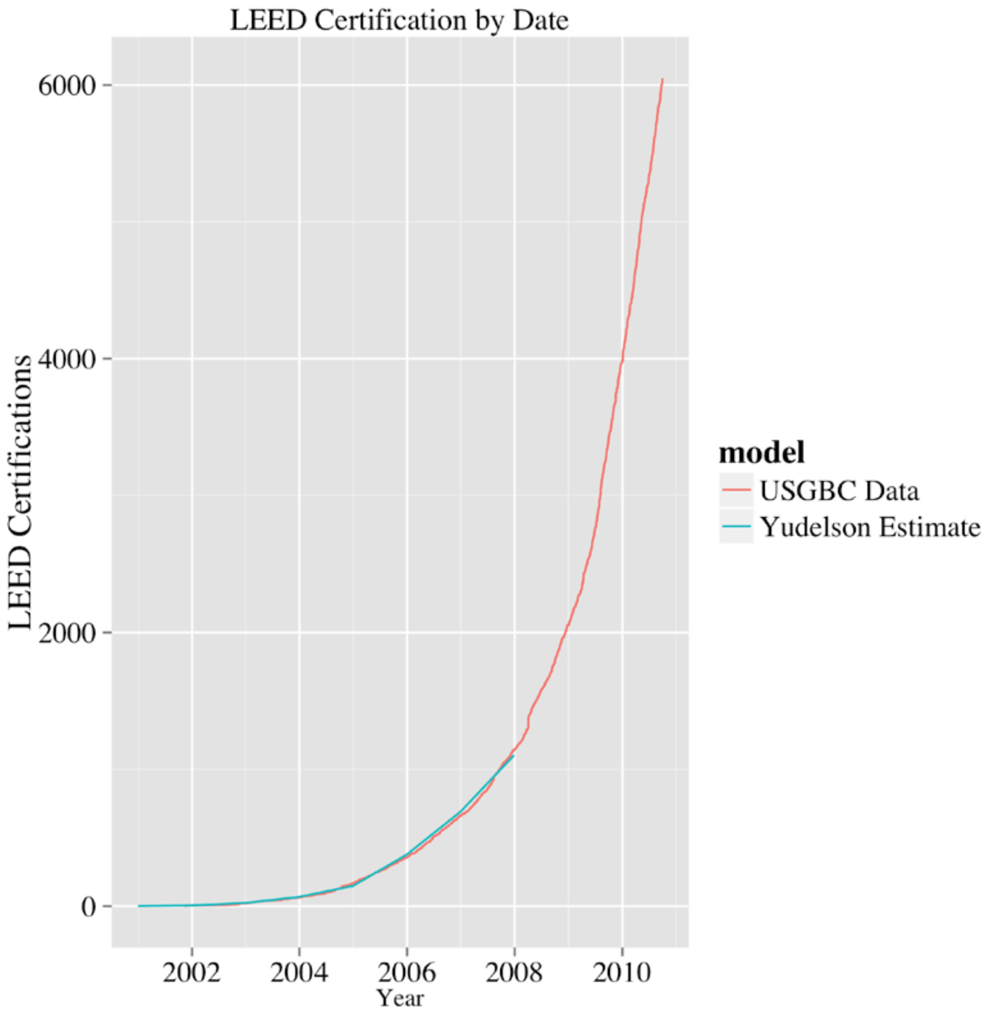

Figure 9. Raw USGBC Data and the Yudelson Model Predictions

The Yudelson diffusion model over-predicted the number of LEED certifications in the first years of the model, and then improved through 2007 as shown in Table 2 and Figure 10 (and discussed in the Findings chapter). However, the general shape of the diffusion curve closely matches the historical data for subsequent years. One limitation of the Yudelson technique as discussed above was the formulation of the diffusion equation, which required an initial condition estimate of the 50% penetration rate. The Bass diffusion model avoids this issue and is considered more appropriate for this study.

The raw data downloaded from USGBC were fit to the Bass model using a range of p (coefficient of innovation) and q (coefficient of imitation) parameters with a range of p between 0.000001 and 0.5 based on the results of Elliott et al. (Elliott et al., 2004). Similarly the value of q varied between 0.005 and 1. These values acted as a low and high range and were laid on top of the USGBC dataset. Once the ranges of the parameters were on the USGBC data, the fit of the p and q parameters was evaluated using the traditional definition of R^2. The results of the R^2 analysis gave the optimal value for both p and q, which were then used to analyze the CBP program. In the following equation, y_i is the observed raw data, $\bar{y}$ is the mean of the raw data, and f_i is the value predicted by the Bass model for each time point.

$$R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \bar{y})^2}$$

Table 1 provides a summary of the modeling inputs and outputs. The final p and q coefficients are based on maximizing the R^2 coefficient. Using a straightforward grid search methodology, a 100x100 matrix of p and q parameters was generated and the predicted number of adoptions was calculated using the Bass model for each pair of parameters. The R^2 coefficient was evaluated for each parameter pair in the matrix and the final pair of parameters was selected on the basis of the best model fit to the raw data.

The maximum market potential (number of buildings) was estimated based on the average commercial buildings size during the time frame of data considered and the estimated total amount of floor space. The market potential is based only on new commercial construction because only a small portion of the USGBC building database is comprised of building renovations (only 5,887 of 41,505 buildings in the USGBC data base are tagged as “Existing Buildings”). The maximum market potential in this case is represented by the total number of buildings in the U.S. *(m)*, which matches fairly well with the number estimated by Yudelson (2005).

Table 1. Bass Model Parameters Determined from the Raw Data

Bass Model Parameter	**Value Determined (Bass Traditional)**	**Source**
p - coefficient of innovation	8.42e-5	Data fitting
q - coefficient of imitation	0.359	Data fitting
m - maximum market potential (number of buildings)	1,068,493	Total new commercial buildings constructed between 2000-2013, estimated from 14,700 ft^2/building and $15.6x10^9$ ft^2 (EIA, 2008; DOE, 2012b)
R^2 - coefficient of determination	0.987	Calculated to compare fit of Bass model with USGBC data

The final Bass model parameters predict the correct trend for certification in the later years, but show a tendency to over-predict diffusion in the first few years of the LEED program. Figure 10 shows the Bass model and raw data on the same scale. While over-predicting the behavior in the first eight years is an issue for the Bass model, it is the slope of the model in the last years that is considered to be the most important result. When using the model to make predictions of market diffusion, the principal variable of interest is the cumulative number of adoptions (total number of buildings). This value is well represented by the Bass model, with the number of predicted energy-efficient buildings only slightly lower than the actual number in 2012 (as shown in the last row of Table 2).

Table 2. Comparison of the USGBC Database with Two Diffusion Models. Data Shown are the Cumulative Number of Buildings (Actual) and Predicted for Each Model.

Year	**USGBC Raw Data (Actual)**	**Yudelson Prediction**	**Bass Model Prediction (Present Work)**
2005	358	377	853
2007	1,145	1,104	2,007
2010	6,674	-	6,350
2012	13,224	-	13,221

The conclusion from this estimation of the Bass model is that it appears to satisfactorily represent the historical cumulative construction metrics for whole-building energy efficiency programs. The Bass model parameters developed also can provide perspectives related to the long-term, future market diffusion of energy efficiency programs.

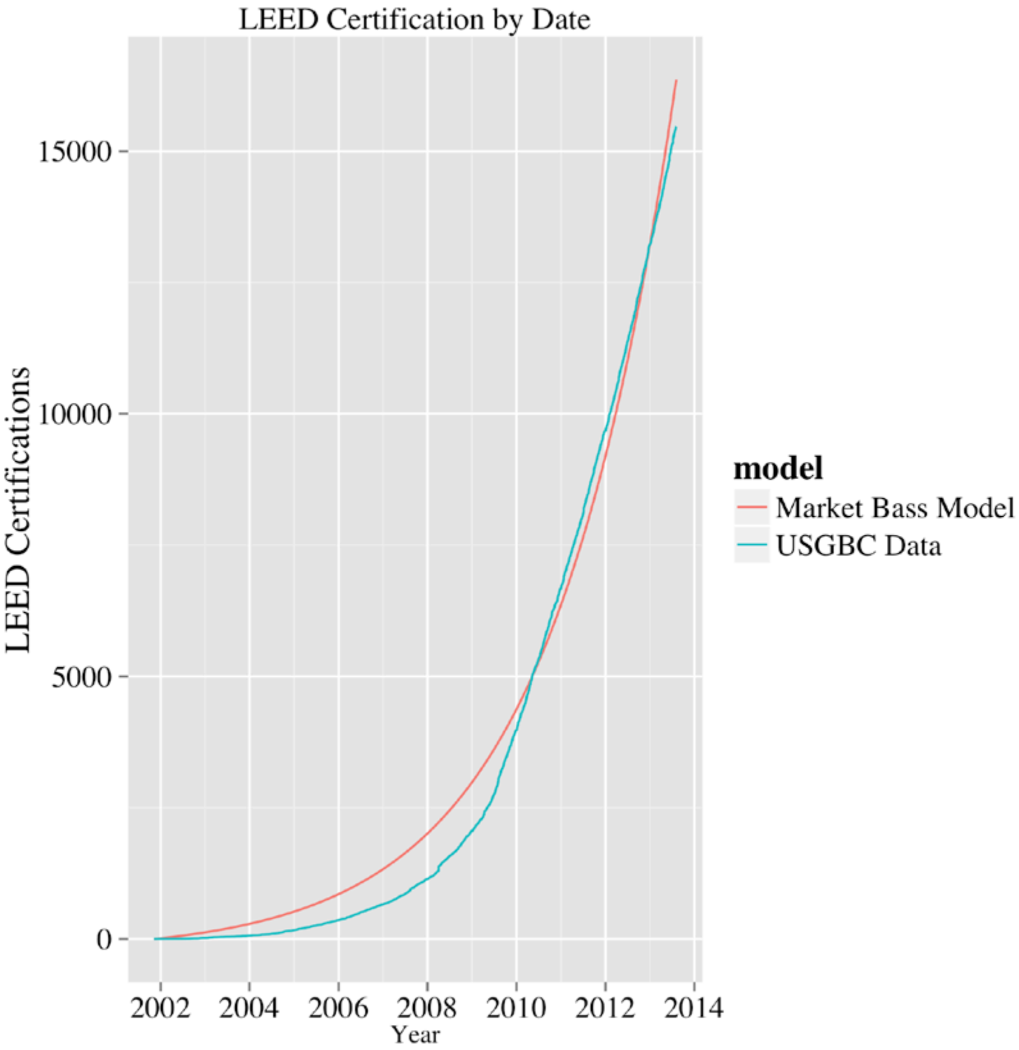

Figure 10. Raw USGBC Data and the Bass Model Fit for This Study

Chapter 6. Findings and Discussion

This section is broken out into two primary sections based on the two types of analyses used. The first section discusses CBP partner replication trends based on survey and interview data, and the second section describes the outputs of the diffusion model analyzing the broader impacts of the CBP program.

Survey Data and Interview Analysis

The survey and interview outcomes were integrated and are presented in the sections below. The first section discusses the basic characteristics of the sample studied for this effort; the second section discusses program participation details; the third section presents specific replication trends; and the fourth section provides information about quality assurance, replication protocol development and objectives.

It is important to note that most CBP partners participated in other commercial green building programs before, during or after the CBP program. Of all survey respondents, 89% indicated participation in the green building initiatives indicated in Figure 11. All CBP partners (100%) who participated in other green building programs were involved in the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program. In addition to LEED, 62.5% participated in the ENERGY STAR program, 25% in the Better Buildings program and 50% in regional utility programs for commercial buildings. Three respondents indicated that achieving LEED certification is part of their building protocol. Only three organizations received incentives to increase the energy efficiency of their building project, all of them from utility programs.

Follow-up interviews conducted for this effort revealed that some of the particular EEMs applied to new and retrofit construction through the CBP program were also utilized by other programs, such as LEED. Because many partners had already been involved in other green building programs utilizing these EEMs, they did not consider transferring these technologies into other buildings as “replication.” This fact leads to the lower replication response rate of 43% discussed in the results section. Three respondents indicated they received utility subsidies for portions of their projects.

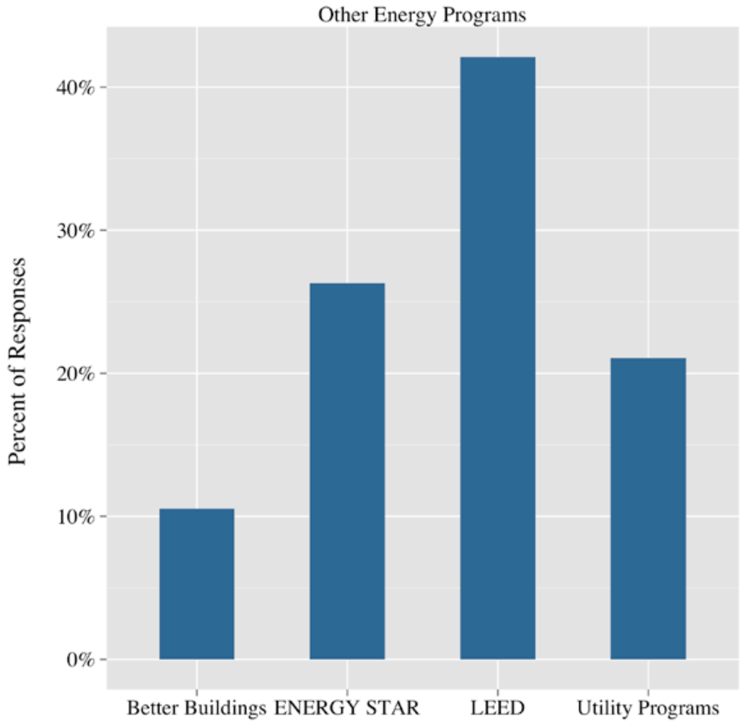

Figure 11. CBP Partner Program Participation Before, During or After their CBP Building Project, by Percentage of Survey Participation

CBP Program Participation Details

This section discusses questionnaire and interview data relating to construction details, energy and cost savings, and investments in green building strategies.

The partners were asked to forecast energy savings over the next 5 to 10 years for their building project. As shown in Figure 12, most partners expect to see whole building energy savings in the range of 31% to 50% compared to existing prototypes for construction (new and existing buildings). A few partners did not respond to the question as shown the left-most bar in the figure. A few partners expect to see energy savings higher than 50%.[1]

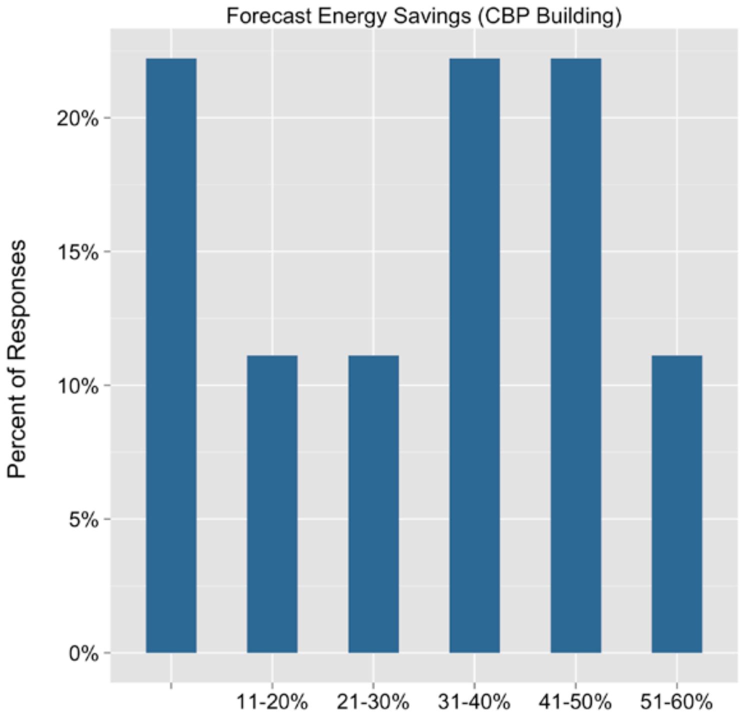

Figure 12. CBP Partner Forecast Energy Savings for the CBP Building in the Next 5-10 Years as Reported in the Survey

The partners were also asked to predict cost savings of energy expenditures for the CBP building as shown below in Figure 13. To better understand the way the partner expects the CBP methods to propagate through the full building portfolio, the partners were also asked to estimate the cost savings expected for the full portfolio. As shown in

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[1] For this analysis, energy savings is defined as site energy use.

