A Drop in the Bucket or a Pebble in a Pond: Commercial Building Partners' Replication of EEMs Across Their Portfolios

Chrissi A. Antonopoulos and Michael C. Baechler, Pacific Northwest National Laboratory
Heather E. Dillon, University of Portland

ABSTRACT

This study presents findings from questionnaire and interview data investigating replication efforts of Commercial Building Partnerships (CBP) partners that worked directly with the Pacific Northwest National Laboratory (PNNL). PNNL partnered with 12 organizations on new and retrofit construction projects as part of the U.S. Department of Energy (DOE) CBP program. PNNL and other national laboratories collaborate with industry leaders that own large portfolios of buildings to develop high performance projects for new construction and renovation. This project accelerates market adoption of commercially available energy saving technologies into the design process for new and upgraded commercial buildings. The labs provide assistance to the partners' design teams and make a business case for energy investments. From the owner's perspective, a sound investment results in energy savings based on corporate objectives and design.

Through a feedback questionnaire, along with personal interviews, PNNL gathered qualitative and quantitative information relating to replication efforts by each organization. Data gathered through this process 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 entire CBP program.

Conclusions of this study indicate by 2030, 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, and an energy savings potential between 2.3 and 77 trillion Btus annually.

Introduction

Of the overall energy footprint in the United States, approximately 40% of total primary energy is consumed by the buildings sector, almost half of which is attributed to commercial buildings (EIA 2012). 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. 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) is a public/private cost-share program addressing new and existing commercial buildings (DOE 2012b). Replication of building measures utilized in the CBP program has significant market transformation potential for the commercial building sector in the United States.

This paper explores potential energy savings potential of CBP partners by forecasting energy savings potential throughout partner portfolios. 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 within the portfolios could result in significant energy and cost savings. This paper provides a synopsis of a full study that used a combination of CBP partner survey data and a diffusion of innovations model to assess current energy savings, and forecast future propagation of program measures throughout the commercial building industry.

Commercial Building Partnerships (CBP)

The CBP program was initiated in 2008 (CBP I), with a second funding opportunity presented in 2010 (CBP II) through the American Recovery and Reinvestment Act (ARRA). The selection process for these projects was competitive, with strict energy savings requirements mandated by DOE. Once selected, each partner committed to savings goals for new construction projects that were at least 50% greater than ANSI/ASHRAE/IESNA Standard 90.1-2004 or 2007. In existing buildings, retrofit projects were designed so that a building would consume at least 30% less energy relative to either Standard 90.1-2004 or its historic consumption (DOE 2012b).

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 (EEMs) 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). 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.

To date, CBP has partnered with 42 entities on 54 specific new construction and retrofit projects, covering 8.3 million square feet of commercial building space (DOE 2012b). Total square footage of commercial building floor area included in partner portfolios amounts to about 4 billion square feet, approximately 6% of the total commercial building stock in the United States (DOE 2011b; EIA 2008).

Research Question and Theoretical Framework

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 on energy efficiency, including overall energy savings, cost-effectiveness and behavioral changes.

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?

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 1 is a representation of Rogers technology adoption curve, representing each phase of market transformation.

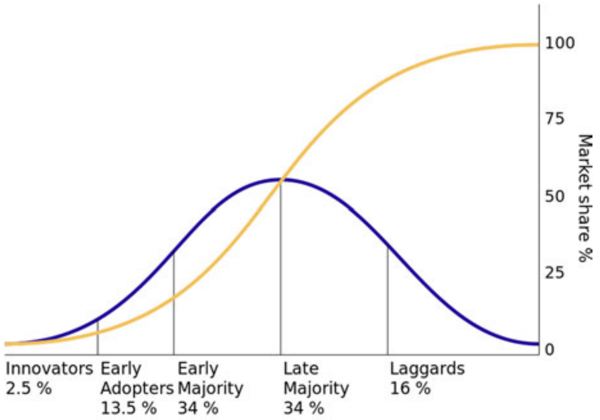

Figure 1. Adopter categories and market penetration of the diffusion of innovations theory. *Source*: Rogers 1995.

