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Energy Efficiency Technologies for Buildings: Potential for Energy, Cost, and Carbon Emission Savings

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ENERGY EFFICIENCY TECHNOLGIES FOR BUILDINGS: POTENTIAL FOR ENERGY, COST, AND CARBON EMISSION SAVINGS

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Abstract

Buildings are a significant energy consumer and are responsible for an increasingly large percent of worldwide greenhouse gas emissions, currently between 30 and 40 percent. Energy efficiency presents unique opportunities for building owners to reduce their environmental footprint and add value through cost savings, tax deductions, and increased market value. An analysis of 183 samples of efficiency measures in seven technology categories found that 74% of efficiency investments had a positive net present value. Building automation system and chiller plant improvements had the highest mean energy and carbon dioxide savings per square foot. Additionally, building automation systems had, on average the highest return on investment, approximately $800 above the cost of implementation per one thousand square feet. Only building envelope modifications had a negative mean return on investment. Building automation system upgrades avoided an average of 350 pounds of CO_2e for every dollar spent, reducing a building's total carbon footprint by as much as 28%. The results suggest that a significant opportunity for cost, energy, and emission savings is available across all technology categories.

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Introduction

The design and operation of buildings substantially shapes the natural environment of our increasingly developed world. Buildings account for nearly 40% of end-use energy consumption and greenhouse gas (GHG) emissions in the United States, according to the United Nation's Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Fortunately, the IPCC concluded in the same report that the building sector has the largest potential for reducing energy consumption and cutting carbon emissions. Using commercially available technologies, the IPCC projects energy use in new and existing buildings can be cut by 30-50% without significantly increasing costs.[1] New policies, incentives, and voluntary behavioral shifts will promote investments in these technologies. Accordingly, both the economic and marketing benefits of sustainable building are growing, thereby increasing the potential for dramatic cuts in building resource consumption.

Building owners can both avoid risks and capitalize on opportunities by investing in energy efficiency measures, such as improvements in lighting, building envelope construction, heating, and air conditioning. An examination of a variety of energy efficiency techniques reveals that significant energy and greenhouse gas savings are possible. The financial impact of these investments will determine to what extent the investments are undertaken and which are chosen. This thesis offers background information on energy efficiency in buildings and climate change, and then presents an analysis of the economic and environmental impact of seven types of energy efficiency technologies.

[1] United Nations Environmental Programme-Sustainable Buildings and Climate Initiative, "Common Carbon Metric," http://www.unep.org/sbci/pdfs/UNEPSBCICarbonMetric.pdf (accessed November 3, 2010).

Chapter 1. Buildings and Energy

Buildings are responsible for a significant share of the world's environmental footprint. In the United States, buildings were responsible for 38.9% of total energy consumption and 72% of electricity consumption in 2006. Heating, ventilation, and air conditioning (HVAC) make up the largest portion of commercial building energy use (52%). The second largest use of energy in commercial buildings is lighting, which accounts for 20% of a building's energy consumption on average. Lighting and HVAC improvements therefore represent a significant opportunity for energy efficiency in buildings.[2] In addition to energy use, building occupants in the U.S. use 3.4 billion gallons of water each day, and are responsible for the majority of waste generation. Building-related construction and demolition debris amounts to 169 million tons per year, or approximately 26% of total non-industrial waste generated. Combined with waste disposed of during operation and renovations, building-related waste constitutes two-thirds of all solid waste generation in the United States.[3]

Projected increases in urban growth in developed countries and the urbanization of developing countries highlight the importance of sustainable building.[4] The U.S. Energy Information Administration (EIA) 2010 International Energy Outlook reports that

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[2] World Business Council for Sustainable Development, *Transforming the Market*, Energy Efficiency in Buildings, http://www.wbcsd.org/DocRoot/rVDgBRKvPngUrqivMHNM/91719_EEBReport_WEB.pdf (accessed November 3, 2010).

[3] U.S. Environmental Protection Agency, *Buildings and the Environment: A Statistical Summary*, http://www.epa.gov/greenbuilding/pubs/gbstats.pdf

[4] Piet Eichholtz et al., "The Economics of Green Buildings," *Berkeley Program on Housing and Urban Policy, Institute of Business Economic Research* (2010).

commercial energy use in developed countries will expand by 0.9 percent per year. Energy demand in emerging economies is projected to grow by 3.2 percent per year. Combined, energy consumption worldwide is expected to rise faster than population. In the U.S., the EIA estimates end-use energy consumption will grow by 0.7 percent per year from 2008, reaching nearly 40 quadrillion BTUs by 2020, under a business as usual (BAU) scenario.[5] As energy use in buildings exceeds consumption in the other major sectors—industrial and transportation—energy efficiency in buildings offers the greatest potential to decrease worldwide consumption.[6]

Annually, commercial buildings spend more than $100 billion on energy, making it the single largest operational cost, but also the most manageable. For an average office building in the U.S., energy represents 30 percent of total operating expenses.[7] Use of energy conservation measures reduces this expense and offers a wide range of other economic and social benefits to building owners, tenants, and the surrounding community.

As a result of several factors, including rising energy costs and the growing attention given to corporate social responsibility, green building has gained substantially in popularity. Since 1980, energy consumption per square foot has decreased 11 percent in residential buildings and 21 percent in commercial buildings.[8] Certified green buildings account for a quarter of office space in some metropolitan areas in the U.S. and the use of the term "green building" has tripled from 2005 to 2009 in the U.S. popular press. The

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[5] Hannah Choi Granade et al., "Unlocking Energy Efficiency in the U.S. Economy," *McKinsey Global Energy and Materials* (2009).
[6] Luis Perez-Lombard et al., "A Review on Building Energy Consumption Information," *Energy and Buildings* 40 (2008): 394-398.
[7] Eichholtz et al., "The Economics," 2.
[8] Ibid., 56.

number of participants at major international green building conferences has also tripled.[9] In collaboration with Siemens Industry, *Building Operating Management* magazine randomly surveyed 12,000 subscribers in its Building Technologies' 2010 Energy Efficiency Survey. More than 90% of respondents are implementing or have completed energy-related upgrades. The most common energy reduction technologies employed are lighting retrofits, likely due to the short payback period. As impressive as the expansion of green building has been, far greater efficiency potential remains.[10]

Commercial buildings; responsible for approximately 18 percent of the 2020 BAU end-use projections (roughly 8 quadrillion BTUs); offer 25 percent of energy efficiency potential, according to a study by McKinsey Global Energy and Materials. The authors additionally found that all geographic regions of the U.S. exhibit significant efficiency potential, with the South and Midwest offering the largest absolute potential. The Northeast offers the greatest efficiency potential relative to total consumption in the region.[11]

According to the McKinsey study, a holistic approach to energy efficiency would yield gross energy savings worth more than $1.2 trillion, well above the estimated $520 billion investment needed through 2020 to realize these savings. This program would save 9.1 quadrillion BTUs, or 23% of projected demand, additionally abating nearly 1.1 gigatons of GHGs per year.[12] The study further reports that employing all NPV-positive efficiency techniques could reduce energy consumption by 29 percent, requiring $125 billion in investment, compared with discounted savings of $290 billion in energy costs. This less

[9] Piet Eichholtz et al., "Doing Well By Doing Good? Green Office Buildings," *Center for the Study of Energy Markets, University of California Energy Institute* (2009).
[10] Granade et al., 7.
[11] Ibid., 11.
[12] Granade et al., 7.

aggressive scenario would result in the abatement of roughly 360 million tons of GHG emissions. Much of this potential exists because the building sector is less sensitive to discount factors, participant costs of capital, and carbon prices. Furthermore, most efficiency measures can be rapidly implemented. [13]

In total, efficiency potential totals 2,300 trillion end-use BTUs. Of this, 87 percent of the potential exists in buildings. The remainder is met by efficiency in non-building community infrastructure such as street lights and water treatment.[14] Of the total potential, government buildings make up 360 trillion end-use BTUs, or 15.65 percent of total potential. Another 35 percent, or 810 trillion end-use BTUs, is offered by non-government existing buildings. New buildings account for approximately 12 percent of this estimate.[15]

Investments in energy efficiency at the time of construction or renovation saves energy cost, reduces greenhouse gas emissions, decreases water use and waste disposed of, decreases operating costs, and insures against future increases in energy prices.[16] Along with these direct resource savings, energy efficiency in buildings offers a host of other economic and social benefits to building owners and communities. A study conducted at the Center for Study of Energy Markets at the University of California Energy Institute utilized 10,000 subject and control buildings to match publicly available information on EnergyStar and LEED-rated office buildings with rental rates and selling prices to determine the economic value of “green building” certifications.

Buildings certified by a green rating system were found to command rental rates approximately three percent higher per square foot than otherwise identical buildings. The

[13] Granade et al., 7.
[14] Ibid., 56
[15] Ibid.
[16] Eichholtz et al., “Doing Well”, 5.

study found that selling prices of green buildings are roughly 16 percent higher, and each dollar of saving in energy costs from increased thermal efficiency yields approximately 18 dollars in increased valuation in the housing market. Evidence also suggests that the intangible effects of green building certifications further increase the value of these buildings in the market.