Figure 14, the majority of respondents indicated 5% to10% cost savings in the full building portfolio. While these savings are relatively modest compared to energy savings, multiple partners indicated that energy expenditures represent one of the largest percentages of total operational costs, and that 5% to10% savings represents significant kWh and dollar amounts.

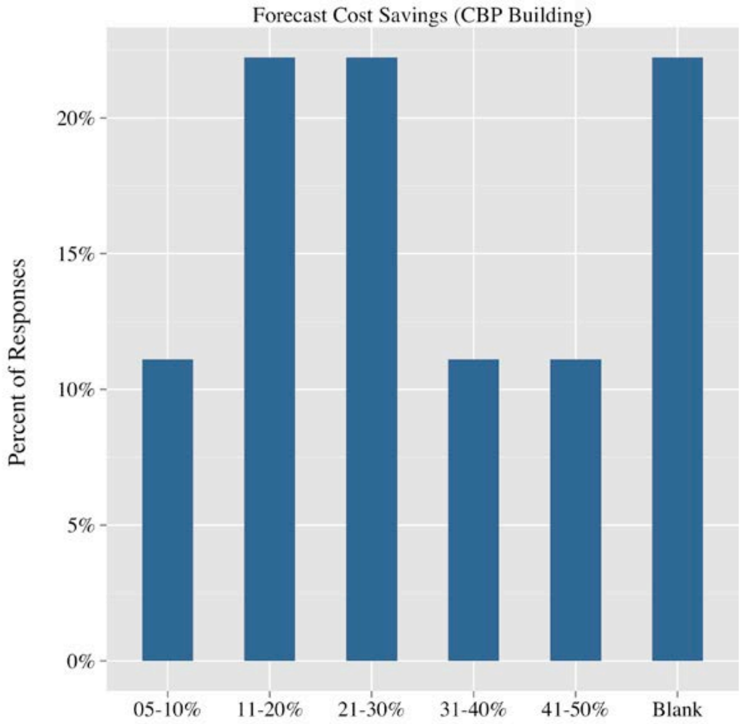

Figure 13. CBP Partner Forecast Cost Savings for the CBP Building in the Next 5-10 Years as Reported in the Survey

Figure 14. CBP Partner Forecast Energy Savings for the Partner Portfolio in the Next 5-10 Years as Reported in the Survey

Partners were asked how they monitored their project during the process of construction. Eight respondents indicated their building projects were commissioned, and monitoring of their project included commissioning agents. As the majority of organizations that participated in the CBP program are large corporations, most respondents indicated the monitoring process was conducted by an in-house team of engineers and project managers who conducted site visits during all steps of the construction process.

When CBP partners were asked about how they prioritize investments in energy efficiency, respondents all indicated that investments in energy efficiency provided substantial operational cost savings. One respondent indicated that a simple payback of 7 years or less was the primary determinant when analyzing EEMs. Four respondents disclosed that energy efficiency investments are highly prioritized by the organization due to voluntary sustainability mandates that include energy reliability.

CBP Partner Replication Trends

Both the questionnaire and interview process yielded data regarding specific replication efforts of a variety of EEMs and reasons for replicating these technologies into other buildings within their portfolios. Most participants indicated their specific CBP efforts will act as a testbed for upcoming new construction or retrofit projects. Multiple interviewees pointed out that their building projects provided valuable lessons that could be applied to other future construction projects, allowing the organizations an opportunity to optimize energy efficiency benefits specific to their energy consumption patterns and needs. This differs from other green building programs, which require a checklist-type system of prescriptive or benchmark requirements.

The questionnaire respondents were split when specifically asked if they would install measures from the CBP project into the rest of the partner building portfolio. 43% indicated they would and 57% indicated they were unsure. None of the respondents indicated they would not replicate measures throughout the portfolio. The split in this response may indicate that many of the questionnaire respondents (57%) are unsure of replication through the *entire* portfolio, but they may be replicating specific measures through part of the portfolio. Follow-up interviews with partners revealed that some EEMs, such as high efficiency HVAC systems and high roof/ceiling insulation, are measures the organization was using prior to participation in the CBP program. Partners indicated that they did not consider implementation of such measures as “replication.” When asked whether replication efforts were a direct result of participation in the CBP program, three respondents indicated yes. A number of partners have identified measures that will be replicated across many buildings or their entire portfolios. Discussion of specific EEM replication efforts are discussed in the next section of this report.

The partners were also asked in how many *other* buildings in which CBP measures had already implemented. Even a few years into the project significant replication is occurring and some respondents indicated replication as high as 6 or 10 buildings. However, most of the partners have not yet replicated the CBP methods beyond the one or two buildings as shown in Figure 15. Still, the majority of partners are replicating measures as a direct result of their participation in the CBP program; 63% said they did not have replication protocols before participating but now do.

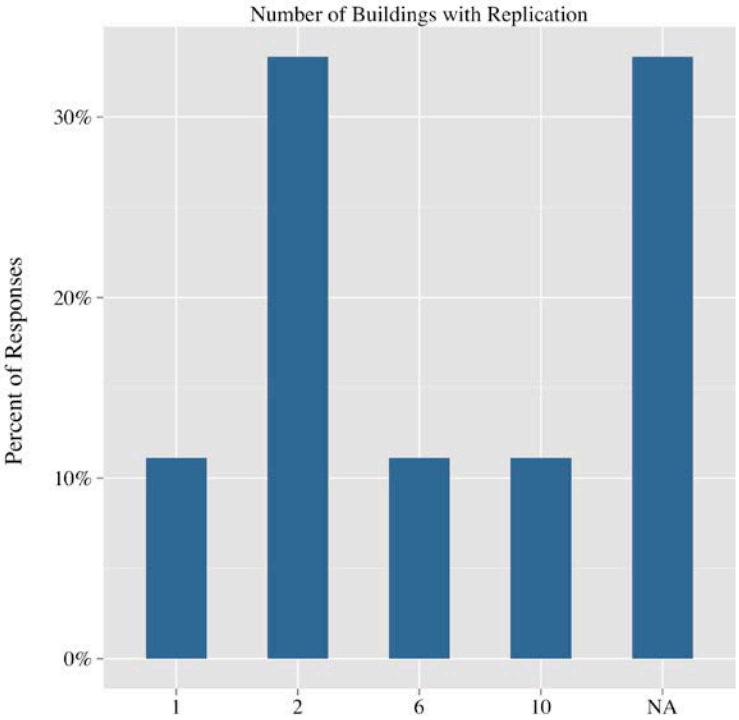

Figure 15. CBP Partner Reported Number of Buildings with Replication at the Time of the Survey

In addition to general program replication, partners were asked to identify specific EEMs (listed in Table 3) applied to their building project(s), which included a variety of HVAC, lighting, envelope, renewables, design and water systems. The technologies in Table 3 are consistent with the State of California's Real Estate Services Division Energy Efficiency and Sustainable Building Measures Checklists (State of California, 2002).

Table 3 below presents a list of these technologies and the rate of replication for each one by CBP partners:

Table 3. Technologies Replicated from the CBP Program

Energy Efficient Measures (EEMs)	**Respondent Replication (%)**
Lighting - low wattage exit signs	100%
Point Use Controls - occupancy sensors	100%
Energy Management System - programming, commissioning and optimization	100%
Lighting - light colored interior finishes	86%
Water - ultra low flush toilets	86%
Water - low-flow faucets & showerheads	86%
ENERGY STAR equipment (computers, TVs, video, etc.)	86%
ENERGY STAR appliances (refrigerators, washing machines, etc.)	86%
HVAC - high efficiency motors	71%
HVAC - high efficiency chillers	71%
Lighting - LED	71%
Point Use Controls - carbon dioxide monitors	71%
Energy Management System - real-time energy metering	71%
Envelope - high-R roof/ceiling insulation	71%
HVAC - high efficiency boilers/furnaces	57%
HVAC - heat recovery	57%
HVAC- carbon monoxide controls	57%
Lighting - low power density	57%
Lighting - exterior lighting (parking lots, etc.)	57%
Point Use Controls - programmable thermostats	57%
Envelope - cool roof system	57%
Water - insulated pipes between supply and faucets	57%
HVAC - high efficiency cooling towers	43%
HVAC - variable-flow chillers	43%
HVAC - demand control variable exhaust	43%
Lighting - indirect lighting options	43%
Daylighting - shading systems	43%
Envelope - high-R windows	43%
Envelope - high-R wall insulation	43%
Energy Sources/Renewables - photovoltaic	43%
Water - exterior management (bioswales, etc.)	43%
Lighting - minimum CFL efficacy 50 lumens/watt	29%
Daylighting - skylights/solar tubes	29%
Envelope - high-R floor/foundation insulation	29%
HVAC - GSHP and/or geothermal heat pumps	14%
Load Shifting/Shedding - cycling, remote metering and controls	14%
Load Shifting/Shedding - on-demand water heaters	14%
Energy Sources/Renewables - solar thermal	14%
HVAC - boiler nitrous oxide emissions control	0%
HVAC - avoid direct evaporative cooling	0%

HVAC - evaporative pre-cooled condensers on rooftop units	0%
Lighting - minimum linear fluorescent efficacy 76 lumens/watt	0%
Point Use Controls - 365 digital clocks	0%
Energy Sources/Renewables - cogeneration plant	0%
Energy Sources/Renewables - onsite wind system	0%

Of all the specific technologies represented in Table 3 above, three have a 100% replication rate:

- Lighting - low wattage exit signs
- Point Use Controls - occupancy sensors
- Energy Management System - programming, commissioning and optimization

Similar to Table 3, Figure 16 below identifies EEMs by primary category, and is broken out to show the penetration rates by building sector. Figure 16 illustrates that the HVAC and lighting measures were the most popular measures for replication for all building sectors, even though some partners did not consider HVAC EEMs to be replicable because they were already doing it. Follow-up interviews revealed that many partners found LED technologies to be very promising for future energy and cost reductions. One partner in particular noted that the approach to LED installation led to savings they had not anticipated before participation in the CBP program.

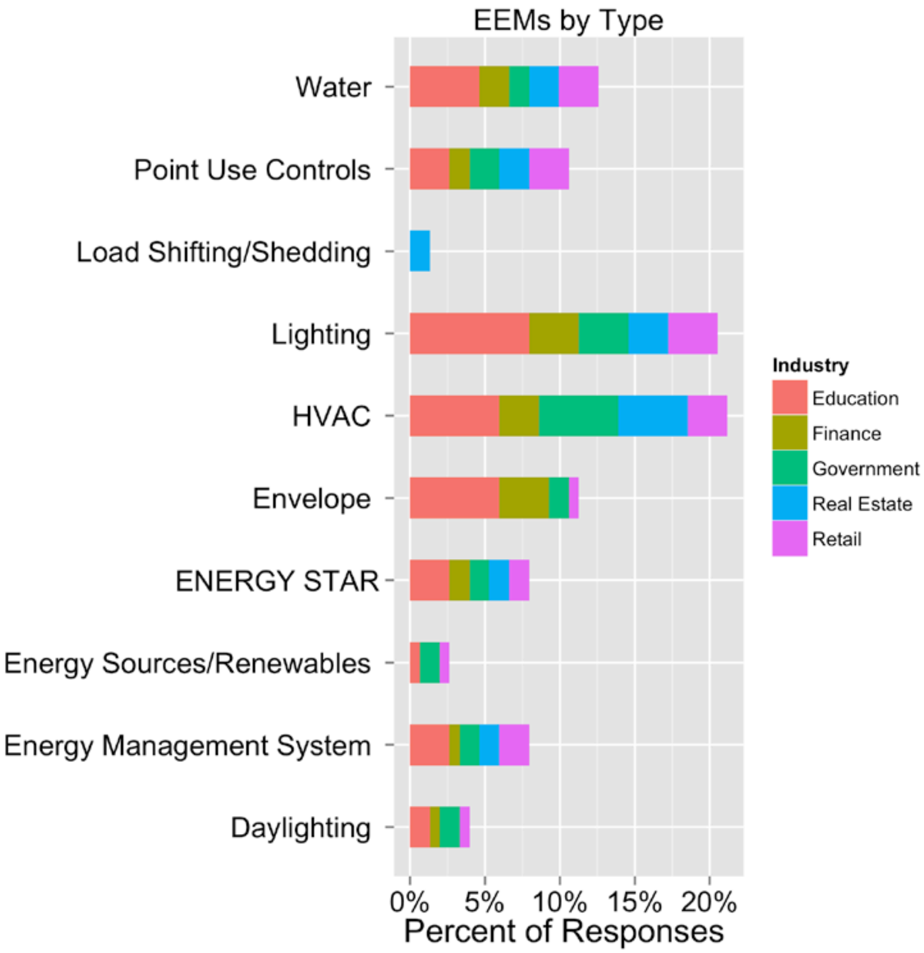

Figure 16. CBP Partner Reported EEMs by Type and Building Sector

In addition to the table above, one partner indicated that they are installing variable frequency drives (VFD) on rooftop HVAC units in 130 stores. Two respondents indicated that VFDs represented the greatest energy savings when installed on chillers and HVAC fan motors, compared to other EEMs. One respondent indicated that VFDs represented the greatest cost savings compared to other EEMs installed during the program. Of questionnaire respondents, the educational sector had the broadest adoption of EEM categories.

In the interviews conducted after the questionnaires were completed, the following takeaways were identified by CBP partners regarding specific measures or implementation strategies they will now replicate based on their experience with the CBP program:

- Two partners indicated that they now have a detailed plan for M&V programs that will be rolled out to all building engineers within the organization.
- One partner indicated significant savings potential from reducing plug loads, an area that was not focused on before participation in the CBP program.
- One partner indicated that the entire package of CBP EEMs will be replicated in all buildings owned by the organization.
- Three partners indicated that LEED standards are mandated in all new construction. Specific elements from the experience gained from the CBP program will be added to their existing energy efficiency protocols.
- Three partners indicated that enhanced weather modeling and EEM package optimization were primary takeaways from program participation.
- Six partners confirmed that LED lighting technology and design will now be used in their entire building portfolios thanks to participation in the CBP program.
- One partner learned they were oversizing HVAC equipment and intends to use right-sized equipment in all new construction and replacements in their portfolio.

The primary motivation for CBP program participation, indicated in both questionnaire and interview results, was cost reduction. In addition to realizing increased efficiency, installation of energy efficient technologies has been determined by many researchers to provide economic benefits. Overall building design can help achieve energy and cost savings. For example, design solutions to existing commercial buildings based on the climate zone in which the building is located has been estimated to have a cost savings potential of 10% to 20% (Belzer, 2009), relatively consistent with the 11% to 30% reported by CBP partners. Other studies point to economic gains from lower operational costs of HVAC systems due to increased envelope efficiencies (Kneifel, 2010; Howarth, 2010).