Figure 2 represents the framework and model for this study based on the diffusion of innovations theory. Instead of the S-curve illustrated in Figure 1, this framework displays market diffusion from the innovators represented in the smallest circle, out to full market transformation, 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.

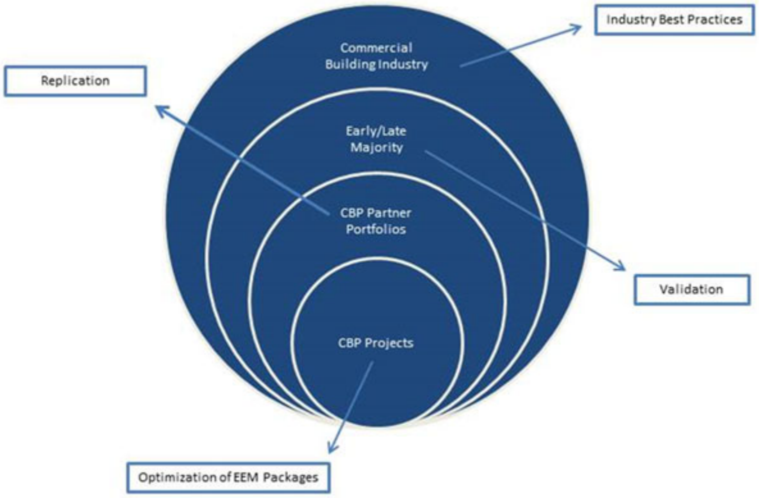

Figure 2. Theoretical framework.

CBP Replication Trends

CBP replication methodology. 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 revealed patterns in motivation for constructing energy efficient buildings, along with better insight into corporate environmental management.

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.

CBP replication findings. CBP partners were asked to forecast energy savings over the next 5 to 10 years for their building project. 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. A few partners expect to see energy savings higher than 50%.[1] The partners were also asked to predict cost savings of energy expenditures for the CBP building as shown below in Figure 3. 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 Figure 4, 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.

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 test-bed 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.

---

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

Primary findings of the CBP partner replication analysis include:

- The CBP program provided an optimized approach to implementing EEMs for cost and energy savings**.**
- 100% of CBP partners contacted for this study indicated they would replicate some or all EEMs and CBP approaches.
- Three EEMs, (low wattage exit signs, occupancy sensors and energy management systems), have a 100% replication rate.
- Lighting and heating, ventilation and air conditioning (HVAC) technologies were most broadly adopted by CBP partners.
- Six partners confirmed that light emitting diode (LED) lighting technology and design will now be used in their building portfolios thanks to participation in the CBP program.
- The CBP program provided a testbed for future energy efficiency projects (new and existing building) within the partner portfolio.
- CBP partners are motivated by cost savings more than other benefits.

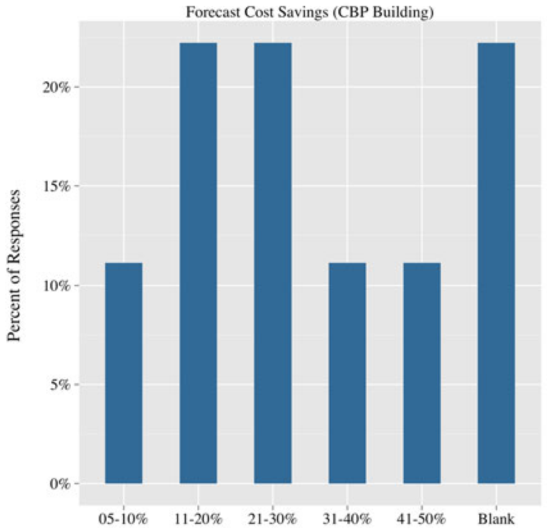

Figure 3. CBP partner forecast cost savings for the CBP building in the next 5-10 years as reported in the survey. *Source*: Antonopoulos et al. 2013.