Locating corporate activities in a certified, green building, affects the corporate image of the building owner and its tenants. Leasing space in a green building acts as a signal of a company's commitment to corporate social responsibility. A more socially responsible reputation can help the company attract not only more customers, but also a better workforce. As a result, building owners benefit because tenants are willing to pay a high premium to rent office space in a certified green building.[17] According to the Center's study there is a statistically significant and substantial premium in rent and market value for certified green buildings.[18]

In a 2001 study, Orlitzky and Benjamin proposed that the better a firm's social reputation, the lower its total market risk. This relation may also apply to the real estate sector, suggesting green buildings are less subject to volatility in market value. A paper from the Berkeley Program on Housing and Urban Policy analyzed a sample of office buildings that have been certified by green building rating systems to discover that increases in the supply of green buildings compounded with the extreme volatility of the housing market in the years before the study have *not* significantly affected relative returns to green buildings, indicating that green buildings are more resilient to recession. The economic downturn in the economy that adversely affected property prices across the U.S. did not significantly

[17] Eichholtz et al., "Doing Well", 6.
[18] Ibid., 7.

damage the financial performance of green buildings. The paper also confirmed that attributes rated for thermal efficiency and sustainability contribute to the premium in rent and market value of green buildings. The authors further found that, "even *among* green buildings, increased energy efficiency is fully capitalized into rents and asset values."[19]

Other indirect economic and social benefits have been reported. A study by Lawrence Berkeley National Laboratory found that higher indoor air quality can increase worker productivity by 5 percent. Occupants of green buildings also survey as more satisfied with their space and experience grater thermal comfort and air quality than occupants of normal buildings. This study suggests that improvements in worker health and productivity due to sustainable building may amount to $37 billion to $210 billion annually. Better indoor air quality can reduce syndromes associated poor indoor air quality such as asthma, respiratory illness, and a condition known as Sick Building Syndrome (SBS). Estimated costs of SBS are $60 billion in annual sick days, medical costs, and lost productivity.[20]

Despite clear benefits, several persistent barriers at the individual and system level remain, preventing the nation's efficiency potential from being fully realized. Energy efficiency challenges include the cost of initial investment, the fragmentation of the opportunities across the nation, low awareness and attention, and the difficulty of measuring changes in energy consumption.[21]

Granade et al. (2009) identify three types of barriers which hinder implementation of efficiency measures: structural, behavioral, and availability barriers. Structural barriers disallow end-users from having the choice to implement what would otherwise be an

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[19] Eichholtz et al., "The Economics," 1.
[20] Granade et al., 13.
[21] Ibid., 21.

attractive energy efficiency option. Structural barriers include agency issues in which the energy bills and the capital rights are misaligned, usually between landlord and tenant; transactional barriers that hide non-monetizable costs, such as R&D; and pricing distortion created by regulation. Behavioral barriers result from a lack of an awareness or disinterest in energy efficiency techniques despite potential savings. This category includes risk aversion, lack of awareness, custom and habit, and elevated hurdle rates in which building owners require extremely short payback periods despite understanding the long-term benefits of energy efficiency technologies. Lastly, availability barriers occur when an end-user wants to pursue an efficiency option but lacks access to it or the needed upfront capital.

Incentive programs are helping efforts to overcome these major barriers. Both the private and public sector offer incentives for commercial building owners to invest in energy reducing technologies. Passed by Congress on July 29, 2005 and signed into law by George W. Bush the following August, the Energy Policy Act of 2005 (EPAct) created the most significant tax incentives program for residential and commercial building owners to reduce energy use.

The EPAct offers owners or designers of commercial buildings that meet the ASHRAE 90.1-2001 standard the following tax deductions:

- Buildings that save 50% or more of projected annual energy costs across all three system components are eligible for a tax deduction of $1.80 per square foot.
- Buildings that save a percentage of projected annual energy costs for one of the three components—building envelope, lighting, and heating & cooling—are eligible for a pro-rated deduction of up to $0.60 per square foot.[22]

[22] The Tax Incentives Assistance Project, “Commercial Incentives Flyer,” http://energytaxincentives.org/uploaded_files/commercialflyer.pdf (accessed September 8, 2010).

- Owners of Combined Heat and Power (CHP) systems smaller than 50 MW and 60% efficient are eligible for a 10% investment tax credit for CHP property for the first 15 MW of CHP property.[23]

The American Recovery and Reinvestment Act of 2009 offers renewable energy tax credits worth 30% of total investment costs for on-site renewables. For systems installed before January 1st, 2009, the maximum credit for individuals is $2000 for photovoltaic systems, solar water heating systems, and geothermal heat pump systems. Systems installed after December 31, 2008 and all small-wind turbine systems are not subject to a cap.[24]

Tax incentives have stimulated consumer behavior in the past. A study by Hassett and Metcalf (1995) used panel data to measure the impact of tax policies that promote energy conservation investments on the probability of people making these investments. Accounting for heterogeneity in tastes for energy-saving opportunities, the study found that a 10 percent point change in tax price for energy investment results in a 24 percent increase in the probability of making an investment.[25]

Certification programs in the United States also encourage energy efficient in buildings, particularly the Energy Star Program, jointly sponsored by the EPA and the U.S. Department of Energy, and the U.S. Green Building Council (USGBC)'s LEED (Leadership in Energy and Environment Design) rating system.[26] The effectiveness of LEED in promoting efficiency was examined in a 2008 study by the New Buildings Institute. The

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[23] The Tax Incentives Assistance Project, "Combined Heat and Power," http://energytaxincentives.org/business/chp.php (accessed September 8, 2010).
[24] The Tax Incentives Assistance Project, "On-site renewables tax incentives," http://energytaxincentives.org/business/renewables.php (accessed September 8, 2010).
[25] Kevin A Hassett and Gilbert E. Metcalf, "Energy tax credits and residential conservation investment: Evidence from panel data," Journal of Public Economics 57 (1995): 201-217.
[26] Eichholtz et al., "Doing Well", 5.

authors found that LEED buildings, on average, consumed 24% less energy per square foot compared with the national average for all commercial building stock.[27]

Despite various challenges, greater awareness, regulatory incentives, and increased energy prices will promote energy efficiency in the building sector and weaken barriers. Progress made in decreasing energy intensity will be mitigated by economic growth, urbanization, and expanded use of electrical appliances and devices unless major changes in public awareness are made.[28] Likely, new policies will force demand- and supply-side trends toward energy efficiency and conservation.

[27] Cathy Turner and Mark Frankel, *Energy Performance of LEED for New Construction Buildings*, *U.S. Green Building Council*, New Buildings Institute, 2008, http://www.usgbc.org/ShowFile.aspx?DocumentID=3930 (accessed April 2, 2011).
[28] Granade et al., 21.

Chapter 2. Buildings and Climate Change

Concern for our impact on the natural environment is shaping policy, consumer behavior, and economic activities. Today, climate change presents one of the greatest environmental challenges. Climate change has been the focus of billions of dollars of research for the past three decades in both the international and national scientific communities. Climatologists have determined with confidence that anthropogenically made greenhouse gases have and will continue to radically alter the Earth's climate. Greenhouse gases include but are not limited to carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons. Carbon dioxide accounts for approximately 50 percent of GHG emissions, and the United States is a leading contributor of greenhouse gases, emitting more per person than any other nation.[29] The U.S. Environmental Protection Agency (EPA) concurs with the United Nation's Intergovernmental Panel on Climate Change (IPCC) projections of a 2.2°F to 10°F rise in temperatures by 2100 as a result of GHGs emitted anthropogenically.[30]

The anticipated increase in global mean and high temperatures in the 21st century will have devastating consequences, resulting in an increase in morbidity and mortality, particularly among the elderly, young, and poor. The IPCC and EPA project with a high confidence that increased maximum temperatures and high atmospheric carbon dioxide

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[29] Janine Maney, "Carbon Dioxide Emissions, Climate Change, and the Clean Air Act: An Analysis of Whether Carbon Dioxide Should be Listed as a Criteria Pollutant," *N.Y.U. Environmental Law Journal* 13 (2005), 317.
[30] United Nations Environmental Programme-Sustainable Buildings and Climate Initiative, *Common Carbon Metric*, http://www.unep.org/sbci/pdfs/UNEPSBCICarbonMetric.pdf (accessed November 3, 2010).

concentrations will increase risk of damage to crops, heat stress in livestock and wildlife, drought, lower crop yields, damage to building foundations due to shrinkage, forest fire, infectious epidemics, coastal erosion, and loss of sensitive ecosystems, such as mangroves and coral reefs. Climate change is also expected to increase the range and activity of some vector and pest-borne diseases, increase peak wind intensities of tropical cyclones, and decrease the quality and quantity of water, leading to more global water shortages and disputes.[31] The Climate Action Report similarly predicts for the 21st century an increase in the frequency and intensity of hurricanes, droughts, flooding, and heat waves, shifts in the ranges of fish and wildlife, ground water shortages, temperature related deaths, and an increase in the spread of infectious diseases.[32]

While these effects will be most devastating in least developed countries, all nations, developed and developing alike, will experience negative consequences as anthropogenic climate change affects public health, economies, and development worldwide.[33] Nations leading in GHG emissions—the United States, China, Russia, and the EU—will inevitably cross a critical threshold ultimately resulting in the aforementioned crises if major reductions in GHG emissions are not realized.