Replication efforts by CBP partners depend greatly on potential cost savings and project economics. When asked about economic analysis metrics, half of the respondents indicated that return on investment (ROI) was their primary economic criterion. Figure 17 illustrates the primary types of economic analyses used to evaluate the investment potential for replicating CBP measures. These measures include simple payback, savings to investment ratio (SIR), return on investment (ROI), life-cycle cost analysis (LCC) and building life-cycle cost analysis (BLCC). BLCC methods allow analysis of capital investments specific to buildings. Most respondents use a form of spreadsheet or commercial software to calculate EEM investment opportunities. Two respondents indicated they do not utilize any financial analysis software, while the rest of the respondents maintained they utilized in-house financial tools or packaged software suites to evaluate the economics of EEMs.

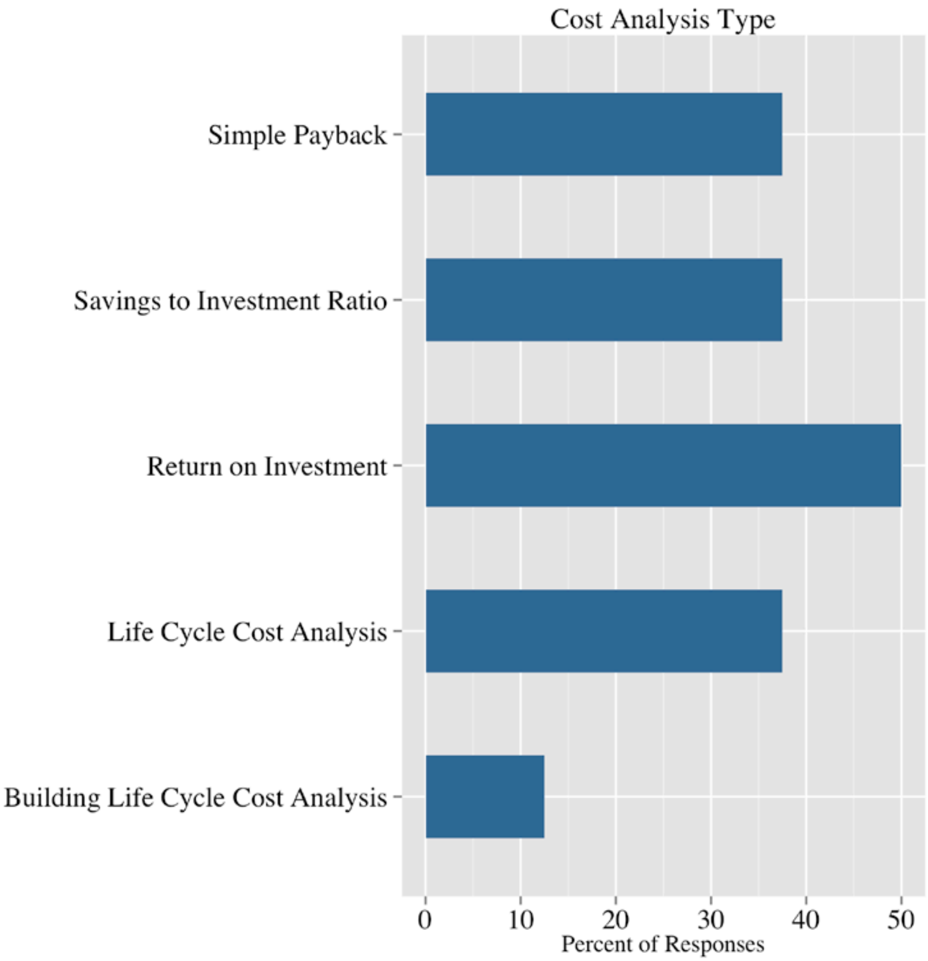

Figure 17. Economic Metrics used by CBP Partners to Measure EEM Cost Effectiveness

Follow-up interviews conducted for this effort indicated the following takeaways from the CBP program regarding cost reduction:

- All participants except one were strongly motivated by cost reduction potential;
- Five CBP partners indicated that energy costs are amongst the largest cost categories in expense budgets;
- Three participants indicated that energy modeling and monitoring techniques will be utilized henceforth to better understand the energy profile of specific buildings

> within the organization’s portfolio. They believe that this enhanced knowledge will help them reduce energy related costs.

Motivation and Evidence of Replication

Survey and interview respondents were asked whether they have organization-wide sustainability protocols for green building, energy efficiency and environmental stewardship. All of the respondents indicated their organization had policies and procedures regarding sustainability. Additionally, 75% of questionnaire respondents indicated that they have company policies regarding implementation of EEMs (Figure 18). When asked whether these protocols impacted their participation in the CBP program, 75% of respondents indicated yes, while 25% indicated no.

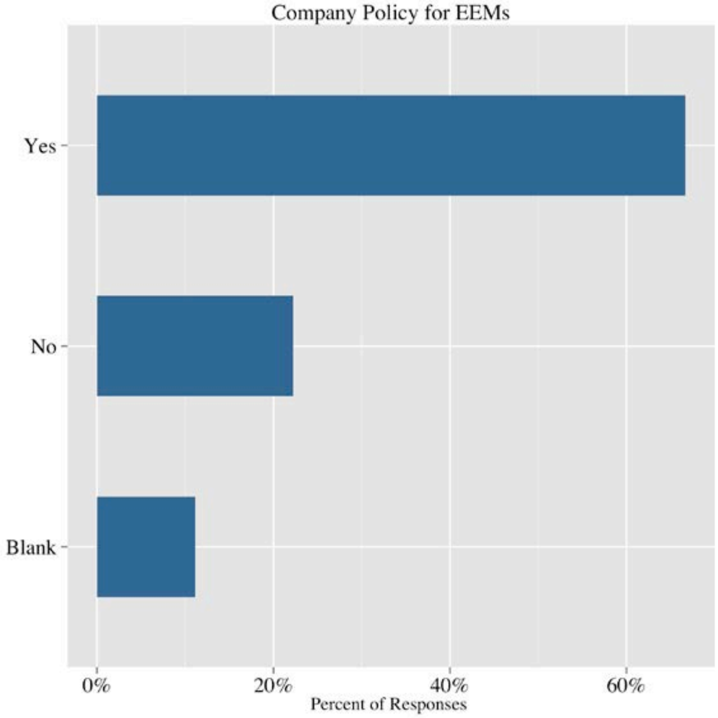

Figure 18. Percentage of Organizations with Policies/Procedures for EEM Implementation

This study also aimed to gain a better understanding of any benefits beyond the energy and cost savings CBP partners realized through program participation. Respondents were asked to rank ten different non-monetary and social benefits associated with increased building efficiency. Figure 19 presents the cumulative results from all respondents; the x-axis represents the number rank per respondent and the y-axis represents the benefit. Decreased maintenance was ranked highly by more than 50% of the questionnaire respondents. This is consistent with the reduced cost of exterior lighting that many partners reported when switching to LED systems. Increased employee productivity and comfort were also ranked highly by the partners. Positive media and marketing opportunities were also a factor for some partners, but typically ranked lower.

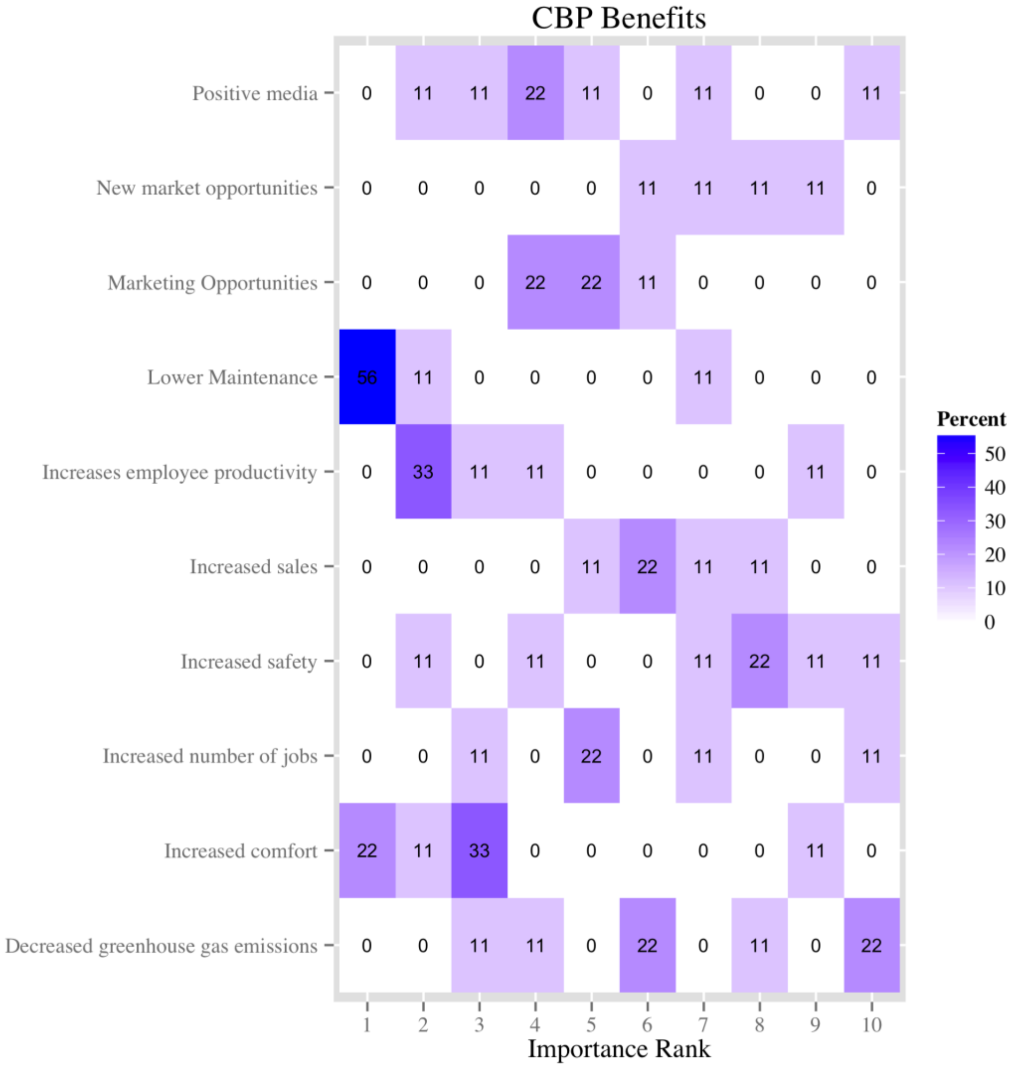

Figure 19. Survey Responses to CBP Benefits beyond Energy and Cost Savings. Respondents Ranked the Benefits and Percentage of Responses are Shaded.

One way to determine replication impacts over the long term is to gain insight into protocol development, monitoring and verification (M&V) activities, and operations plans and documentation of CBP partners. Better understanding of these organizational structures can help provide validation and demonstration that replication is occurring, and that it is successful and impactful when compared to the overall energy footprint of an entire organization.

Building commissioning is a term used to describe a comprehensive project management process for new and retrofit (retro-commissioning) construction that provides an in-depth quality assurance process from the design through the occupancy phase of the building project (ASHRAE, 2011). Successful building commissioning can reduce energy costs and enhance systems operation of building projects. In an effort to better understand long-term replication objectives, CBP partners were asked whether their building projects were commissioned (or retro-commissioned). As noted previously, 88% responded yes. When asked whether all buildings are commissioned, 75% replied yes, 12.5% no, and 12.5% “I don’t know.”

Respondents were also asked whether they have a documentation process for building design and energy efficiency. Of the seven participants that responded to the question, four indicated they did, and three indicated their organization did not. One of the organizations that answered no to that question is a franchised property management company, which is not involved in all their franchise’s building projects.

When asked about protocols for M&V, all but one respondent indicated they had some form of M&V process, which included metering. However, three respondents reported they did not have a process for monitoring before the CBP program. Two respondents did not answer the question. Respondents that answered “yes” indicated either in-house, third party or no M&V. All CBP projects are monitored by the DOE design team for a specified period of time; this question was designed to gain insight into how the organization plans for long-term building monitoring.

When asked about prototype plans, four partners indicated they develop and maintain building construction prototypes. Three respondents keep the prototype plans in-house, and one is maintained by a third party engineering firm, hired by the organization to maintain their energy profile. In a follow-up interview, one partner reported that their CBP project details have been passed up to high-level management, who has adopted the building project as a prototype for future building construction. The same organization indicated that the CBP program gave them an opportunity to enhance and optimize measures they already employed in their building practice and fine-tune their process for energy efficiency.

Finally, when asked about actual energy savings versus modeled or expected savings, the majority of CBP partners reported that it was too soon to tell, as their building projects have not had enough time to yield robust data. Three respondents reported that they were realizing predicted energy savings, and one partner reported their savings was very close to that predicted. One partner reported there had been a default setting in the control sequence of the HVAC system, causing the system to continuously operate. However, the issue has been corrected and they are now expecting modeled and actual savings to align. Also in the follow-up interviews, one partner indicated that the solar photovoltaic system, installed as part of their new construction EEM package, sent enough electricity to the grid in May 2013 to make the building net energy positive, in terms of electricity consumption.

Diffusion Model Analysis and Output

Two Bass models ("CBP Construction" and "Market Bass Model") were developed which resulted in a large difference between modeled outputs. On a personal note, I find it appropriate to mention that a colleague of mine, Heather Dillon, helped me with the scripts for the final model. The CBP Construction model (conservative) was developed using data from CBP partners only, with the output representing the maximum number of buildings impacted normalized by total number of buildings in CBP partner portfolios. The Market Bass model (optimistic) was developed by extrapolating the dataset out to the broader market, and represents market diffusion potential for the full partner portfolios based on the observed diffusion of other green building programs. This section presents outputs from the analysis.

The previous section outlines the development of a Bass diffusion model calibrated using the most comprehensive existing database of a building-scale energy efficiency program, USGBC LEED data. Because USGBC LEED data provided the best, dataset obtainable to help define *q* and *p*, the Bass model developed for this study was laid on top of the LEED data to see how well the model fit. After fitting the model, *q* and *p* was adjusted using the R^2 function to determine the best values for those variables. See the Methodology Chapter for detailed discussion of the Bass Model calibration. The calibrated Bass model was then utilized to provide a mechanism to determine the best-case impacts of the CBP program. In order to do this, a Bass model was developed based on building-level implementation of EEMs.

Table 4 presents the parameters for determining model inputs. Since the focus of this analysis is on the market potential for CBP program replication, the normalizer *(m)*, represented by number of buildings, should focus on market potential based on maximum number of buildings within the entire CBP portfolio. This was calculated as the quotient of total existing CBP partner portfolio square footage and average commercial building size in the U.S., giving an estimate of 250,709 buildings to represent the market maximum. Because the research team only had access to data on the existing portfolios of CBP partners, the final analysis is conservative, because it would be appropriate to assume the partners would continue to construct new buildings. However, no method to quantify this was obvious so a construction rate increase was omitted from this study.