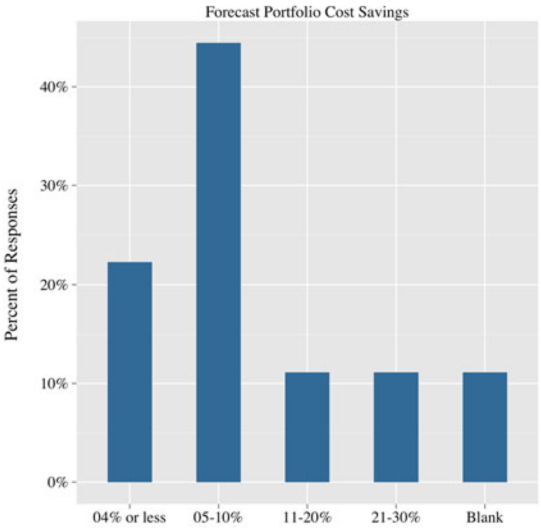

Figure 4. cbp partner forecast energy savings for the partner portfolio in the next 5-10 years as reported in the survey. *Source*: Antonopoulos et al. 2013.

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

- Two partners indicated that they now have a detailed plan for measurement and verification (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 new and existing buildings owned by the organization.

- Three partners indicated that LEED standards are mandated in all new construction. Takeaways from the CBP program will be added to their existing protocol.
- Three partners indicated that enhanced modeling and optimizing an EEM package that included climate zone considerations were primary takeaways from program participation.

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 5 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.

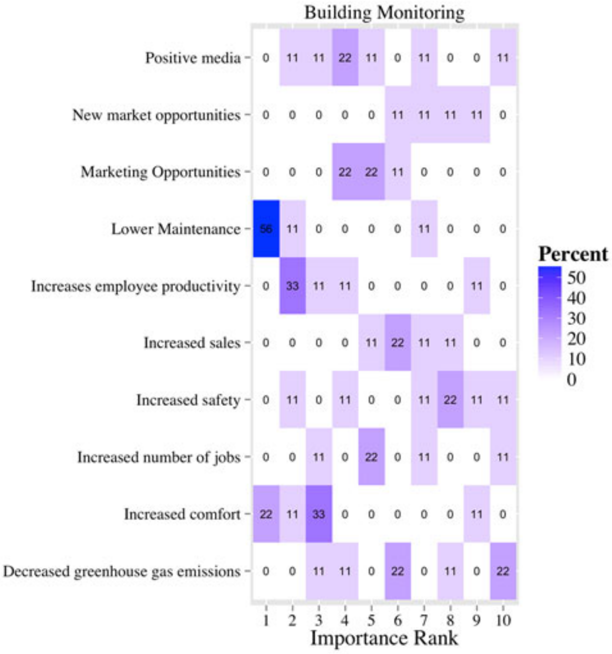

Figure 4. Survey responses to CBP benefits beyond energy and cost savings. Respondents ranked the benefits and percentage of responses are shaded. *Source:* Antonopoulos et al. 2013.

Diffusion of Innovations Modeling and Outcomes

Diffusion of innovation modeling methodology. 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). 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; Rogers 1995).

Different versions of a diffusion model have been used by several authors to predict energy efficiency technology diffusion in the building sector. 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 1969). Internal influences are impacts of media, government and other broad adoption efforts, and external influences involve social interaction (Bass 1969). 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 was 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).

$$\frac{\mathrm{dN(t)}}{\mathrm{dt}} = \left(\mathrm{p} + \frac{\mathrm{q}}{\mathrm{M}} \cdot \mathrm{N(t)}\right) \cdot \left(\mathrm{M} - \mathrm{N(t)}\right) \qquad \text{(Eq 1)}$$

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.

$$F(t) = \frac{1 - exp(-(p+q)t)}{1 + \left(\frac{q}{p}\right) exp(-(p+q)t)} \qquad \text{(Eq 2)}$$

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 USGBC certification database was considered. 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 dataset was downloaded from the USGBC website and the Yudelson estimate was compared to actual LEED certifications.