As major consumers of energy and generators of waste, U.S. buildings contribute significantly to nationwide greenhouse gas emissions and, accordingly, the nation's carbon footprint. Buildings are responsible for 39% of U.S. GHG emissions and are the fastest

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[31] Maney 313
[32] Ibid.
[33] Maney 314.

growing source of emissions. Globally, buildings accounted for 30-40% of carbon dioxide emissions in 2004, reaching 8.6 billion metric tons of CO_2e. [34]

Emission Sources

There are several major anthropogenic sources of greenhouse gases. Representing 39 percent of all emissions and 41 percent of emissions from fossil fuel combustion, electrical generation is the single largest source in the United States. Emissions from electrical generation are a factor of the fuel mix used to produce the electricity. Coal-fired power plants contributed 47% of electrical power generated in the U.S. and 81% of carbon emissions from electricity generation. Natural gas-fired power plants contributed 17% of power generation and roughly 10% of emissions. Fuel oil-fired plants generated 0.9% of total electricity and 2% of electricity-related emissions. Approximately 27% of electrical generation comes from relatively carbon-free sources (20% nuclear, 7% hydroelectric).[35]

The second major stationary source of fossil fuel emissions is the combustion of natural gas. In commercial and residential buildings, natural gas is the largest contributor of direct (on-site) emissions. As electricity's fuel mix in the U.S. is predominately coal, the most carbon intensive fossil fuel in common use, combustion of natural gas typically emits less per BTU than electricity. Only U.S. states with high concentrations of nuclear and hydroelectric power, such as Washington (48.4% hydroelectric, 20% nuclear), generate electricity that emits less than natural gas.

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[34] United Nations Environmental Programme-Sustainable Buildings and Climate Initiative, *Common Carbon Metric*, http://www.unep.org/sbci/pdfs/UNEPSBCICarbonMetric.pdf (accessed November 3, 2010).
[35] U.S. Energy Information Administration, "Electric Power Monthly," http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html and U.S. and Environmental Protection Agency, "2011 U.S. Greenhouse Gas Inventory Report," *USEPA # 430-R-11-005*, http://www.epa.gov/climatechange/emissions/usinventoryreport.html (accessed March 21, 2011).

Building-related emissions also arise from non-energy sources. Waste and recycling management programs offer significant opportunities for reducing CO_2 emissions. An average of 81% of mixed municipal solid waste (MSW) is landfilled, releasing 725 metric tons of carbon dioxide equivalent per pound.[36] Compounded with savings from reduced raw material demand, recycling avoids over 6,000 metric tons of CO_2e per pound, according to estimates by EPA's Solid Waste Management and Greenhouse Gases report published in 2006.[37]

Refrigerants are another measurable source of greenhouse gas emissions. Refrigerants common in commercial chiller plants have exorbitantly high global warming potentials. For example, common refrigerants R-22 and R-12 have a global warming potential of 1,810 and 10,900 respectively. R-22, therefore, is 1,810 times as potent a greenhouse gas as CO_2. Despite high potency, refrigerant emissions comprise a very small portion of a building's carbon footprint because of low leakage rates.

Diesel fuel consumption is a last substantial source of emissions in large commercial buildings. Typically, diesel fuel is used for backup generators which are common in high-technology buildings such as data centers. When burned, diesel fuel emits 22.2 lbs CO_2 per gallon of fuel consumed.[38]

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[36] U.S. Environmental Protection Agency, "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Detailed Tables and Figures for 2008" *Office of Resource Conservation and Recovery* November 2009, http://www.epa.gov/epawaste/nonhaz/municipal/pubs/m (accessed September 17, 2010).
[37] U.S. Environmental Protection Agency, "Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks," *Office of Resource Conservation and Recovery* September 2006, http://epa.gov/climatechange/wycd/waste/downloads/chapter8.pdf (accessed September 18, 2010).
[38] U.S. Environmental Protection Agency, "Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel," *Greenhouse Gas Emissions from Mobile Sources*, http://www.epa.gov/otaq/climate/420f05001.htm (accessed September 18, 2010).

Carbon Footprinting

A carbon footprint is the total amount of greenhouse gases emitted by a person, organization, asset, region, or product in a year. A summary of an organization's total carbon footprint, also known as a greenhouse gas inventory, is a common way for corporate and government entities to manage their carbon releases. An inventory should take into account the six major greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6). To simplify measurements, gases are converted into units of carbon dioxide equivalent (CO_2e) based on their respective GWP. One pound of methane, for example, is equal to 21 pounds of carbon dioxide equivalent. To further standardize inventories, emissions are classified into three scopes:

- **Scope 1 – Direct Emissions:** Emissions resulting from activities within a business' control, including on-site fuel combustion, manufacturing and processing, refrigerant losses, and company vehicles.
- **Scope 2 – Indirect emissions (electricity and heat):** Emissions from electricity, heat, or steam purchased and used by the business.
- **Scope 3 – Other indirect emissions:** Emissions from other sources not directly controlled by the business, including employee commuting, outsourced transportation, waste disposal, and employee business travel.[39]

A building's carbon footprint begins with its construction and the collection, treatment, and transport of raw materials. Demolition, recovery, and disposal occurring during the after-use stage of a building's life-cycle also contribute to a building's footprint;

[39] Carbon Trust, "Carbon Footprint," http://www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/carbon-footprinting/pages/organisation-carbon-footprint.aspx (accessed September 18, 2010).

however, the vast majority of a building's environmental impact, including upwards of 90% of its energy use, results from the operational phase of its life-cycle.[40]

Tackling increasing emissions of greenhouse gases from commercial buildings will undoubtedly involve new federal policy or regulatory standards. There are two distinct pathways by which federal regulation of greenhouse gases prices carbon. The U.S. Environmental Protection Agency has the authority to regulate emissions under the Clean Air Act and Congress could choose to pass a climate bill that would most likely establish a cap and trade system for carbon trading. The two paths are *not* mutually exclusive and could work in tandem; however, Congress may choose to curb EPA authority so as to override Clean Air Act standards with carbon trading.

Clean Air Act Regulation

The main mechanism by which air pollutants are regulated federally is the Clean Air Act (CAA). Enacted in 1963 and significantly amended in 1970 and 1990, the act gives EPA considerable flexibility in its directive. The statute directs the EPA to set standards on the basis of health considerations, and disallows consideration of the cost and feasibility of compliance. Furthermore, EPA cannot cite scientific complexity or uncertainty as reasons for inaction or delay. Congress intended the statute to precommit EPA to address and protect the human health and environmental needs of the country regardless of the sway of the

[40] World Business Council for Sustainable Development, *Transforming the Market*, Energy Efficiency in Buildings, http://www.wbcsd.org/DocRoot/rVDgBRKvPngUrqivMHNM/91719_EEBReport_WEB.pdf.

political climate. [41] As it stands, this mandate applies to greenhouse gas emissions, the regulation of which effectively puts a price on emitting carbon.

The battle to list GHGs as pollutants under the Clean Air Act gained force in 2003 during the George W. Bush Administration.[42] The EPA ruled at the time that GHGs were not "agents of air pollution" as defined by the CAA. This ruling reneged on the view of the previous administration, as expressed in a memorandum by the EPA's General Counsel in 1998. Bush's General Counsel, Robert Fabricant, withdrew his predecessor's memorandum on the issue as "no longer representing the views of the EPA's general counsel."[43]

In the response to Fabricant's ruling, 12 states, 3 cities, a U.S. territory, and 13 non-governmental organizations filed action against EPA, challenging its refusal to regulate GHGs under the CAA, specifically from mobile sources. EPA, joined by 10 states and 19 industry and utility groups, served as defendants. The court held 5-4 that Section 202 of the CAA, which discusses mobile sources, not only gives EPA statutory authority to regulate GHG emissions, but also forces EPA to address whether there is sufficient evidence to make an endangerment finding.[44] If there is sufficient evidence, the court directed EPA to make a decision determining whether GHGs presented a threat to human health and the environment. The decision did not force EPA to list GHGs as criteria pollutants or to

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[41] Christopher T. Giovinazzo, "Defending Overstatement: The Symbolic Clean Air Act and Carbon Dioxide," *Harvard University Law Review* 30 (2006): 99.
[42] Giovinazzo 100.
[43] Janine Maney, "Carbon Dioxide Emissions, Climate Change, and the Clean Air Act: An Analysis of Whether Carbon Dioxide Should be Listed as a Criteria Pollutant," *N.Y.U. Environmental Law Journal* 13 (2005), 304.
[44] William C.G. Burns and Hari M. Osofsky, *Adjudicating Climate* Change (New York: Cambridge University Press, 2009), 139.

regulate them under the CAA; it only mandated EPA consider GHGs.[45] *Massachusetts v. EPA* held that the CAA authorizes EPA to regulate GHGs from mobile sources, and that EPA's reasoning, which primarily reflected policy concerns of the Bush Administration, is inconsistent with the Act's mandate.[46]

On December 15, 2009, EPA released the endangerment finding along with a cause or contribute finding, which addresses Part B above. The endangerment finding reported that:

> Pursuant to CAA section 202(a), the Administrator finds that greenhouse gases in the atmosphere may reasonably be anticipated both to endanger public health and to endanger public welfare. Specifically, the Administrator is defining the "air pollution" referred to in CAA section 202(a) to be the mix of six long-lived and directly-emitted greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride… The Administrator has determined that the body of scientific evidence compellingly supports this finding.[47]

There are distinct pathways by which regulation of air pollutants can be achieved through the Clean Air Act. The direct results of the endangerment finding were plans to limit GHGs from new motor vehicles.[48] On April 1, 2010, EPA and the Department of Transportation jointly finalized rulemaking to create light-duty vehicle emission standards for new cars and truck model years 2012-2016. The plan is estimated to reduce emissions by 950 million metric tons in its lifetime, and save, according to President Obama, "more oil

[45] Patricia Ross McCubbin, "EPA's Endangerment Finding for Greenhouse Gases and the Potential Duty to Adopt National Ambient Air Quality Standards to Address Global Climate Change," *So. Ill. U. Law Journal* (2009), 9.
[46] Lisa Heinzerling "Climate Change and the Clean Air Act," *University of San Francisco Law Review* 42 (December 2007).
[47] 74 Federal Register 239 p. 66497. December 15, 2009.
[48] McCubbin 7.

than we imported [in 2008] from Saudi Arabia, Venezuela, Libya, and Nigeria combined."[49] The rule was the first national GHG emission standard. Under authority delegated to the National Highway Traffic Safety Administration (NHTSA) by the Energy Policy and Conservation Act (1975), the rule increased Corporate Average Fuel Economy (CAFE) standards in conjunction with tailpipe greenhouse gas emission limits under the CAA. The rule raised the average fuel efficiency of new cars by 30 percent and sets a GHG emissions standard of 250 grams per mile for vehicles sold in 2016.[50] On October 25, 2010 EPA and NHTSA announced similar standards for heavy-duty vehicles, which include semi trucks, work trucks, and buses. The heavy-duty program is expected to reduce emissions by approximately 72 million metric tons of carbon dioxide equivalent by 2030.

Although the endangerment finding applied specifically to mobile sources (section 2), the finding is applicable to other sections of the Act. If GHGs are listed as criteria pollutants under section 108, the Administrator will be prompted to create national ambient air quality standards, which, like listings, are determined without consideration of the costs of compliance.

The pathway EPA chose to commence regulation of GHGs under the CAA is the prevention of significant deterioration (PSD) program established in sections 160-169 of the Act. The PSD program establishes permits for new and modified major stationary sources of pollution.[51] PSD requires of permit-applicants the installation of the Best Available Control Technology (BACT), an air quality analysis, additional impacts analysis, and public

[49] Barack Obama, "Remarks by the President, Oil National Fuel Efficiency Standards," White House, whitehouse.gov. and McCubbin 9.
[50] Steven Mufson. "Vehicle emission rules to tighten." *The Washington Post*, May 19, 2009. http://www.washingtonpost.com/wp-dyn/content/article/2009/05/18/AR200905 1801848.html?nav=emailpage (accessed May 21, 2009).

[51] Daniels *et al.* 4.

involvement. The program does not require facilities to decrease emissions to a specific level, but instead mandates BACT, an emissions limitation based on the maximum degree of control that can be achieved.

In May 2010 EPA issued a final rule setting thresholds for regulation of GHGs emitted by new and existing industrial facilities under the PSD program's New Source Review permitting and Title V Operating Permit programs.[52] The rule tailors CAA permitting requirements to limit carbon regulation to only the largest emitters. Under the rule, EPA, as of January 2, 2011, regulates facilities responsible for approximately 70% of national stationary greenhouse gas emissions, including most coal-fired power plants, petroleum refineries, and cement kilns.[53] The remaining 30% of U.S. greenhouse gas emissions are produced by small stationary sources, such as restaurants, small farms, and most commercial facilities. The rulemaking also requires states to revise their State Implementation Plans to cover GHG emissions.

A last CAA pathway is a significant contribution finding for stationary sources under section 111, which creates new source performance standards (NSPS). Section 111 mandates that the EPA develop technology-based standards for new and modified stationary sources of air pollution.[54] The NSPS program could also establish a trading market that works in tandem with legislative efforts.[55] On December 23, 2010, the Environmental Protection Agency committed to two settlement agreements to issue NSPS for greenhouse gas emissions from fossil fuel-fired power plants and refineries.

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[52] U.S. Environmental Protection Agency, "Final Rule: Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule Fact Sheet," http://www.epa.gov/NSR/documents/20100413fs.pdf (accessed October 2, 2010).
[53] Ibid
[54] Giovinazzo 158.
[55] Daniels *et al.* 3-4.

Federal Policy

While there is no federal policy that regulates stationary sources of greenhouse gases, proposals in Congress are frequent. Market-based solutions for managing the nation's carbon footprint are the most popular and likely scenario for future climate legislation. Under climate bills proposed in Congress, major emitters receive or purchase "carbon permits" (also "credits" or "allowances") equal to one metric ton of carbon dioxide equivalent (CO_2e). If a company cuts its emissions so much that it has excess permits, it can sell them to other companies or bank them for future use. If a company has too few permits it can buy them from other companies or borrow its future credits plus interest. If a company emits more than it has in permits it will be fined at twice the market value.

Permits would be allocated to regulated industries for use, to various government entities to sell for profit, and to utilities to sell to keep electricity prices low for consumers. Permits would also be auctioned off by the federal government. Banks, other organizations, and individuals can also buy, trade, and invest in permits to sell to emitters.

Currently, private carbon markets exist worldwide. The Chicago Climate Exchange, for example, operates a voluntary, but legally binding, cap and trade market for all six greenhouse gases in North America. The exchange has over 400 members including Ford Motor Co., DuPont, Sony, the city of Chicago, the University of Minnesota, and Amtrak.

In both the House of Representatives and Senate, major cap and trade/energy bills have been proposed but have been unsuccessful. The most recent bills were introduced in late 2009 and early 2010. In the House, Henry Waxman (D-CA) and Edward Markey (D-

MA) introduced the American Clean Energy and Security Act H.R. 2454, also known as Waxman-Markey. Passed by the House in June 2009, the bill would have established an economy wide cap & trade program, and would have created incentives and standards to promote energy efficiency and low-carbon technology.[56] The bill capped GHGs from 85% of the economy, including utilities, refineries, natural gas suppliers, and industrial manufacturing like iron, steel, cement, and paper producers. The cap is set to reduce GHG emissions to 3% below 2005 levels by 2012, 17% below by 2020, and 83% below by 2050. Based on the cap and amount of offsets allowed, EPA estimates the price per metric ton of CO_2 equivalent would have been $13 in 2015 and $16 in 2020 under Waxman-Markey. In addition to creating a carbon market, Waxman-Markey would have also created new energy efficiency standards for lighting products, furnaces, and buildings.

A similar bill, drafted by John Kerry (D-MA) and Joe Lieberman (I-CT), was proposed in the Senate in May 2010. The Clean Energy and American Power Act, or Kerry-Lieberman, introduced a cap and trade system nearly identical to the Waxman-Markey bill passed in the House, but offered separate allowances for emissions from transportation-related fuels. The bill contains a price floor of $12 per metric ton CO_2e and ceiling of $25, with each increasing, respectively, at 3% and 5% above inflation annually. Kerry-Lieberman was not successful, and did not come to a vote. As a result, the House bill had to be abandoned as well.

Policies Abroad

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[56] U.S. Environmental Protection Agency, "Major Findings" *EPA Analysis of H.R. 2454. U.S. EPA,* http://www.epa.gov/climatechange/ economics/pdfs/HR2454_Analysis.pdf (accessed September 28, 2010).

Greenhouse gas regulation abroad may set the example for the United States. Canada's most recent greenhouse gas regulation proposal is the Climate Change Accountability Act. The act sets a target of an 80% cut in emissions by 2050 and provides authority for the government to make regulations to meet the target and set penalties. In addition, the Canadian government announced increased vehicle fuel economy standards that match the new EPA standards in order to homogenize fleets across Canada and the U.S. [57]

The United Kingdom's Climate Change Act (2008) also mandates an 80% cut in GHGs by 2050. The Act also adjusts building regulations to include maximum CO_2 emissions caps for new and renovated buildings, requiring a 25% reduction in emissions from the 2002 standard, which reduced emissions by 15%. The U.K. also operates within the European Union's Climate Change Programme. The Programme set the following targets for 2020: 20% cut from 1990 levels, 20% improvement in energy efficiency, and 20% of energy from renewable sources. To meet targets, the Programme set energy efficiency standards for new buildings and created the EU Emissions Trading Scheme for companies in the electricity generation, cement, iron, steel, refining, glass, and paper industries.[58]

As the fastest growing source of greenhouse gas emissions, how buildings are constructed and retrofitted will have a profound impact on the world's climate future. Furthermore, new regulation will inevitably increase the price of carbon-intensive processes and energy sources, making the carbon footprint of a building an increasingly important

[57] Carbon Trust, U.K. "Policies and Regulation," http://www.carbontrust.co.uk/policy-legislation/international-frameworks/european-union-policy/pages/eu-renewables-directive.aspx(accessed September 1, 2010).
[58] Ibid

metric to monitor. Energy efficiency technologies potentially offer significant opportunity to achieve extensive reductions in building-related carbon emissions.