Two distinct Bass diffusion models were then used to bind the eventual diffusion of the CBP program. The “Market Bass” model is simply a projection of the Bass model using the *q* and *p* parameters determined from the larger USGBC data set. This model is deemed to represent the way one other building-scale energy efficiency programs have diffused in the commercial buildings sector. A second Bass model, termed the "CBP Bass" model is a version of the model analyzing the CBP partners only, where *q* and *p* parameters were determined from the actual CBP construction data while maximizing the R^2 coefficient. The parameters used in the CBP Bass model are shown in Table 4.

Table 4. Bass Model Parameters Determined from the CBP Data

Bass Model Parameter	**Value Determined (Bass Traditional)**	**Source**
p - coefficient of innovation	1.344828e-5	Data fitting
q - coefficient of imitation	0.2448	Data fitting
m - maximum market potential (number of buildings)	250,709	Total new commercial buildings constructed by CBP partners, estimated from total CBP partner portfolios (ft^2) and 14,700 ft^2/building (EIA, 2008)
R^2 - coefficient of determination	0.951	Calculated to compare fit of Bass model with USGBC data

Figure 20 and Table 5 present diffusion potential of the CBP program by number of buildings, predicted using the CBP Bass model. The projection range is from 2008 to 2020 and the diffusion rate is the percentage of total buildings in CBP partner portfolios based on the Bass model output. The raw CBP construction data was calculated as the cumulative CBP buildings based on data gathered and monitored by ANL, LBNL, NREL and PNNL. Each lab compiled and tracked partner data which included project specific information, overall partner portfolio square footage, building type, location, project completion date (actual or anticipated), and a synopsis of EEMs.

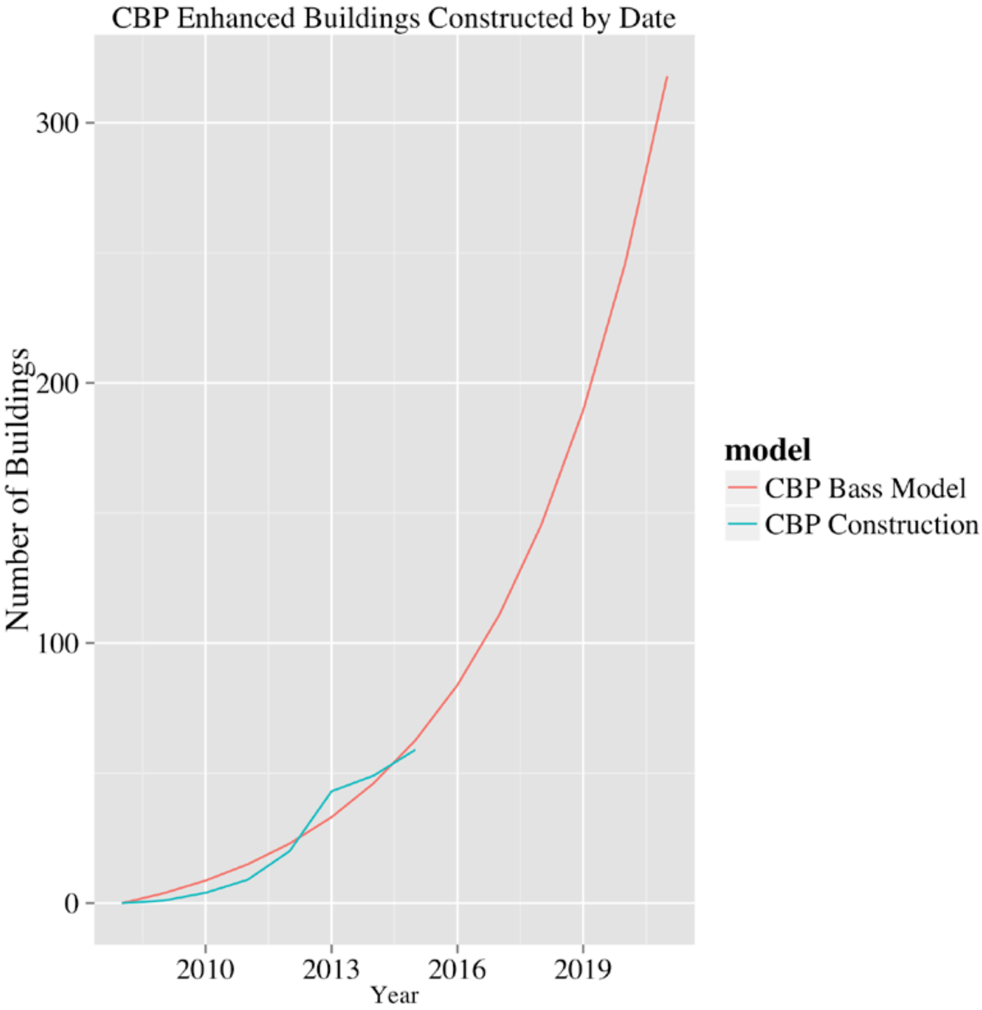

Figure 20. CBP Diffusion Prediction Using the Bass Model, R^2=0.95

Figure 21 shows the CBP Bass and CBP Construction diffusion model predictions through the year 2030. The Market Bass model (optimistic scenario) represents a best case scenario for CBP diffusion based on the way the commercial building sector has adopted another larger, but somewhat similar, whole-building energy efficiency program.

The CBP Bass model represents a conservative (worst case scenario) based only on the CBP enhanced buildings constructed to date.

Table 5 shows the comparison of the two Bass models with the CBP construction data. The CBP Bass model does an excellent job predicting the construction in 2015 (“actual” data include projections of completed buildings from LBNL, NREL and PNNL), high by only a few buildings. The conservative model indicates that nearly 3,000 buildings will be enhanced by the CBP program by 2030. The more optimistic diffusion model indicates that CBP enhancements could penetrate as many as 97,000 buildings by the same year. The discrepancy between the optimistic and worse case is due to the large difference in input data based on the normalizer (*m*) which represents the market maximum number of buildings the program can diffuse into.

It is important to note that the actual number of projects presented in Table 5 and Figure 21 below include only partner buildings directly involved in CBP, not replication efforts already underway by partners. This implies that the Market Bass model (optimistic scenario) may be closer to the actual number of buildings impacted by CBP.

Table 5. Comparison of CBP Construction to Date with Bass Prediction. Data Shown are the Cumulative Number of Buildings (Actual) and Predicted for Each Model.

Year	CBP Construction (Number of Buildings Actual)	Market Bass Model – Optimistic Scenario (Number of Buildings Predicted)	CBP Bass Model – Worst Case Scenario (Number of Buildings Predicted)
2012	20	188	23
2015	59 (scheduled completion)	665	63
2030	-	97,101	2,957

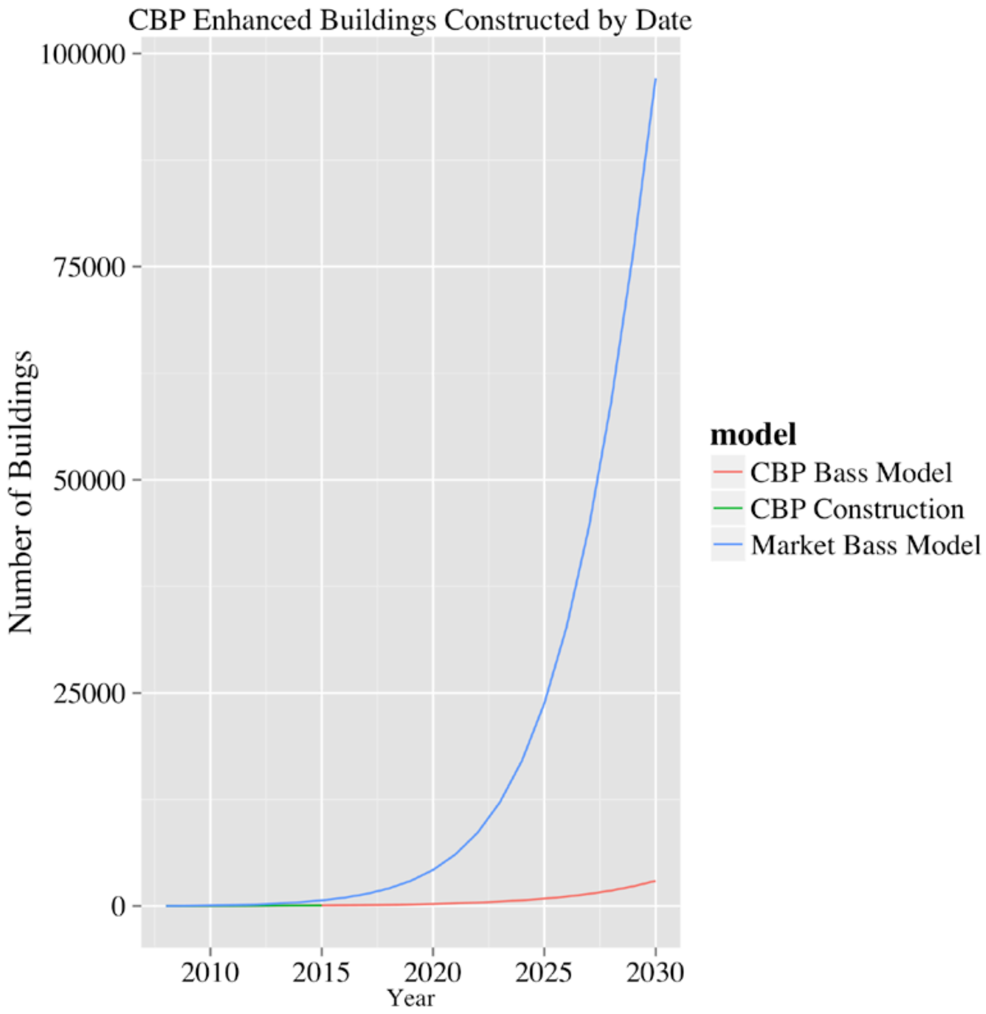

Figure 21. CBP Market Penetration Prediction Using the Bass Model

Energy Savings Calculations

In addition to modeling total number of buildings that can potentially be impacted through replication efforts of CBP partners, this research is also interested in broader energy savings potential. As such, potential energy savings was calculated two ways, measured by modeled decreases in energy use intensity of a building.

By 2030, the diffusion model forecasts that a range of 2,957 to 97,101 buildings will be impacted by the CBP program through partner replication efforts, representing over 22% of all buildings in partner portfolios. This translates to between 43.5 million to 1.4 billion square feet of commercial building floor space throughout the United States. Previous analysis efforts of CBP projects modeled energy use intensity (EUI) reductions of 53 kBtu/ft^2 for new construction projects overseen by PNNL (Baechler et al., 2012). In an effort to extrapolate broader energy savings data, I compared this decrease in modeled CBP EUIs with median EUI data for commercial buildings using the CBECS dataset. Based on this analysis, the energy savings potential is between 2.3 and 77 trillion Btus annually.

As a final part of this study, I ran a second savings calculation based on ENERGY STAR's portfolio manager data trends instead of CBECS. ENERGY STAR data may be a better source for EUI numbers since it is current. CBECS data has not been updated since 2003, so one can assume these data may be incorrect. Energy use benchmarking is available for office, retail, K-12 school and hotel buildings, which includes median EUIs for each building type (ENERGY STAR, 2012). I averaged the median EUI data for all four commercial building types to use in this analysis. Note that not all building types represented by CBP partners fall under these four categories, but it does represent the majority of partners. The median EUIs for office, retail and hotel buildings were averaged and calculated with EUI reductions of 53 kBtu/ft^2 (from Baechler et al., 2012).

The resulting energy savings numbers were very similar to the comparison with CBECS, ranging between 2.3 and 75 trillion Btus annually.

Chapter 7. Limitations

One of the primary limitations of this research is the small overall sample size of CBP partners. In total, 10 respondents participated in the survey and interview data-gathering efforts, out of a possible 11. Although small, these projects do represent approximately 28% of the entire CBP program and approximately 1% of all commercial building square footage in the U.S. The small sample size limited the amount of quantitative analysis that could be done for survey and interview data, to investigate partner replication. While still robust, the qualitative approach to the replication section does not allow this research to speak broadly for all CBP partners, partner portfolios or outwards to the broader commercial building market. The partners that participated in CBP applied to the program and were chosen by DOE based on unknown criteria; these partners may already be energy-conscious organizations compared to competitors in their industry.

Another limitation was the fact that replication data was gathered from PNNL CBP partners only, and not projects overseen by other national laboratories. This required assumptions to be made regarding the approach take for energy savings and cost analysis. The assumption that all labs would have the same recommendations regarding design of energy efficiency and cost savings measures was made. That is to say, that it was assumed that all labs would have assessed, modeled and implemented the same technologies for each partner. Furthermore, that all labs would estimate the same energy and cost savings. While approaches to building science are relatively synonymous, different researchers, engineers and scientists have expertise that may sway their preference over one technology compared to another. The same issue presents itself when estimating cost perspectives for different technologies.

Additionally, there are potential limitations relating to spatial components of the green building industry in the United States. Each CBP partner that participated in this study indicated that cost savings were a primary objective, and motivation for participating in this study. From a spatial perspective, the motivation to participate in green building programs, or to replicate CBP measures may vary depending on a variety of factors relating to location. These factors include variance in electricity prices, affecting the overall cost burden of energy expenditures in the first place; firms located in areas with low electricity prices may not be motivated by cost savings to replicate green building measures. Similarly, spatial influences such as codes, standards, green building programs and social norms may impact firms' decisions whether to replicate CBP measures. Firms located in progressive areas with many green certified buildings, or denser urban areas may be more likely to have higher replication rates. The diffusion model used in this study did not measure these spatial influences.

The final limitation of this research applies to the approach taken for diffusion modeling. The greatest limitation here lies in the fact that USGBC data may not accurately measure the coefficients for use with CBP data. There is no doubt that

USGBC data is the best possible option that exists, but, those data represent a program that is different from CBP. In the first case, only new construction data was input in the model, while the CBP program includes both new construction and existing buildings. This was due to the fact that the overwhelming majority of USGBC data was for new buildings, and the measurements for existing buildings was unknown when analyzing their data. Second, the LEED program is not exactly the same as the CBP program; both represent a whole-building approach to green building, but the CBP program does not require a checklist-type approach to achieving certification. However, when the model was developed, the outputs for USGBC diffusion prediction were very close to the actual data, which justified using the dataset for this analysis.

Chapter 8. Conclusions

As opposed to separating conclusions based on survey/interview results and diffusion modeling sections, this section deviates from the Findings and Discussion Chapter by combining conclusions per the literature reviewed for this study. Thus, the three primary sections for conclusions are: diffusion theory findings; organizational theory, corporate social responsibility and business environmental management findings; and energy economics findings. This approach was used in an effort to directly link the findings of this study back to the literature and previous study in this area.

Diffusion Theory Conclusions

One of the primary findings relating to the diffusion model developed for this analysis was an unexpected conclusion. The conclusion is that the model developed by Bass is an effective approach to analyzing diffusion of green buildings on a whole-building level, as opposed to individual energy efficiency measures.

When literature relating green buildings to the diffusion of technologies theory was being reviewed, one of the primary studies found was Yudelson's 2005 work analyzing the market diffusion of USGBC's LEED program (Yudelson, 2005). For his analysis on the diffusion of USGBC LEED buildings, Yudelson used the Fisher-Pry model for technology substitution which incorporated a 50% substitution rate into the equation. While his analysis was focused on diffusion on the whole-building level, similar to the objective of this analysis, I found it inappropriate to assume a 50% penetration rate. So, the work of Bass (1969) was used for development of the diffusion model, omitting the 50% substitution rate.