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 calculated they were compared to the USGBC data, and 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.

Diffusion of innovation modeling findings. Two distinct Bass diffusion models ("CBP Construction" and "Market Bass Model") were developed, which resulted in a large difference between modeled outputs. The CBP Construction model (conservative) was developed using CBP partner data 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 observed diffusion of other green building programs (i.e., LEED).

Table 1 presents the parameters for determining model inputs for the CBP Construction (conservative) model. 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 United States, 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.

Table 1. CBP construction model parameters determined from the CBP data

Bass Model Parameter	Value (Bass Traditional)	Source
p - coefficient of innovation	1.344828e-5	Data fit optimization of the R^2 values for a matrix of possible p values.
q - coefficient of imitation	0.2448	Data fit optimization of the R^2 values for a matrix of possible q values.
m - maximum market potential (number of buildings)	250,709	Total new 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

Table 2 provides a summary of the modeling inputs and outputs for the Market Bass Model (optimistic). The final *p* and *q* coefficients are based on maximizing the R^2 coefficient. The maximum market potential (number of buildings) was estimated based on the average commercial building 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 database are tagged as “Existing Buildings”). The maximum market potential in this case is represented by the total number of buildings in the United States. *(m),* which matches fairly well with the number estimated by Yudelson.

Table 2. Market bass model parameters determined from the raw data

Bass Model Parameter	Value (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

Table 3 and Figure 6 show the comparison of the two Bass models with the CBP construction data. It is important to note that the actual number of projects presented in Table 3 and Figure 6 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 3. 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

Energy savings calculations. In addition to modeling the 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 (EUI) 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 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, this decrease in modeled CBP EUIs was compared 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.

A second savings calculation was conducted 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. Energy use benchmarking is available for office, retail, K-12 school and hotel buildings, which includes median EUIs for each building type (EPA 2012). The median EUI data was averaged for all four commercial building types used 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. The resulting energy savings numbers were very similar to the comparison with CBECS, ranging between 2.3 and 75 trillion Btus annually.