Chapter 3. Methodology

To garner insight on the effectiveness of various efficiency techniques, an analysis of 2009 energy audits was conducted to determine average energy savings from various energy efficiency measures. The analysis covered 18 existing government buildings, a major potential source for reductions in energy consumption and greenhouse gas emissions. The 21.2 billion square feet of government buildings in the United States account for 1,180 trillion end-use BTUs of energy consumption.[59]

All buildings were located in the Midwestern United States, and as such, exhibit energy savings typical of the climate and architectural style of the region. As a result, findings in this analysis cannot necessarily be extrapolated to other regions and building types; however similar trends across technology categories would be expected. To determine relative feasibility and effectiveness of efficiency measures, samples were grouped into seven categories based on the Energy Independence and Security Act's (EISA) Technology Categories for reporting energy and water efficiency measures in federal buildings (42 U.S.C. 8253(f)). The technology categories analyzed were as follows:

- Lighting Improvements
- Electric Motors and Drives

[59] Hannah Choi Granade et al., "Unlocking Energy Efficiency in the U.S. Economy," *McKinsey Global Energy and Materials* (2009).

- Building Automation Systems (BAS)
- Building Envelope Modifications
- Chiller Plant Improvements
- Chilled water, hot water, and steam distribution systems
- Other heating, ventilation, and air conditioning (HVAC)

A total of 183 samples of efficiency measures were analyzed.

Lighting Improvements

The lighting improvements category includes 59 samples of four main types of efficiency techniques: occupancy controls, daylight harvesting, efficiency replacements, and other modifications and controls upgrades. Occupancy sensor controls, as the name implies, detect activity in an area and automatically switch on and off lights depending on occupancy. This control modification reduces energy use by correcting for human behavior.[60] Traditionally, installing occupancy sensors is expected to save 35% of lighting energy use.[61]

Daylight harvesting is an electrical control to optimize the use of natural light in place of artificial light when possible. Using photosensors, daylight harvesting controls automatically reduce or turn off artificial light when a sufficient amount of natural light is detected. Arranging windows to maximize natural light is a common technique in sustainable and traditional architecture that can provide significant energy savings when

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60 U.S. Department of Energy, “Energy Savers: Lighting Occupancy Sensors,” *Energy Efficiency and Renewable Energy*, http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=12210 (accessed April 2, 2011).

61 Anca Galasiu, Guy Newsham, Christian Suvagu, and Daniel Sanders, "Energy saving lighting control systems for open-plan offices: a field study," *National Research Council Canada* 4(2007): 7–29, http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc49498/nrcc49498.pdf (accessed April 1, 2011).

daylight harvesting controls are installed to automatically detect and adjust for natural light. On average, daylight harvesting is expected to save approximately 20% in lighting energy use.[62]

Efficiency replacements are lighting improvements in which traditional ballasts or bulbs are replaced with fluorescent lighting, a more energy efficient option. Efficiency replacements are the lowest cost option in the lighting improvement category. Other modifications and controls upgrades include improvements resulting from rewiring and adjustment modifications, and non-sensor lighting control upgrades, such as timeclock lighting.

Lighting improvements solely affect electricity consumption, and are considered inexpensive methods of reducing consumption in both large buildings and average households. A partial tax deduction of $0.60 per square foot is available for commercial building owners that reduce lighting energy use by 20% below ASHRAE 90.1-2001.[63]

Electric Motors and Drives

The Electric Motors and Drives technology category describes savings from the installation of a variable frequency drive (VFD) on a fan or pump. VFDs can reduce energy consumption by controlling the rotational speed of an electric motor. Nine samples were analyzed.

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[62] Ibid.
[63] The Tax Incentives Assistance Project, "Commercial Incentives Flyer," http://energytaxincentives.org/uploaded_files/commercialflyer.pdf.

Building Automation System

This technology category includes improvements resulting from the installation, reprogramming, or upgrade of the building automation system (BAS). There were 50 samples of BAS improvements. BAS improvements that reduce HVAC energy use by 20% below ASHRAE 90.1-2001 are eligible for tax partial deductions of $0.60.

Building Envelope Modifications

The building envelope is the area that separates a building’s conditioned space from the outdoors and/or unconditioned space, such as walls, doors, and windows. Unconditioned space is area of a building that has no heating or cooling. Energy conservation measures in this category include replacements to parts of the envelope, ventilation control, weatherization, insulation additions or improvements, and solar window film (tinting) applications. These modifications are designed to reduce heat transfer to save energy consumption related to heating and cooling. The category’s sample size totaled 23. A ten percent decrease in energy use below ASHRAE 90.1-2001 offers commercial building owners a partial tax deduction of $0.60 per square foot.

Chiller Plant Improvements

Chiller and chiller plant retrofits and replacements make up this technique category (n = 11).

Chilled Water, Hot Water, and Steam Distribution Systems

The chilled water, hot water, and steam (CW/HW/Steam) distribution systems category includes efficiency measures such as piping insulation installation, and the repair or replacement of hot water heaters, steam traps, or condensate return systems (n = 8).

Other Heating, Ventilation, and Air Conditioning (HVAC)

This technology category includes HVAC improvements other than techniques related to boilers, chillers, and the building automation system. Examples of these efficiency measures include replacement, retrofit, and installation of packaged air conditioning units, cooling towers, economizers, fans, pumps, ventilation controls, HVAC zone controls, and air handling units. Twenty-four samples were analyzed.

Energy Savings

Annual cost savings (given in million BTUs) were determined through energy audits and compared with total implementation cost (investment). Energy and cost savings per square foot were also analyzed to compare buildings of various sizes. For example, estimated annual energy savings per 1000 sq ft was calculated as follows:

$$\text{Annual Energy Savings per 1000 sq ft} = \frac{\text{Annual Energy Cost Savings}}{\text{Gross square footage (Thou.)}}$$

Estimated present value life-cycle cost (LCC) savings and net present value

The discounted value of life-cycle cost savings was used to examine the net present value of all investments, given the initial investment cost. Net present value (NPV) is used to determine the financial impact of undertaking an investment. A positive NPV (NPV > 0) indicates an investment that adds value to a firm, while a NPV less than zero reduces value. In this analysis, NPV did not include cash inflows from funding sources, tax credits, or increases in the market value of the retrofitted building; only money *saved* from implementing the conservation measure.

$$\textit{Net present value} = \begin{array}{c}\textit{Estimated present value}\\ \\ \textit{life-cycle cost savings}\end{array} - \textit{Investment cost}$$

LCC Savings-to-Investment Ratio (SIR)

The LCC Savings-to-Investment Ratio is an important indicator of financial impact for building owners considering efficiency techniques and measures. SIR is calculated by dividing life-cycle energy cost savings by implementation cost. Many low-cost investments with a comparatively low NPV may have a high SIR, as savings are several times higher than costs, but the overall return (and cost) has a small dollar value. An SIR greater than 1 indicates a positive net present value of the investment.

$$\text{Savings to Investment Ratio} = \frac{\text{Estimated present value LCC savings}}{\text{Investment cost}}$$

Simple Payback Period

A significant determiner in choosing efficiency investments is the payback period, or the number of years before the investment's returns exceed its initial cost. Simple payback period does not take into account discounted cash inflows, as it only compares construction cost with yearly estimated savings in energy bills. Simple payback period is measured in years.

$$\text{Simple Payback Period} = \frac{\text{Investment cost}}{\text{Estimated Annual Energy Cost Savings}}$$

LCC Dollar Return on Investment (ROI) per 1000 sq ft

Similar to net present value, the LCC return on investment per square foot measures the difference between estimated present value LCC savings and investment costs. This value describes the total dollar return on investment per square foot, to enable comparisons between buildings of various sizes. A positive ROI per square foot indicates an investment with a positive overall net present value.

$$\text{ROI per 1000 sq ft} = \text{PV LCC savings per 1000 sq ft} - \text{Investment cost per 1000 sq ft}$$

Electrical Emissions Output Rate

The electrical generation emissions output rate for the state of Illinois was used to estimate emission savings. Nationwide electric power systems air emissions data were collected from the Emissions and Generation Resource Integrated Database (eGRID) Summary Tables for the year 2005.[64] By integrating power generation data from EPA, EIA, and the Federal Energy Regulatory Commission, eGRID provides aggregated data by state for air emissions in pounds per megawatt-hour of electricity. Pounds of methane and nitrous oxide per megawatt hour of electricity produced were converted into pounds of carbon dioxide equivalent based on their respective 100-year global warming potential. GWP values were equivalent to those used in eGRID 2007, as identified by its Technical Support Document.[65] GWP values used by eGRID were from the IPCC Second (1996) Assessment Report (SAR).