As the Bass model was developed, coefficients were determined by exploring other literature relating to individual energy efficiency measures applied in green buildings (See: Elliott et al., 2004; Kok and Quigley, 2011; Andrews and Krogmann, 2009). These coefficients (*q* and *p*) were normalized by total number of buildings in the CBP program (*m*), and results were compared to Yudelson's original 2005 diffusion estimate. The results (see Table 6), of the raw data compared to Yudelson's estimate by 2007 was only off by 41 buildings, and while the model tends to over-predict diffusion in the early years, the shape of the curve is correct, indicating correct diffusion predictions over a period of time. This conclusion is further supported by the diffusion modeling done for this study; the conservative model is high by only four buildings.

Table 6. Comparison of CBP Construction to Date with Diffusion Modeling Prediction. Data Shown are the Cumulative Number of Buildings (Actual) and Predicted for Each Model.

Year	**CBP Construction (Number of Buildings Actual)**	**Market Bass Model – Optimistic Scenario (Number of Buildings Predicted)**	**CBP Bass Model – Worst Case Scenario (Number of Buildings Predicted)**
2012	20	188	23
2015	59 (scheduled completion)	665	63
2030	-	97,101	2,957

The conclusion from the estimation of the Bass model is that it appears to satisfactorily represent the historical cumulative construction metrics for whole-building energy efficiency programs. The Bass model parameters developed also can provide perspectives related to the long-term, future market diffusion of energy efficiency programs. This conclusion was an unexpected result of this study.

Another conclusion based on diffusion analysis relates specifically to the number of buildings potentially impacted by this program and market potential for energy efficiency in buildings. Maximum diffusion potential for the CBP program was modeled at over 97,000 buildings by 2030, saving between 75—77 trillion Btus of site energy consumption annually. Market transformation occurs in the later phases of innovation, once a particular idea has significantly penetrated the market (Lutzenhiser et al., 2001). As CBP partners propagate energy savings into their portfolios, market transformation of green building on a whole-building scale becomes more measureable. While green building programs have made significant market impacts over the past decade, the CBP program offers an optimized approach to green building as opposed to a checklist-type approach to efficiency. This approach may promote market transformation in a broader sense; this study can be one step in analyzing this approach.

Organizational Theory, Corporate Social Responsibility and Environmental Management Conclusions

The conclusions in this section are primary results of survey and interview data relating to replication efforts by CBP partners. All participants surveyed and interviewed for this study indicated that CSR, company culture, and sustainability initiatives played a part in the organization’s willingness to participate in the CBP program and invest the upfront capital necessary for efficiency upgrades in new or existing buildings. This points to literature supporting these initiatives as discussed in the literature review. Specifically, participation in voluntary environmental management programs must be bi-directional since voluntary programs impact the competitiveness within an industry (Alberini and Segerson, 2002). This means that the non-monetary motivations for partner participation must have some sort of measurable benefits. CBP partners indicated lower maintenance, increased employee productivity and increased comfort as the top three motivations beyond direct cost savings. The literature points out that are environmentally minded tend to be more willing to invest in technologies or applications that improve building or operational efficiency (Kahanna et al., 2007, Lyon and Maxwell, 2008). This study generally supports previous literature.

One partner interview focused specifically on company culture as being a primary motivator for participation in the CBP program. The interview respondent noted their organization had been promoting green building initiatives since 2004 as one of their approaches to CSR initiatives. This respondent said that the strong company culture towards sustainability related directly to the CEO who promoted sustainable business development. The literature review found studies that noted companies with socially conscious CEOs or upper management are also more likely to have voluntary environmental programs (Delmas and Toffel, 2008; Ervin et al., undated; Martin et al. 2012). Findings from this study tend to support these conclusions. However, lower maintenance and increased employee productivity, while non-monetary in terms of energy costs, still represent overall cost savings for the organization. Cost savings, discuss next, far outweighed any non-monetary benefits or motivations.

When asked about economic analysis metrics, half of the respondents indicated that return on investment (ROI) was their primary economic criterion. While cost savings were a primary motivator for most organizations, the presence of a sustainability program may motivate these organizations to look closer at energy savings opportunities to close the gap between base and optimal building performance. In addition to ROI assessments, over 35% of respondents indicate a life-cycle cost analysis is conducted by the firm speaking to this issue. Since life-cycle cost analyses focus on environmental attributes of potential investments, organizations may be using these methods as a way to better look at energy efficiency investments compared to traditional ones. Such analysis would promote green building measures that may otherwise be seen as unfavorable through a traditional ROI assessment.

Energy Economics Conclusions

Unlike the previous two conclusion sections, the findings relating to energy economics relate to both survey and interview data, along with diffusion modeling outputs. The number one conclusion reached relating to energy economics, primarily from survey and interview results is that operating cost reductions were the primary motivation for all organizations that participated in the CBP program. Additionally, five CBP partners indicated that energy costs are amongst the largest cost categories in expense budgets. The terms “triple bottom line” and “win-win-win” are used to describe firms who are trying to maximize profits, reduce costs and protect the environment. In an effort to achieve this, many companies aim for product differentiation and profit maximizing potential (Reinhardt, 2000; Blackman, 2010; Lyon and Maxwell, 2008). Participation in the CBP program allowed partners to optimize packages allowing them to save energy and costs for their building project based directly on their location and usage profile, supporting the literature regarding cost reduction and CSR motivations.

In addition, specific technologies were chosen by CBP partners for their cost reduction potentials. LED lighting, energy management systems, and occupancy sensors all had 100% replication rate. In addition, one partner indicated that they are installing variable frequency drives (VFD) on rooftop HVAC units in 130 stores. Two respondents indicated that VFDs represented the greatest energy savings when installed on chillers and HVAC fan motors, compared to other EEMs. Studies have explored cost savings related to specific technologies and climate modeling (Kneifel, 2010; Howarth, 2010; Belzer, 2009). Technology-specific replication data from the survey and follow-up interviews seem to be in conjunction with this.

One way to determine replication impacts over the long term is to gain insight into protocol development, monitoring and verification (M&V) activities, and operations plans and documentation of CBP partners. Better understanding of these organizational structures can help provide validation and demonstration that replication is occurring, and that it is successful and impactful when compared to the overall energy footprint of an entire organization. In one sense, this can be seen as risk management efforts for the organizations participating in the CBP program. Because each organization had the opportunity to "test" technologies, and develop a testbed for benchmark energy operations, these may be used in the future as a way to prove certain technologies meet cost savings requirements of the firm, motivating them to implement the measures into other buildings. Similarly, M&V procedures further allow organizations to monitor the performance of these technologies over the long term. Maintaining optimal performance of these technologies can promote more company investment in energy saving technologies.

Although organizations were highly motivated by cost savings potential, incentives seemed to play a small role in decision making related to replication. Only three organizations received incentives to increase the energy efficiency of their building project, all of them from utility programs.

Diffusion model outputs, while focused specifically on number of buildings potentially impacted by the CBP program, did also have a cost component. Cost savings associated with the CBP program is associated with the extrapolation of broader energy savings data from model outputs. Previous analysis efforts of CBP projects modeled energy use intensity (EUI) reductions of 53 kBtu/ft2 for new construction projects overseen by PNNL (Baechler et al., 2012). The upper bound of energy savings potential was calculated between 75 and 77 trillion Btus annually of site energy consumption. While further calculations pertaining to specific cost savings potential for these amounts were not conducted, it is fair to assume the savings associated with such large amounts is significant.

Finally, this research may be able to help lay foundations for further study relating structural approaches to building energy efficiency and behavior. Unlike other green building programs, the CBP program includes a monitoring and verification period for one year. While the program is still too young to accurately measure whether energy savings modeled is the same as actual, it is now an objective of the management. Weber found that energy efficiency decisions in office buildings tend to be about investments, with specialists inside the firm being the primary decision maker (Weber, 1999). Because the CBP program partnered with firms engineering or construction projects, and because the program has a measurement and verification component, it may be likely that these buildings operate closer to modeled performance.

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Appendix A: CBP Partner Introductory Letter

April 15, 2013

Hello CBP Partner,

Thank you for participating in our efforts to assess replication efforts by CBP program participants. This outline provides information about the two mechanisms PNNL will be utilizing to gather feedback about replication efforts of your company. PNNL will focus on two primary questions for this study:

1. How are CBP partners replicating specific measures, treatments and processes?
2. How does the public know that these measures are being replicated?

In an effort to streamline this process and respect the limited time of each partner, PNNL has developed a two-step approach to receiving replication information from each partner. First, PNNL will be distributing an online feedback mechanism (through Survey Monkey) for each partner to complete. PNNL requests each partner complete the questionnaire and returns back to PNNL within 2 weeks.

We will also schedule a 15 minute follow-up phone conversation to ask a few additional questions and to gather further information about the questionnaire. You will be speaking with Chrissi Antonopoulos, Energy Analyst with PNNL. The follow-up meeting will take no longer than 15 minutes, unless otherwise preferred by each partner.

The questionnaire and phone interview contain questions that inform PNNL about your organization's approach to implementing energy efficiency measures and how your company is replicating these measures throughout your entire building portfolios. The primary focus will be on measures implemented during the CBP program process.

We are excited to hear about your experience with the CBP program and are looking forward to our discussion. All data gathered will be used for analysis only and no company will be specifically identified directly in this research.

The schedule for these efforts is broken out below:

May 10, 2013: Feedback questionnaire distributed electronically

May 24, 2013: Feedback questionnaire due back to PNNL

Week of May 24, 2013: Follow-up interviews scheduled

Week of June 10, 2013: Follow-up interviews concluded

Feel free to contact me with any questions.

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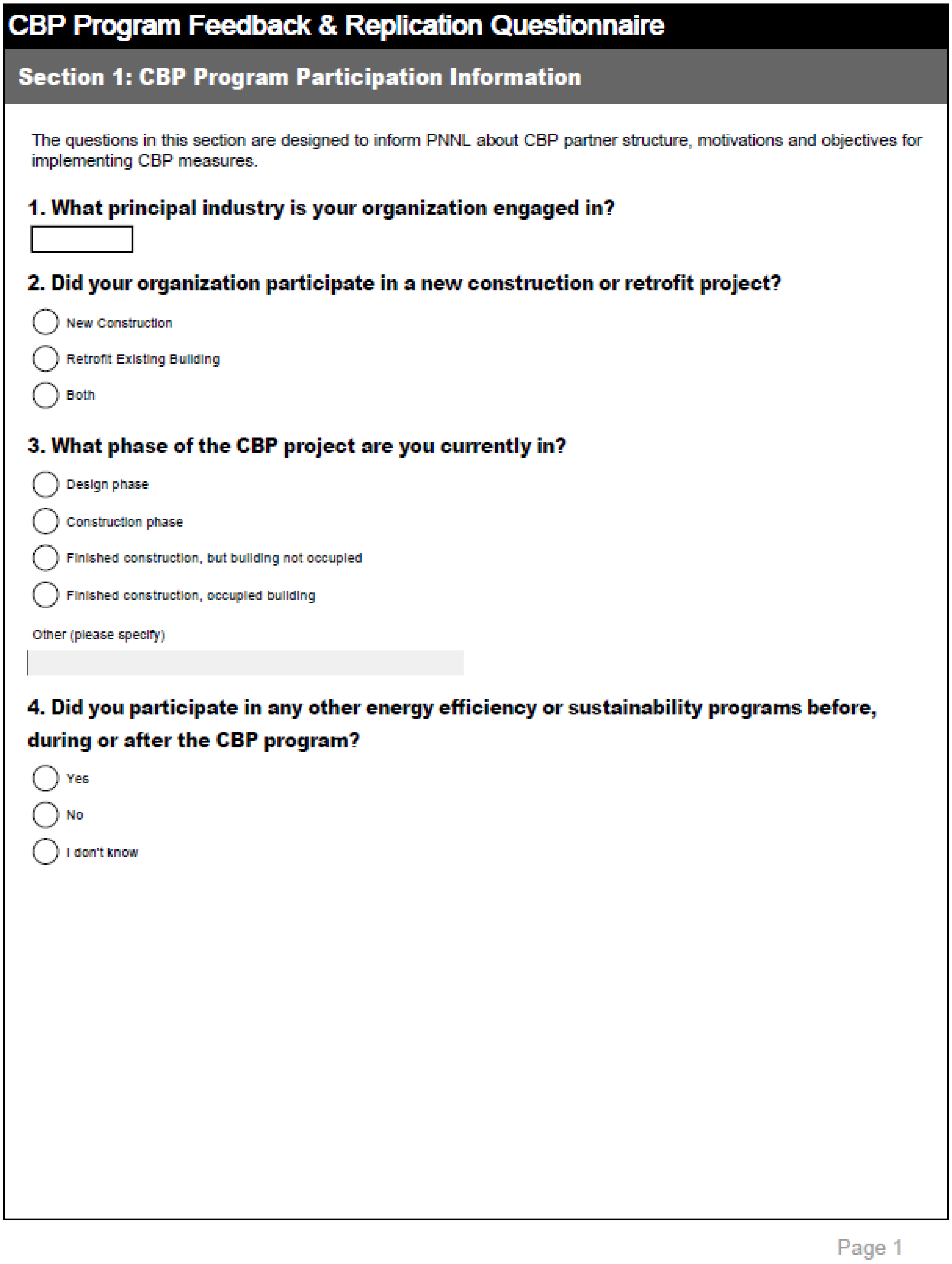
Appendix B: CBP Partner Survey Instrument



CBP Program Feedback & Replication Questionnaire

Section 1: CBP Program Participation Information

The questions in this section are designed to inform PNNL about CBP partner structure, motivations and objectives for implementing CBP measures.