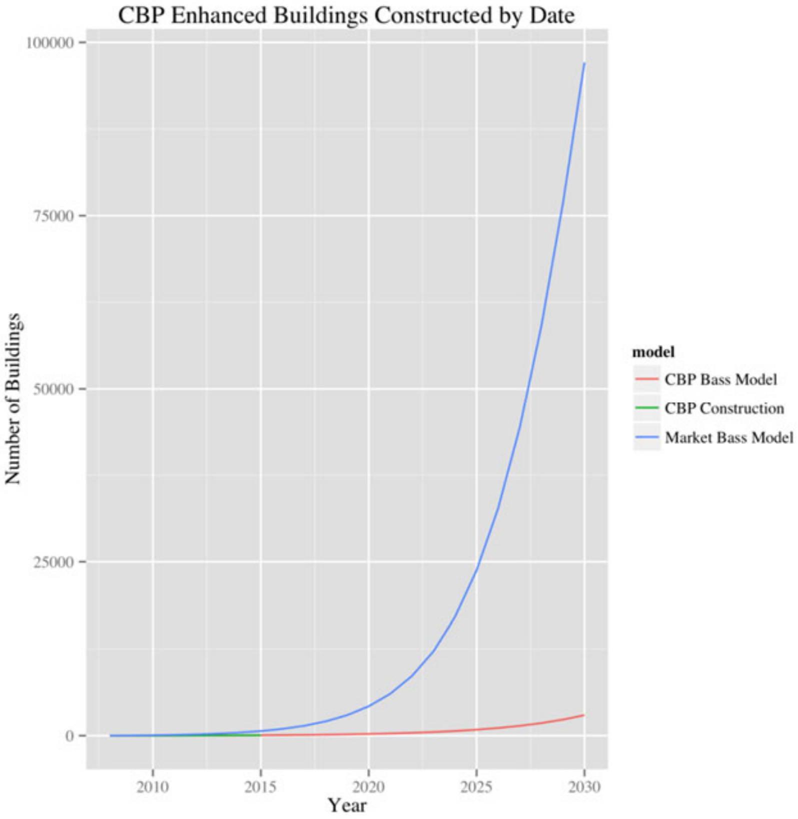

Figure 6. CBP market penetration prediction using the bass model.

Conclusion

This research may be able to help lay foundations for further study relating structural approaches to building energy efficiency and behavior. Using the diffusion of innovations theory to model energy efficiency replication and market transformation in the commercial building sector was determined to be an appropriate approach for energy efficiency forecasting in the commercial sector. 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, and an energy savings potential between 2.3 and 77 trillion Btus annually.

Analysis from both the diffusion model and the survey results indicates that the CBP format for market change is effective. The CBP program provided an optimized approach to implementing EEMs for cost and energy savings in buildings and partner portfolios**.** Partners completed projects based on internal targets for cost effectiveness and all the survey respondents plan to replicate the chosen EEMs.

References

Antonopoulos, C., Dillon, H. and M. Baechler. 2013. *Commercial Building Partnerships Replication and Diffusion*. PNNL-SA-22833. Richland, WA.

Baechler, M., Dillon, H., and R. Bartlett. 2012. "Commercial Building Partners Catalyze Energy Efficient Buildings Across the Nation." In *2012 ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA.

Bass, F. M. 1969. "A New Product Growth for Model Consumer Durables." *Management Science*, 15 (5), 215-227.

DOE (U.S. Department of Energy). 2012b. *Buildings Energy Data Book. 3.2: Commercial Sector Characteristics*. March 1, Department of Energy, Washington D.C. http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.2.1.

DOE (U.S. Department of Energy). 2013. *Commercial Building Partnerships*. March 1, Department of Energy, Washington, D.C. http://www1.eere.energy.gov/buildings/commercial/cbp.html.

EIA (U.S. Energy Information Administration). 2012. *Annual Energy Review 2011*. DOE/EIA-0384 (2011). U.S. Energy Information Administration, Washington, D.C. http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf.

EIA (Energy Information Administration). 2008. *Commercial Building Energy Consumption Survey (CBECS)*. Energy Information Administration, Washington, D.C. http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html.

EPA (Environmental Protection Agency). 2012. *Portfolio Manager Data Trends*. Environmental Protection Agency, Washington, D.C. http://www.energystar.gov/buildings/about-us/research-and-reports/portfolio-manager-datatrends.

Elliott, D. B., Anderson, D. M., Belzer, D. B., Cort, K. A., Dirks, J. A., and Hostick, D. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. Pacific Northwest National Laboratory, Richland, WA.

Fagerberg, J. 2003. *Innovation: A Guide to the Literature*. Paper presented at the Workshop "The Many Guises of Innovation: What we have learnt and where we are heading", Ottawa, October 23-24.2003, organized by Statistics Canada.

Fisher, J. C., and Pry, R. H. 1971. "A Simple Substitution Model of Technological Change". *Technological Forecasting and Social Change*, 3, 75-88.

Rogers, E. M. 1995. *Diffusion of Innovations*. Fourth Edition. New York, NY: The Free Press.

USGBC—U.S. Green Building Council. (2012). *LEED*. U.S. Green Building Council, Washington, D.C. https://new.usgbc.org/leed.

Yudelson, J. 2005. *Predicting the Growth of Green Buildings using the "Diffusion of Innovations" Theory*. Yudelson Associates, Tucson, AZ.