Natural Gas Emissions Output Rate

The amount of CO_2 emitted per therm of natural gas consumed is estimated using EPA Voluntary GHG Reporting Technical Guidelines document. Based on an estimated heating value of 1,010 BTU per square foot, EPA assumes a default emissions factor of 52.65 $MTCO_2$ per Billion BTU. The analysis uses a converted 11.023 lbs CO_2/therm of

[64] U.S. Environmental Protection Agency, "eGrid2007 Version 1.1 Year 2005 Summary Tables," December 2008, http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007V1_1_year05_SummaryTables.pdf.
[65] U.S. Environmental Protection Agency, "eGRID2007 Technical Support Document," *Office of Atmospheric Programs*, September 2008, http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007TechnicalSupport Document.pdf.

natural gas consumed.[66] CO_2 emissions from natural gas combustion = fuel combusted x carbon content coefficient x fraction oxidized x (44/12).[67]

Chilled Water and Steam Output Rates

Purchased chilled/hot water and steam are used in buildings both as a heating and cooling source in place of or in tandem with electricity and natural gas. The U.S. Department of Energy's Energy Information Administration's Voluntary Reporting Program Technical Guidelines report that the production of steam emits approximately 86 kilograms of carbon dioxide per million BTU produced.[68] Chilled water production at district plants emits 0.87 kilograms of carbon dioxide per ton hour.

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[66] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: Fast Facts 1990-2006." http://www.epa.gov/climatechange/emissions/downloads/2008_GHG_Fast_Facts.pdf.
[67] Ibid
[68] U.S. Department of Energy, *Voluntary Reporting of Greenhouse Gases: Appendix N. Emissions Benchmarks of Purchased Steam and Hot Water*, http://www.eia.doe.gov/oiaf/1605/pdf/Appendix%20N.pdf.

Chapter 4. Results and Analysis

The results include mean annual and life-cycle energy, cost, and carbon savings for each technology category, based on energy audits conducted for existing government buildings in the Midwestern United States. Data are presented in bar graphs depicting the mean for each category ± standard error, or in box and whisker plots depicting the first third quartile boundaries for the box, and the 10th and 90th percentile in the whiskers. Outliers are plotted outside the whiskers.[69]

Cost of implementation

On average, implementation costs were highest per square foot for building envelope modifications and chiller plant improvements. The electric motors and drives technology category had the lowest mean construction cost (roughly 27 cents per square foot), but the cost was not significantly different from the lighting improvements, CW/HW/steam distribution systems, and the other HVAC technology categories. Efficiency measures dealing with lighting, electric motors and drives, and CW/HW/steam systems are low cost options compared with the typically large-scale, expensive options within the BAS, envelope, and chiller plant technology categories. Chiller plant modifications are typically expensive because equipment costs are high compared with other technology groups and chiller plants are not easily accessible in a building, as a result, it can be expensive to move

[69] Note: The electric motors and drives and chilled water/hot water/steam distribution system categories had too few samples (8) to generate whiskers.

or replace equipment. The BAS technology category exhibits the third highest mean construction cost. The high cost of installing or replacing a building automation system offsets the relative inexpensiveness of BAS control upgrades that are also included in the technology category. As the Energy Policy Act of 2005 offers tax deductions of $0.60 per square foot for partial reductions in building envelope, lighting, or HVAC, eligible owners could receive $600 per thousand square feet for reductions in respective technology categories, significantly offsetting the implementation costs exhibited in Figure 1.

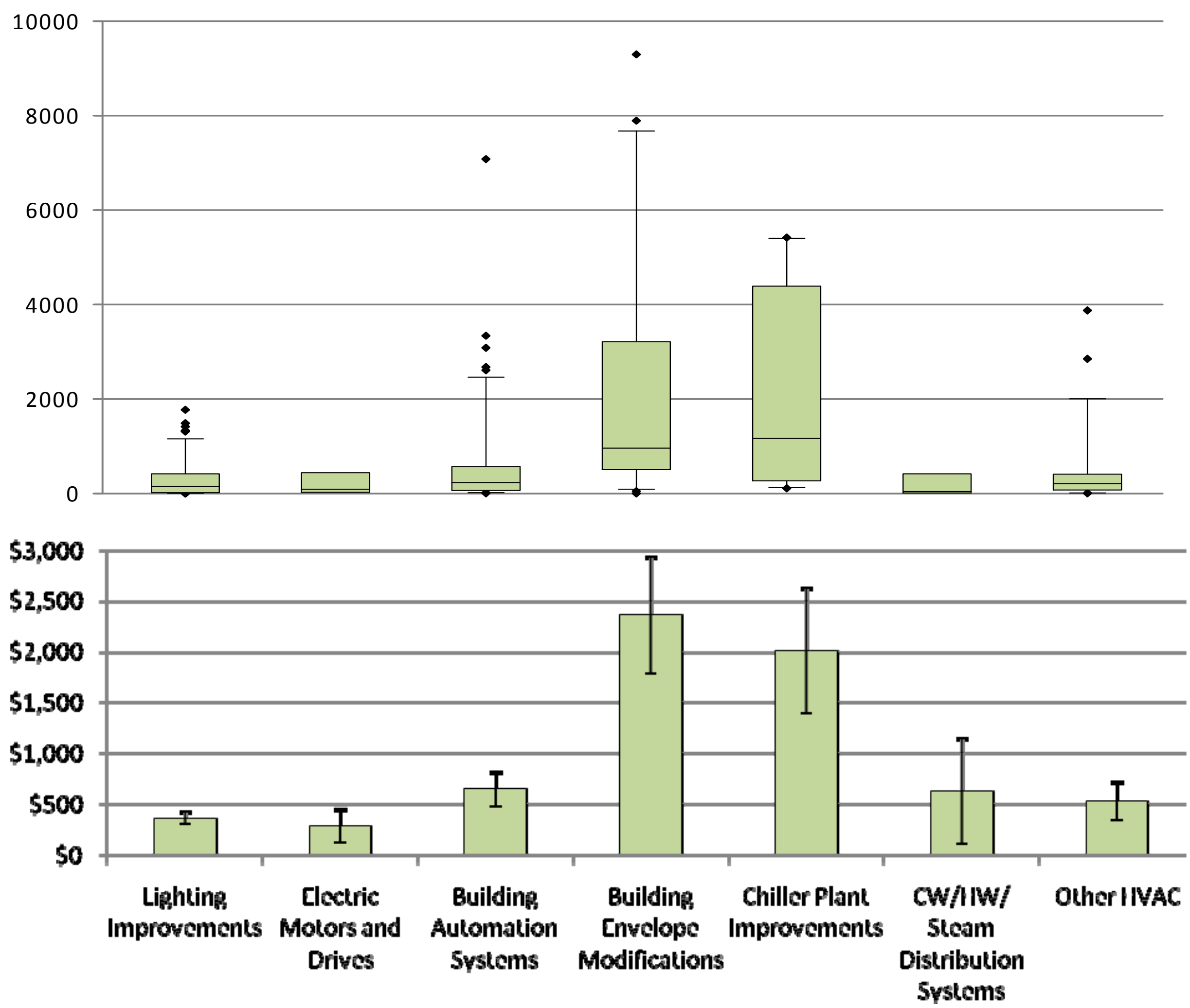

Figure 1. Cost of implementation (dollars) per thousand sq ft (above) and mean for each category ± SE (below).

Annual Energy Savings

Mean annual energy savings (MMBTU) were calculated for each technology category per thousand square feet (Fig. 2). CW/HW/Steam distribution system improvements had a wide variety of energy saving results per square foot, and exhibited a high standard error. This category aside, BAS and chiller plant improvements had significantly higher annual energy savings than other technology categories. Chiller plant improvements had the highest mean annual energy savings per square foot, approximately 5,450 BTUs saved per square foot each year. As cooling can account for up to one-third of a building's energy consumption, this result is unsurprising. Additionally, the ability for BAS improvements to significantly alter an entire building's HVAC operations, large savings are typically expected. Electric motors and drives and lighting improvements had the lowest mean per square foot savings and were insignificant from one another. While significant percent reductions (compared with previous consumption) are typical, both technology categories represent a small portion of a building's total energy consumption compared with heating, ventilation, and cooling.

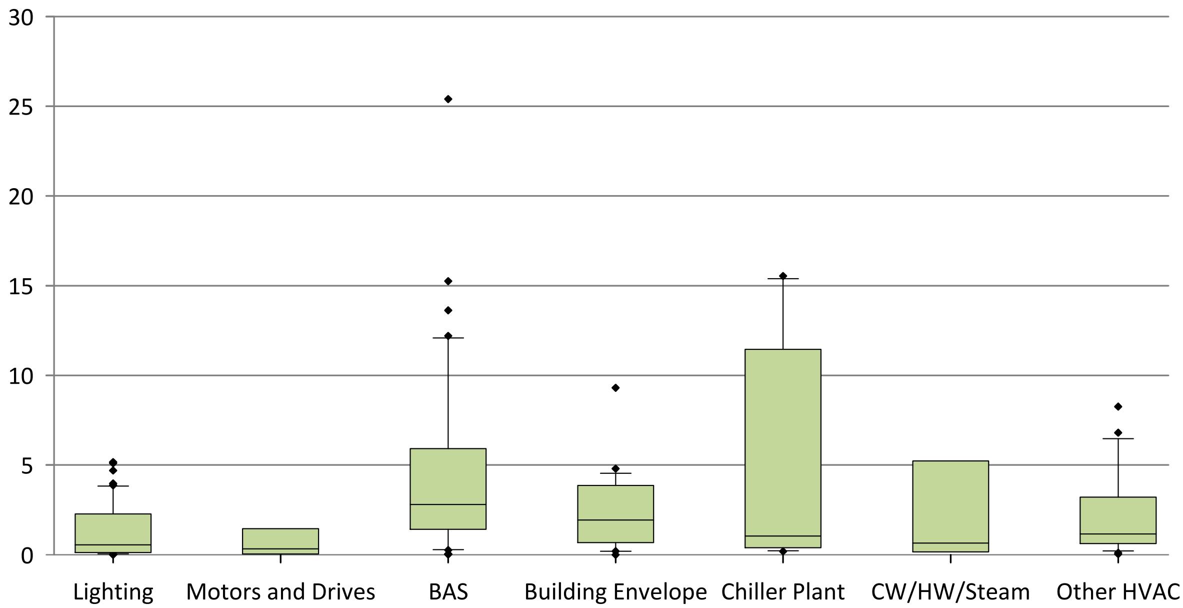

Figure 2. Annual energy savings (MMBTU) per thousand sq ft.