1. What principal industry is your organization engaged in?

2. Did your organization participate in a new construction or retrofit project?

○ New Construction

○ Retrofit Existing Building

○ Both

3. What phase of the CBP project are you currently in?

○ Design phase

○ Construction phase

○ Finished construction, but building not occupied

○ Finished construction, occupied building

Other (please specify)

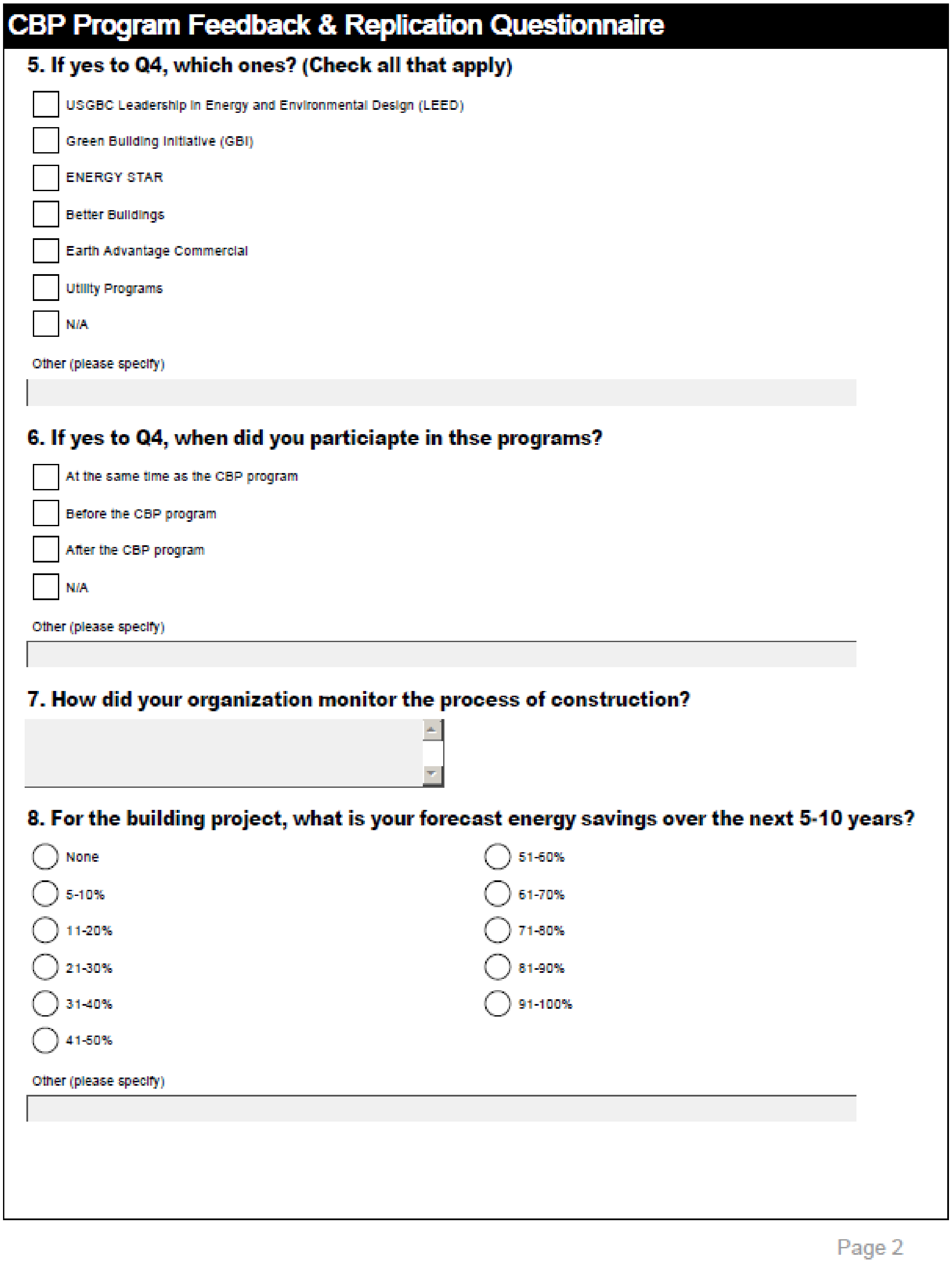
4. Did you participate in any other energy efficiency or sustainability programs before, during or after the CBP program?

○ Yes

○ No

○ I don't know

Page 1



CBP Program Feedback & Replication Questionnaire

5. If yes to Q4, which ones? (Check all that apply)

☐ USGBC Leadership in Energy and Environmental Design (LEED)
☐ Green Building Initiative (GBI)
☐ ENERGY STAR
☐ Better Buildings
☐ Earth Advantage Commercial
☐ Utility Programs
☐ N/A

Other (please specify)

6. If yes to Q4, when did you particiapte in thse programs?

☐ At the same time as the CBP program
☐ Before the CBP program
☐ After the CBP program
☐ N/A

Other (please specify)

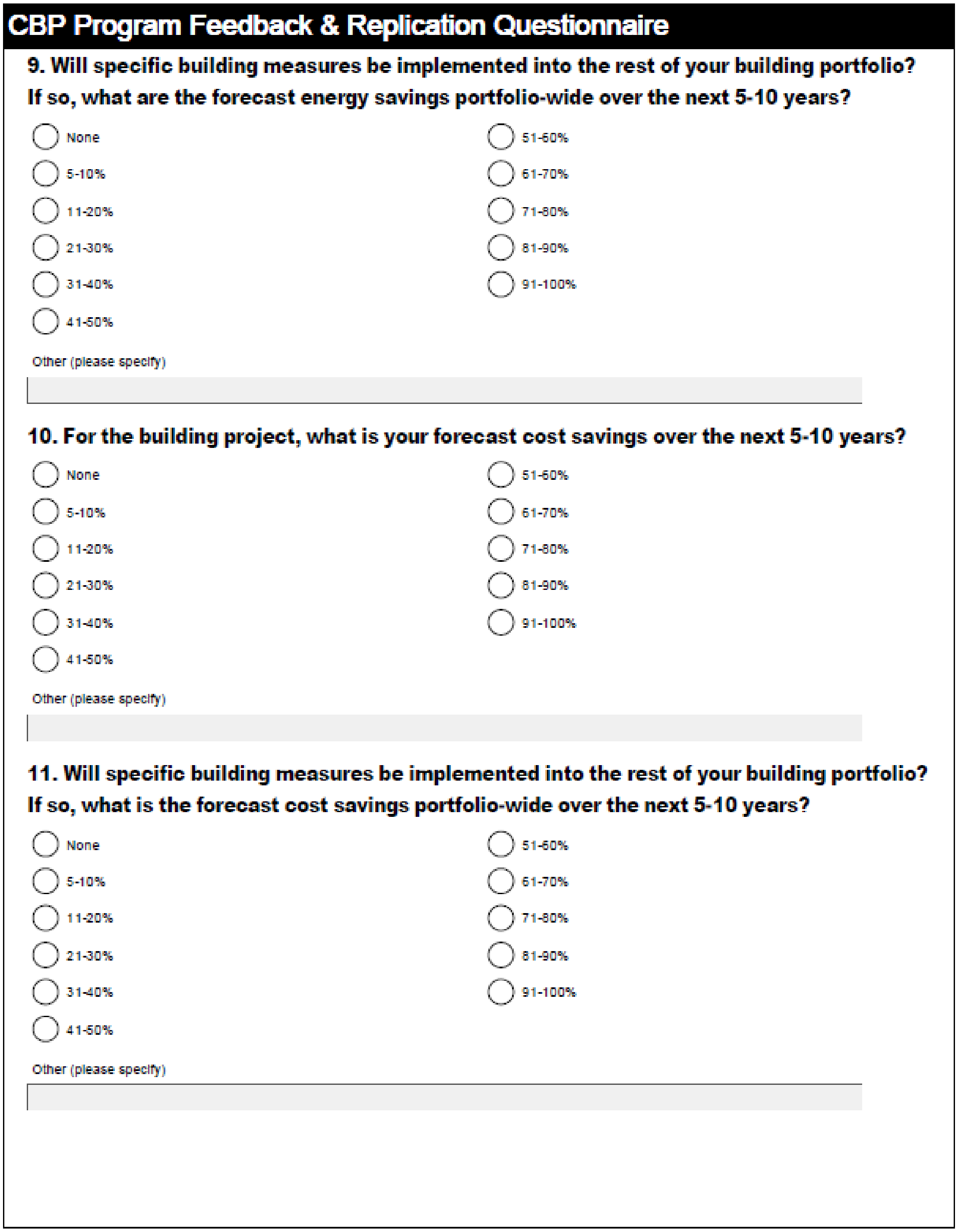
7. How did your organization monitor the process of construction?

8. For the building project, what is your forecast energy savings over the next 5-10 years?

○ None	○ 51-60%
○ 5-10%	○ 61-70%
○ 11-20%	○ 71-80%
○ 21-30%	○ 81-90%
○ 31-40%	○ 91-100%
○ 41-50%	

Other (please specify)

Page 2



CBP Program Feedback & Replication Questionnaire

9. Will specific building measures be implemented into the rest of your building portfolio? If so, what are the forecast energy savings portfolio-wide over the next 5-10 years?

○ None
○ 5-10%
○ 11-20%
○ 21-30%
○ 31-40%
○ 41-50%
○ 51-60%
○ 61-70%
○ 71-80%
○ 81-90%
○ 91-100%

Other (please specify)

10. For the building project, what is your forecast cost savings over the next 5-10 years?

○ None
○ 5-10%
○ 11-20%
○ 21-30%
○ 31-40%
○ 41-50%
○ 51-60%
○ 61-70%
○ 71-80%
○ 81-90%
○ 91-100%

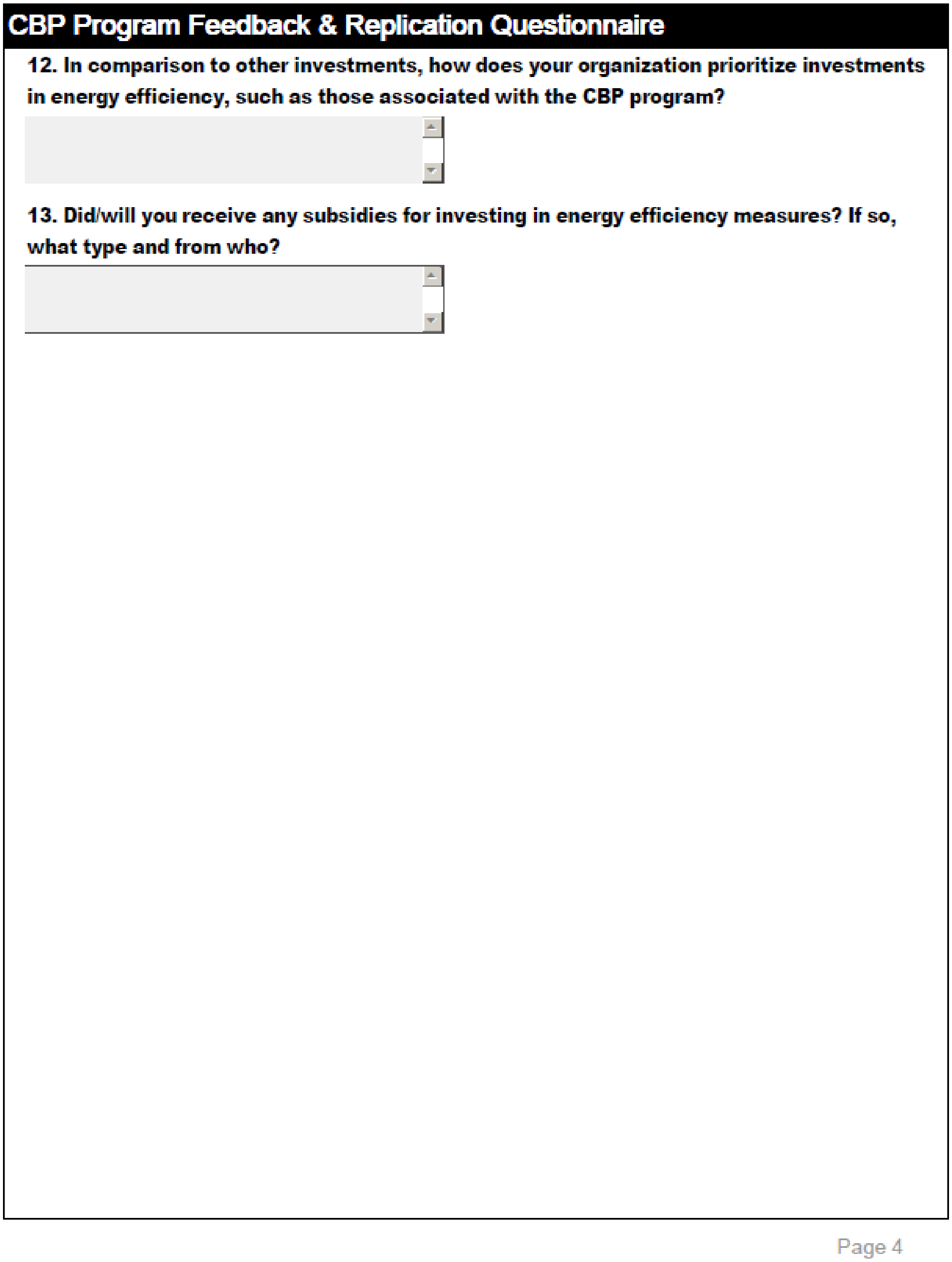
Other (please specify)

11. Will specific building measures be implemented into the rest of your building portfolio? If so, what is the forecast cost savings portfolio-wide over the next 5-10 years?

○ None
○ 5-10%
○ 11-20%
○ 21-30%
○ 31-40%
○ 41-50%
○ 51-60%
○ 61-70%
○ 71-80%
○ 81-90%
○ 91-100%

Other (please specify)

Page 3



CBP Program Feedback & Replication Questionnaire

12. In comparison to other investments, how does your organization prioritize investments in energy efficiency, such as those associated with the CBP program?

13. Did/will you receive any subsidies for investing in energy efficiency measures? If so, what type and from who?

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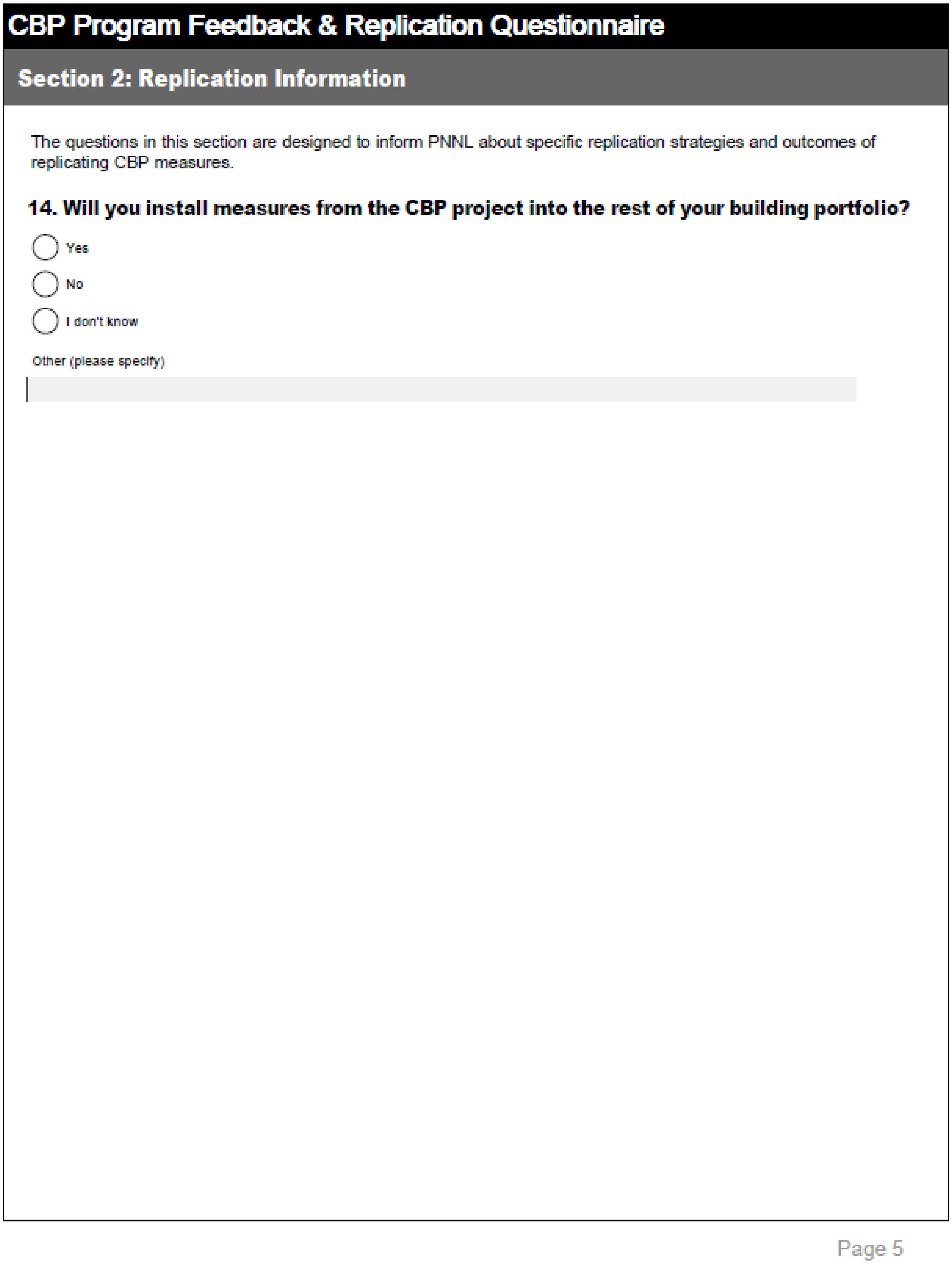

CBP Program Feedback & Replication Questionnaire

Section 2: Replication Information

The questions in this section are designed to inform PNNL about specific replication strategies and outcomes of replicating CBP measures.

14. Will you install measures from the CBP project into the rest of your building portfolio?

○ Yes

○ No

○ I don't know

Other (please specify)

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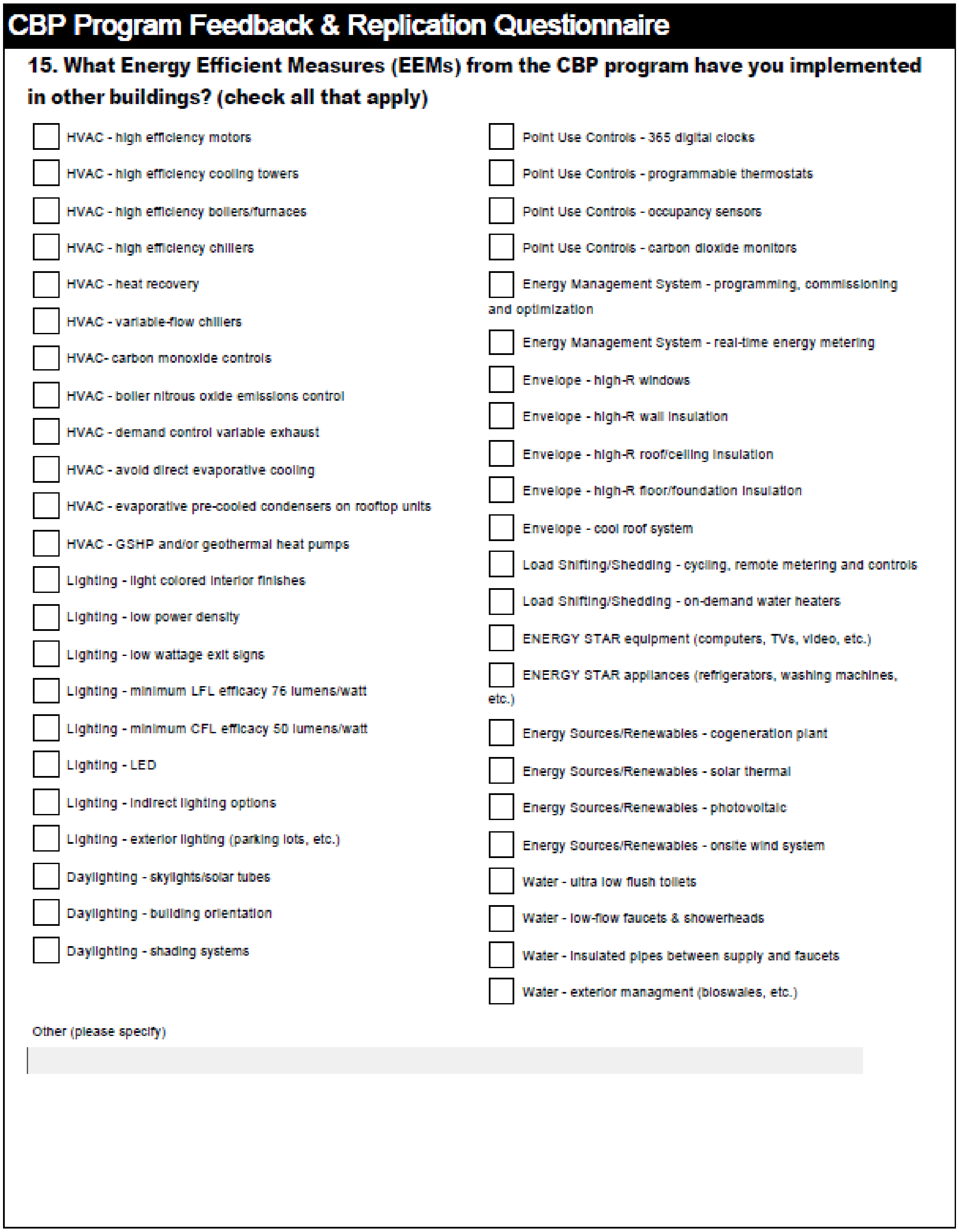

CBP Program Feedback & Replication Questionnaire

15. What Energy Efficient Measures (EEMs) from the CBP program have you implemented in other buildings? (check all that apply)

☐ HVAC - high efficiency motors

☐ HVAC - high efficiency cooling towers

☐ HVAC - high efficiency boilers/furnaces

☐ HVAC - high efficiency chillers

☐ HVAC - heat recovery

☐ HVAC - variable-flow chillers

☐ HVAC- carbon monoxide controls

☐ HVAC - boiler nitrous oxide emissions control

☐ HVAC - demand control variable exhaust

☐ HVAC - avoid direct evaporative cooling

☐ HVAC - evaporative pre-cooled condensers on rooftop units

☐ HVAC - GSHP and/or geothermal heat pumps

☐ Lighting - light colored interior finishes

☐ Lighting - low power density

☐ Lighting - low wattage exit signs

☐ Lighting - minimum LFL efficacy 76 lumens/watt

☐ Lighting - minimum CFL efficacy 50 lumens/watt

☐ Lighting - LED

☐ Lighting - indirect lighting options

☐ Lighting - exterior lighting (parking lots, etc.)

☐ Daylighting - skylights/solar tubes

☐ Daylighting - building orientation

☐ Daylighting - shading systems

☐ Point Use Controls - 365 digital clocks

☐ Point Use Controls - programmable thermostats

☐ Point Use Controls - occupancy sensors

☐ Point Use Controls - carbon dioxide monitors

☐ Energy Management System - programming, commissioning and optimization

☐ Energy Management System - real-time energy metering

☐ Envelope - high-R windows

☐ Envelope - high-R wall insulation

☐ Envelope - high-R roof/ceiling insulation

☐ Envelope - high-R floor/foundation insulation

☐ Envelope - cool roof system

☐ Load Shifting/Shedding - cycling, remote metering and controls

☐ Load Shifting/Shedding - on-demand water heaters

☐ ENERGY STAR equipment (computers, TVs, video, etc.)

☐ ENERGY STAR appliances (refrigerators, washing machines, etc.)

☐ Energy Sources/Renewables - cogeneration plant

☐ Energy Sources/Renewables - solar thermal

☐ Energy Sources/Renewables - photovoltaic

☐ Energy Sources/Renewables - onsite wind system

☐ Water - ultra low flush toilets

☐ Water - low-flow faucets & showerheads

☐ Water - insulated pipes between supply and faucets

☐ Water - exterior managment (bioswales, etc.)

Other (please specify)

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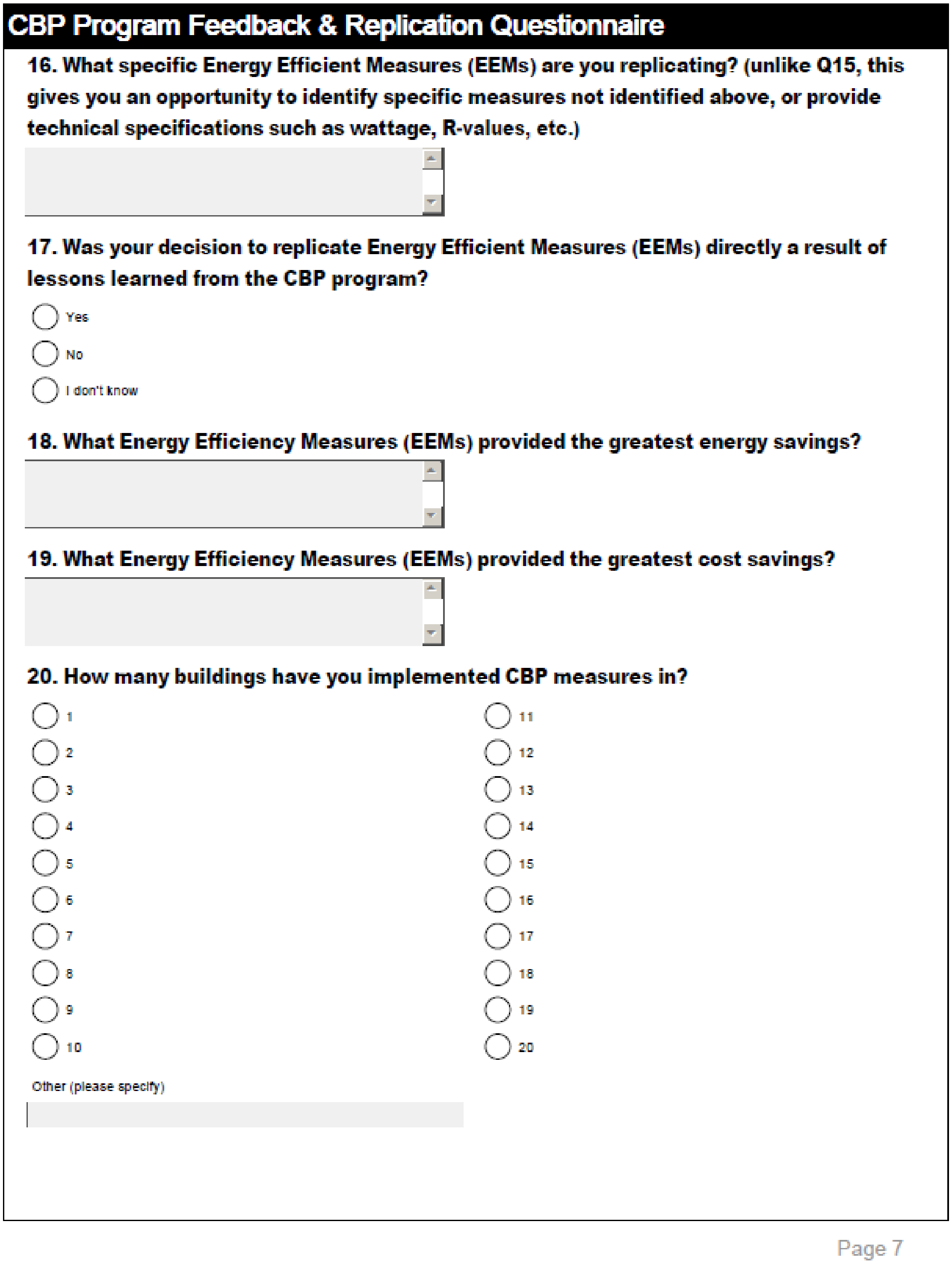

CBP Program Feedback & Replication Questionnaire

16. What specific Energy Efficient Measures (EEMs) are you replicating? (unlike Q15, this gives you an opportunity to identify specific measures not identified above, or provide technical specifications such as wattage, R-values, etc.)

17. Was your decision to replicate Energy Efficient Measures (EEMs) directly a result of lessons learned from the CBP program?

○ Yes
○ No
○ I don't know

18. What Energy Efficiency Measures (EEMs) provided the greatest energy savings?

19. What Energy Efficiency Measures (EEMs) provided the greatest cost savings?

20. How many buildings have you implemented CBP measures in?

○ 1
○ 2
○ 3
○ 4
○ 5
○ 6
○ 7
○ 8
○ 9
○ 10
○ 11
○ 12
○ 13
○ 14
○ 15
○ 16
○ 17
○ 18
○ 19
○ 20

Other (please specify)

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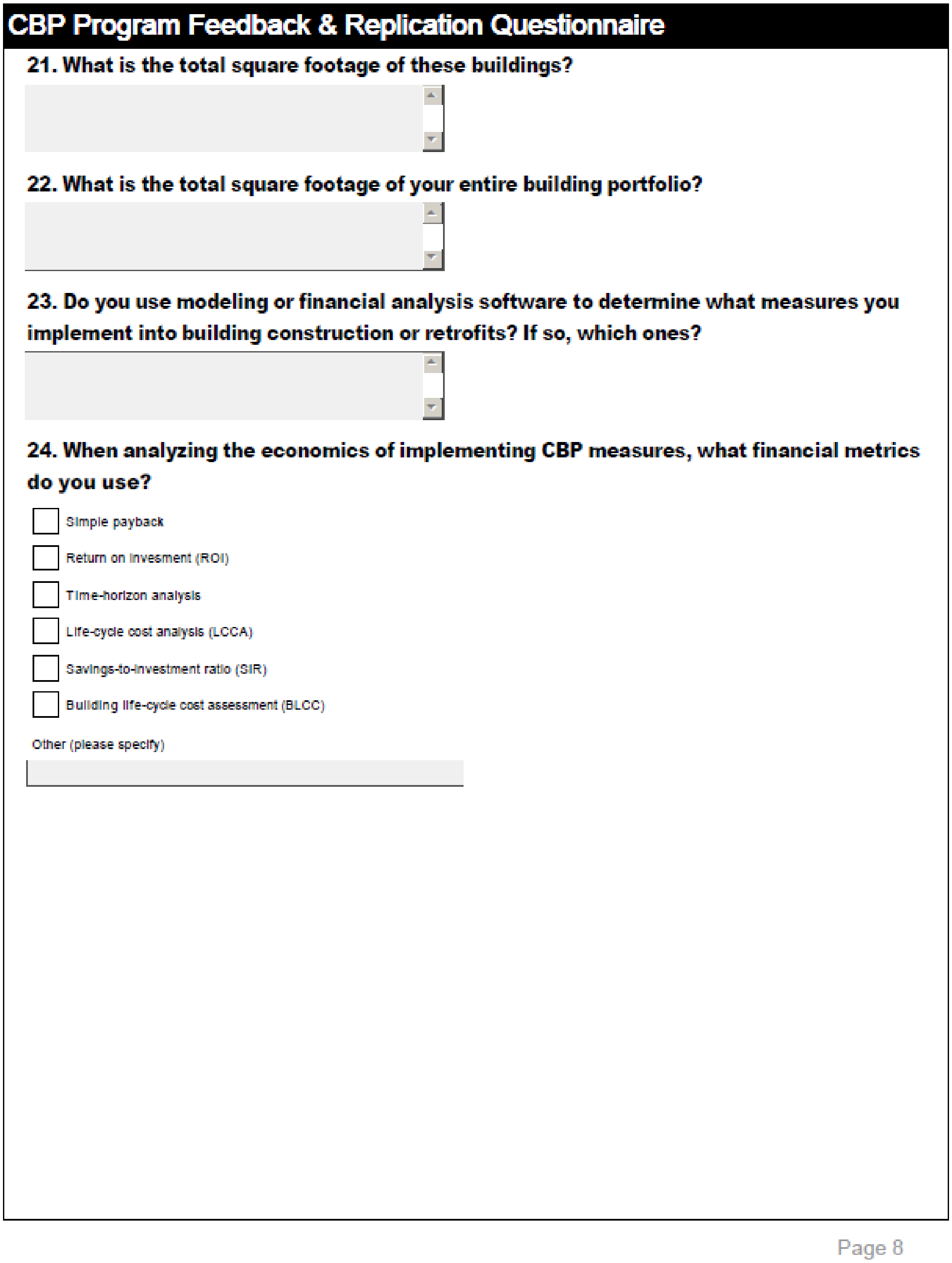

CBP Program Feedback & Replication Questionnaire

21. What is the total square footage of these buildings?

22. What is the total square footage of your entire building portfolio?

23. Do you use modeling or financial analysis software to determine what measures you implement into building construction or retrofits? If so, which ones?