Life-Cycle Cost Savings

Life-cycle cost (LCC) savings take into account only savings from reduced energy consumption. The present value of future savings is given per thousand square feet for each technology category in Figure 3. The same trend is exhibited for annual cost savings. LCC savings do not include potential tax benefits or the potential additional costs avoided if carbon regulation increases energy prices. Chiller plant improvements offered the highest mean cost savings over a buildings lifetime, nearly $2,400 saved per thousand square feet of gross area. Present value savings were highly dependent on the individual efficiency measure, rather than the technology category (Fig. 3).

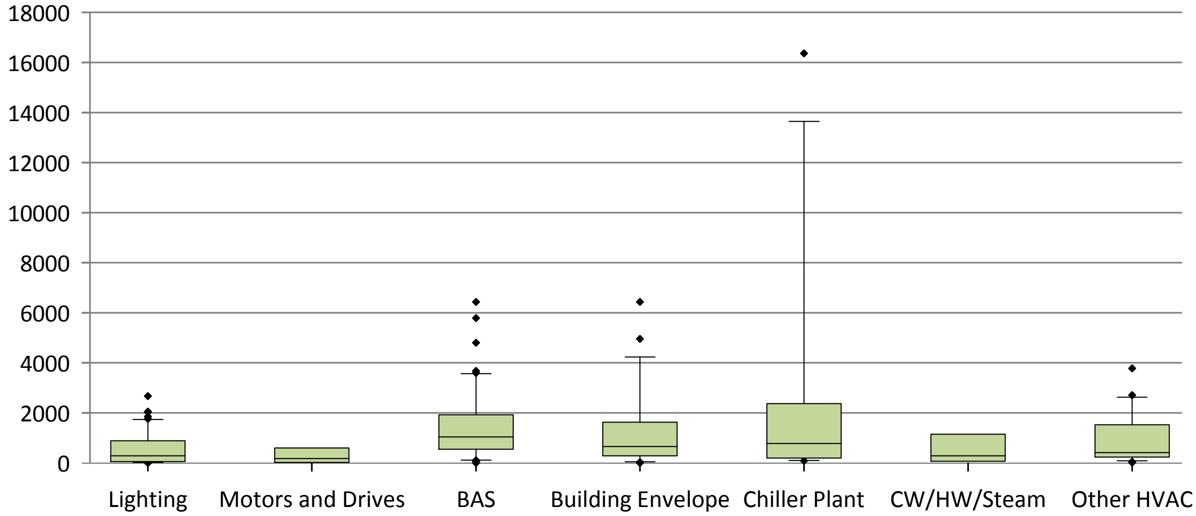

Figure 3. Present value of life-cycle cost savings (dollars) per thousand sq ft.

Life-Cycle Return on Investment

Mean life-cycle return on investment nets LCC savings (Fig. 3) against implementation costs (Fig 1.). All but one technology categorically had, on average, a positive return on investment per square foot. Figure 4 illustrates net dollar return for each technology category over the building's lifetime per thousand square feet. One hundred percent of CW/HW/steam distribution system upgrades, 88.1 percent of lighting improvements, and 80 percent of BAS improvements had a positive return on investment. BAS efficiency measures had the highest mean return on investment. Only 36 and 35 percent of chiller plant and building envelope plant improvements were NPV positive, respectively. The cost of most envelope modifications outweighed life-cycle savings, resulting in a negative return on investment on average. Building envelope modifications are often prohibitively expensive as many require complete reconstruction of curtain walls.

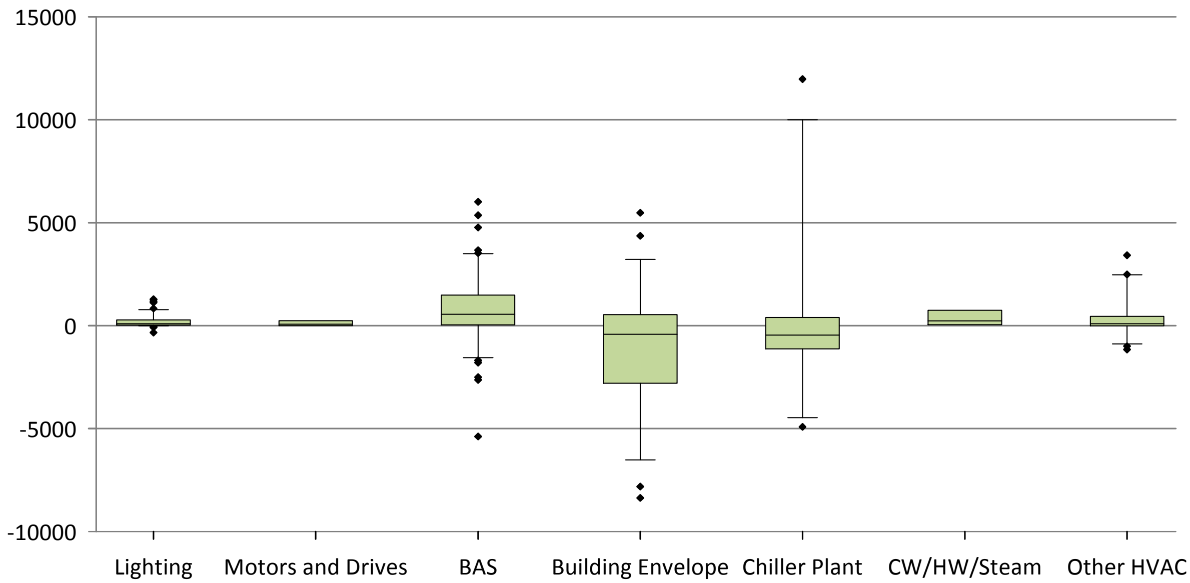

Figure 4. Life-cycle dollar return on investment per thousand sq ft.

Figure 5 illustrates mean percent returns of each technology. It follows a similar trend as dollar returns (Fig. 4); however, Fig. 5 better illustrates the high percentage return of lighting improvements despite the category's low dollar returns.

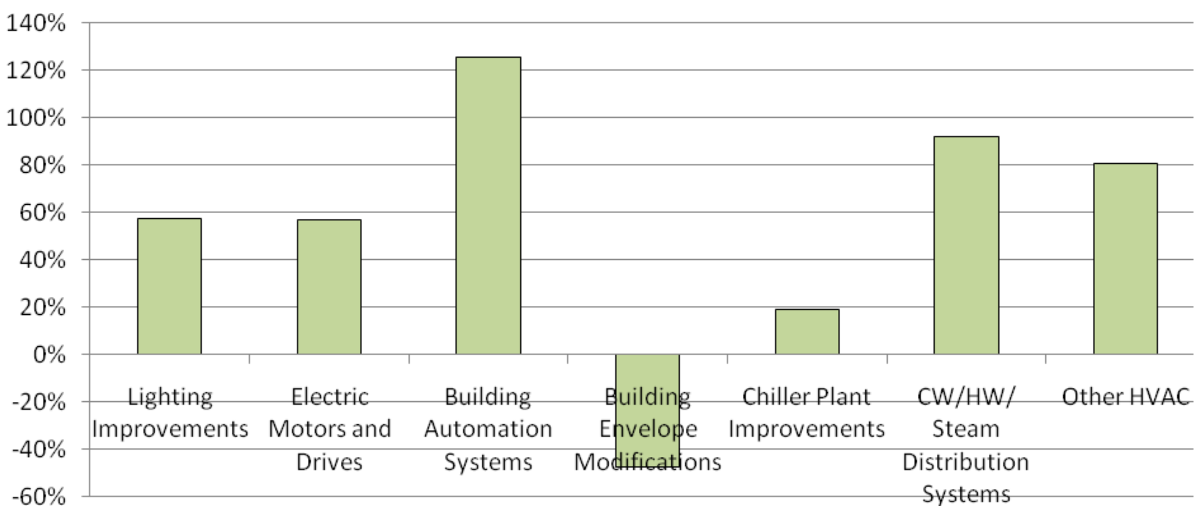

Figure 5. Percentage mean return on investment per thousand sq ft.

Savings-to-Investment Ratio

Mean SIR for each technology category was compared to determine, on average, which measures resulted in savings several times higher than implementation cost, regardless of the relative expensiveness of the measures. BAS efficiency measures had the highest mean SIR: life-cycle savings were over 17 times higher than implementation costs. Electric motors and drives, building envelope, and chiller plant efficiency measures offered the lowest SIR opportunities.