24. When analyzing the economics of implementing CBP measures, what financial metrics do you use?

- ☐ Simple payback
- ☐ Return on invesment (ROI)
- ☐ Time-horizon analysis
- ☐ Life-cycle cost analysis (LCCA)
- ☐ Savings-to-investment ratio (SIR)
- ☐ Building life-cycle cost assessment (BLCC)

Other (please specify)

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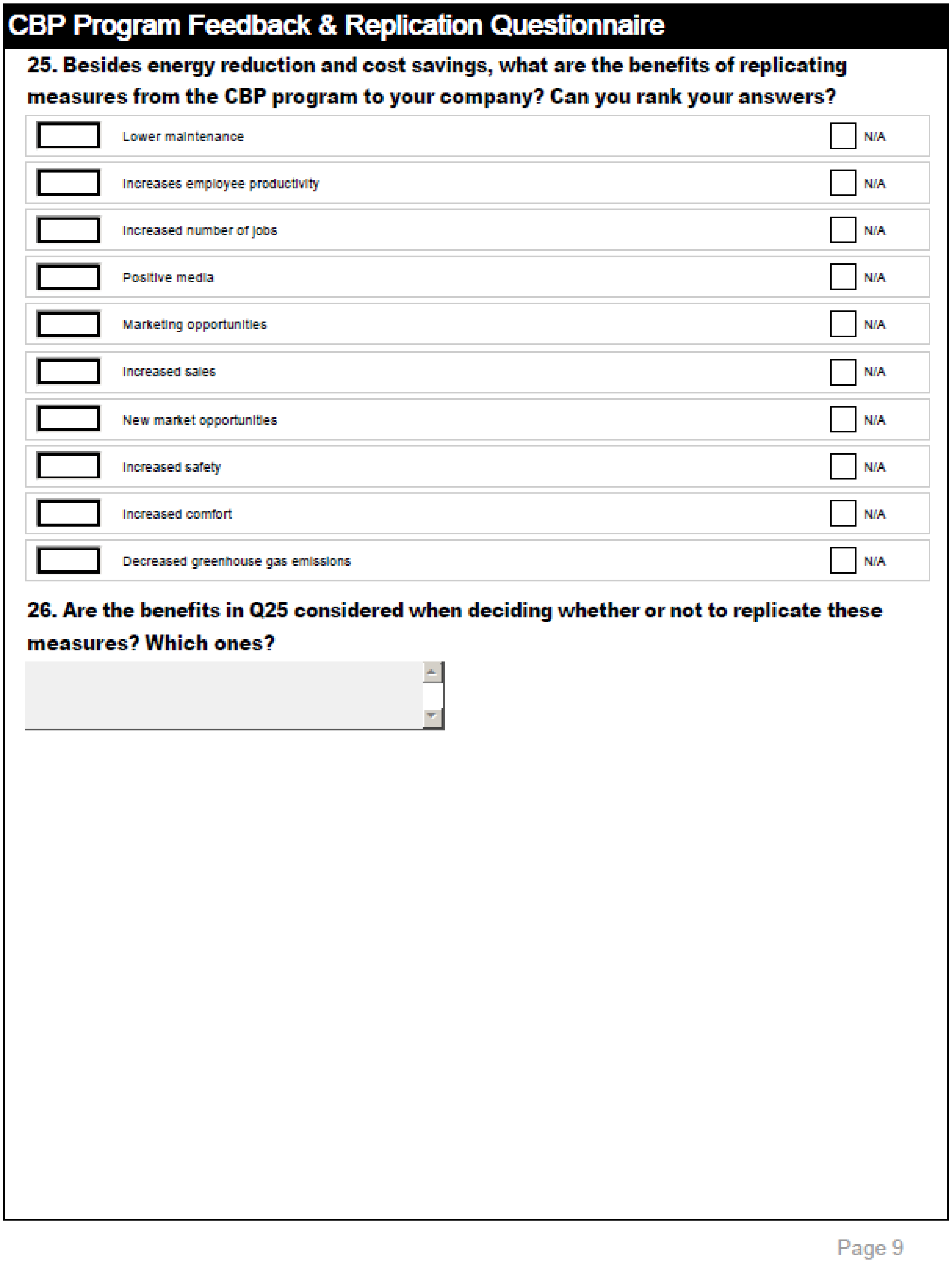

CBP Program Feedback & Replication Questionnaire

25. Besides energy reduction and cost savings, what are the benefits of replicating measures from the CBP program to your company? Can you rank your answers?

☐ Lower maintenance ☐ N/A
☐ Increases employee productivity ☐ N/A
☐ Increased number of jobs ☐ N/A
☐ Positive media ☐ N/A
☐ Marketing opportunities ☐ N/A
☐ Increased sales ☐ N/A
☐ New market opportunities ☐ N/A
☐ Increased safety ☐ N/A
☐ Increased comfort ☐ N/A
☐ Decreased greenhouse gas emissions ☐ N/A

26. Are the benefits in Q25 considered when deciding whether or not to replicate these measures? Which ones?

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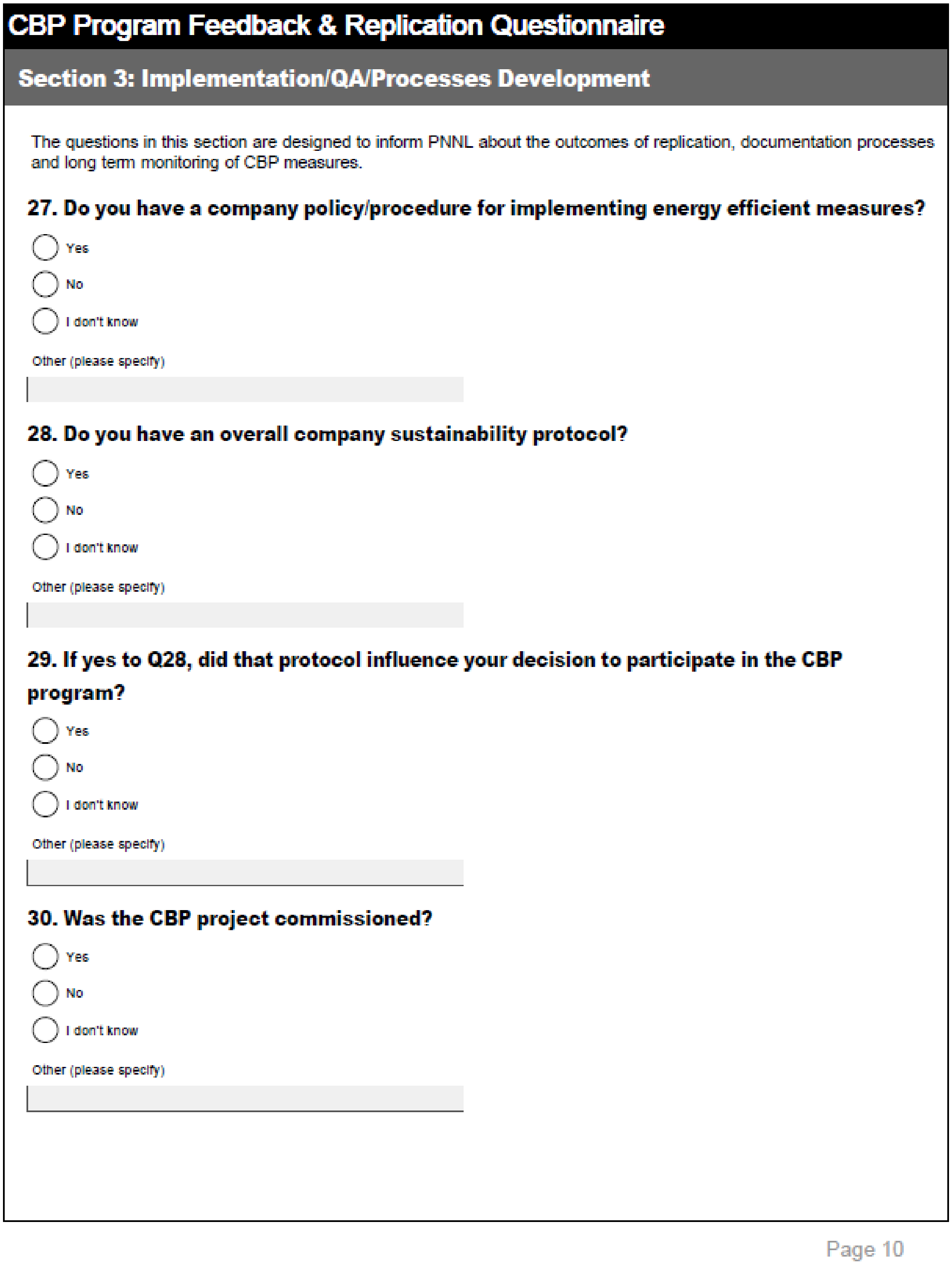

CBP Program Feedback & Replication Questionnaire

Section 3: Implementation/QA/Processes Development

The questions in this section are designed to inform PNNL about the outcomes of replication, documentation processes and long term monitoring of CBP measures.

27. Do you have a company policy/procedure for implementing energy efficient measures?

○ Yes
○ No
○ I don't know

Other (please specify)

28. Do you have an overall company sustainability protocol?

○ Yes
○ No
○ I don't know

Other (please specify)

29. If yes to Q28, did that protocol influence your decision to participate in the CBP program?

○ Yes
○ No
○ I don't know

Other (please specify)

30. Was the CBP project commissioned?

○ Yes
○ No
○ I don't know

Other (please specify)

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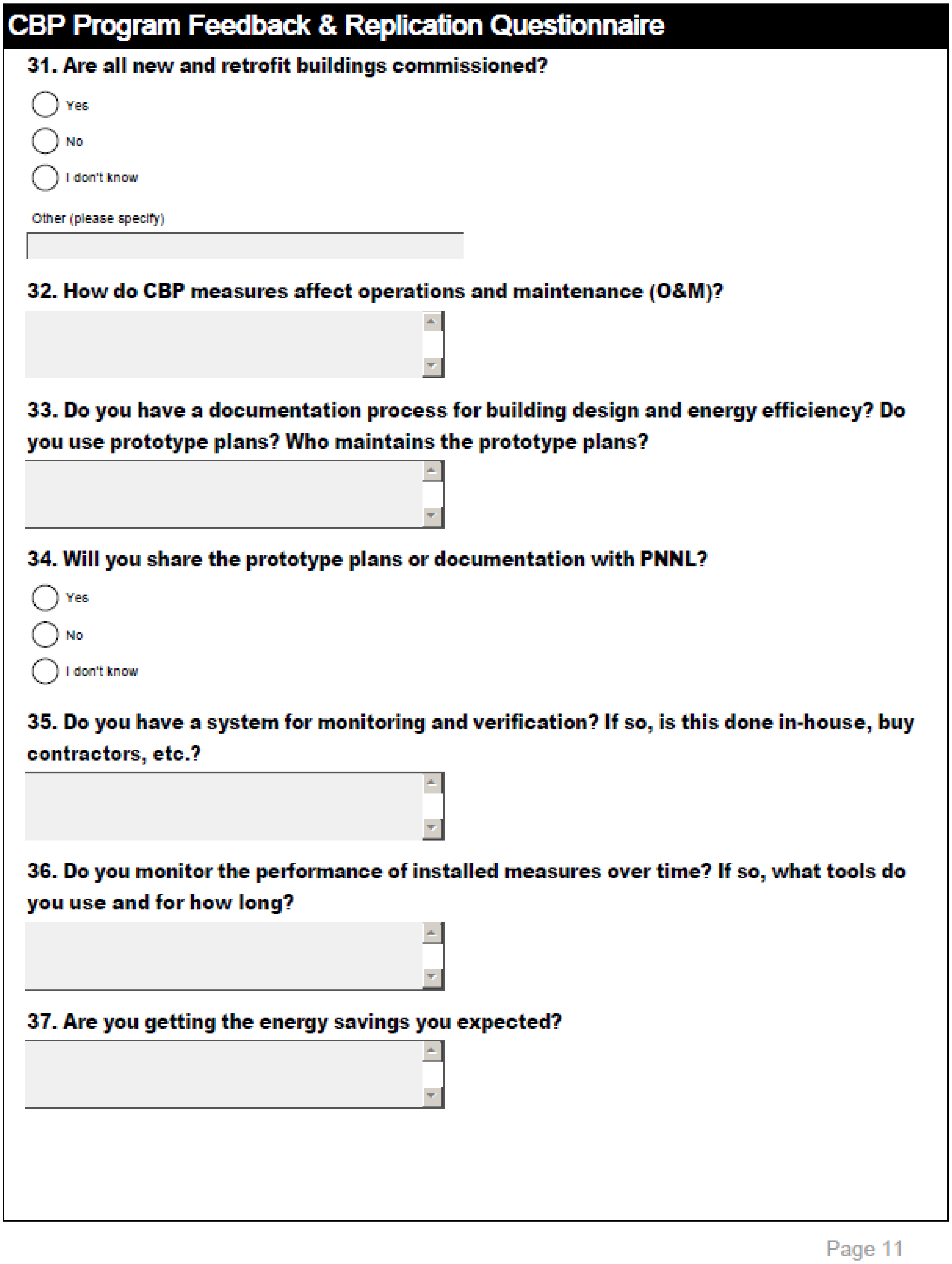

CBP Program Feedback & Replication Questionnaire

31. Are all new and retrofit buildings commissioned?

○ Yes
○ No
○ I don't know

Other (please specify)

32. How do CBP measures affect operations and maintenance (O&M)?

33. Do you have a documentation process for building design and energy efficiency? Do you use prototype plans? Who maintains the prototype plans?

34. Will you share the prototype plans or documentation with PNNL?

○ Yes
○ No
○ I don't know

35. Do you have a system for monitoring and verification? If so, is this done in-house, buy contractors, etc.?

36. Do you monitor the performance of installed measures over time? If so, what tools do you use and for how long?

37. Are you getting the energy savings you expected?

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Appendix C: CBP Partner Follow-Up Interview Questions

Section 1: CBP Program Participation Information

1. Why did your firm participate in the CBP Program?
2. What were the primary objectives your company had? What were the goals?
3. How did your firm ensure quality assurance during the project? Do you use the same procedures for all construction and renovation projects?
4. What are your firm's motivations for investing in energy efficient components?
5. Do you have any other comments about CBP program participation?

Section 2: Replication Information

1. Can you break down the specific measures per ft^2 from the survey (refer to corresponding survey question) by technology type (HVAC, lighting, thermal enclosure)?
2. How does your firm decide whether or not to implement these measures?
3. Who is responsible for overseeing such investments? Do you have an official oversight mechanism in place?
4. If yes to number 6, are these protocols mandated through company procedures?
5. What is the organizational view of the role of energy efficient investments? For example, it is seen as part of the organizational mission or as a requirement? Is this view shared by the board? By executives? By staff?
6. Do you have any other comments you have about CBP Replication?

Section 3: Implementation/QA/Processes Development

1. If the company indicated policy/procedure for EE measures, ask them to elaborate.
2. If the company indicated a sustainability protocol, what else is included in that protocol outside of energy considerations?
3. Are energy efficiency technologies, such as those included in the CBP program monitored through company documentation like annual reports? Are there general performance standards for these measures?
4. The rest of the interview portion for this section will include follow-up to the questions above.