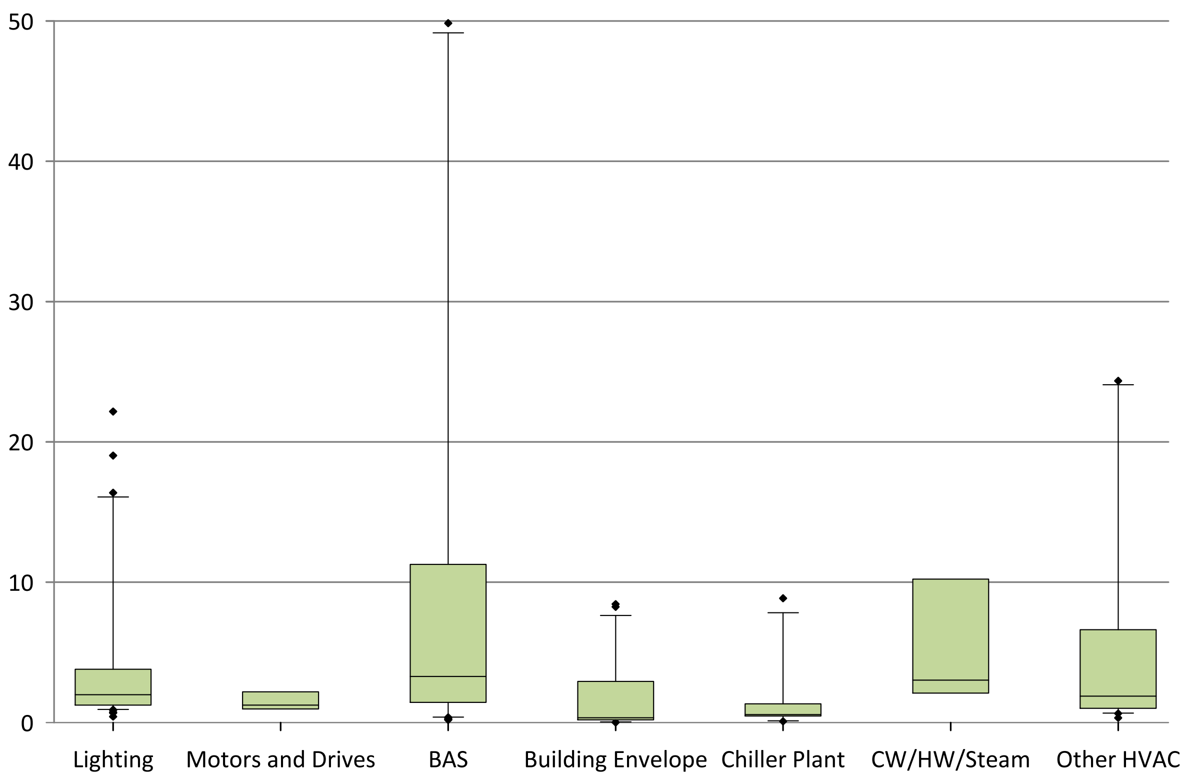

Figure 6. Life-cycle savings-to-investment ratio (SIR).

Payback Period

Mean simple payback period (years) for each technology category is illustrated in figure 7. CW/HW/Steam distribution system efficiency measures had the quickest payback period. Other HVAC, lighting, and BAS improvements also had relatively short mean payback periods, indicating investment cash outflows were quickly recovered, on average within 5-13 years. Building envelope modifications had by far the longest mean payback period, however significant deviation is evident. Payback periods for chiller plant improvements were also prohibitively high in many cases, resulting in the second slowest simple payback period.

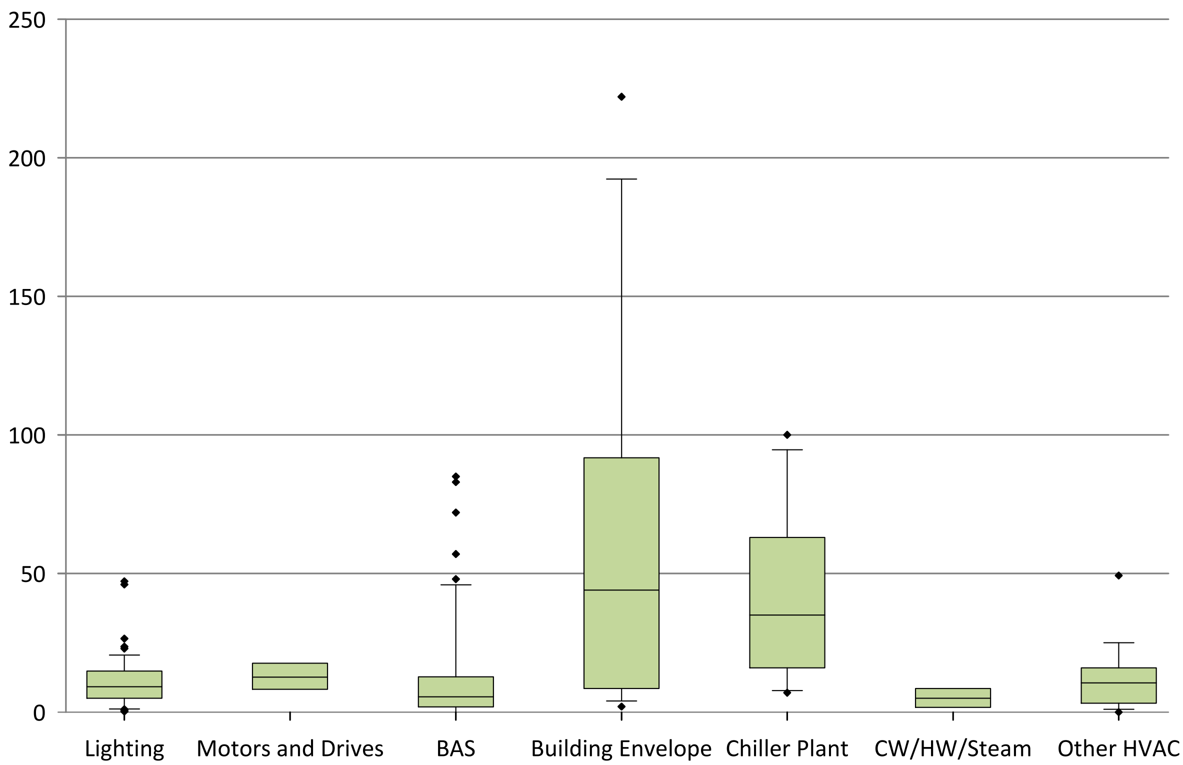

Figure 7. Simple payback period (Years).

A general trend of high investment resulting in high savings is evident, with the exception of building envelope modifications which represent an outlier due to negative returns.

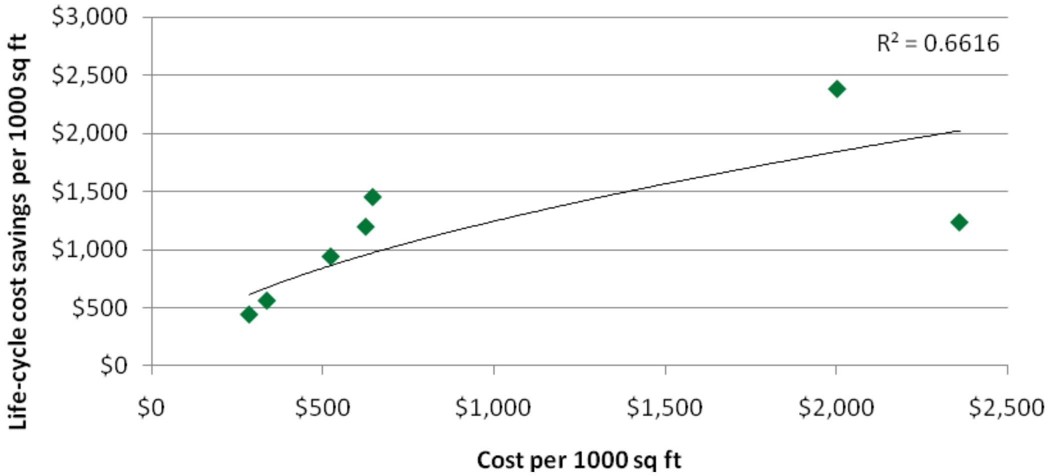

Figure 8. Relationship between cost and life-cycle cost savings per 1000 sq ft.

Life-Cycle Emissions

Greenhouse gas emissions savings were determined by multiplying an emissions output rate by energy savings. Output rates for electricity, natural gas, chilled water, or some combination of the three were estimated for individual efficiency measures. As the greenhouse gas output rate per BTU consumed is highest for electricity (roughly three times as high in Illinois as the output rate for natural gas and steam) efficiency measures that reduced electricity consumption had the largest impact on a building's total carbon footprint. For each technology category, figure 9 illustrates the pounds of carbon dioxide equivalent saved per million BTU saved (i.e. average emissions output rate). Lighting improvements and electric motors and drives had the highest emissions output rate because all efficiency measures in both technology categories affected only electricity use.

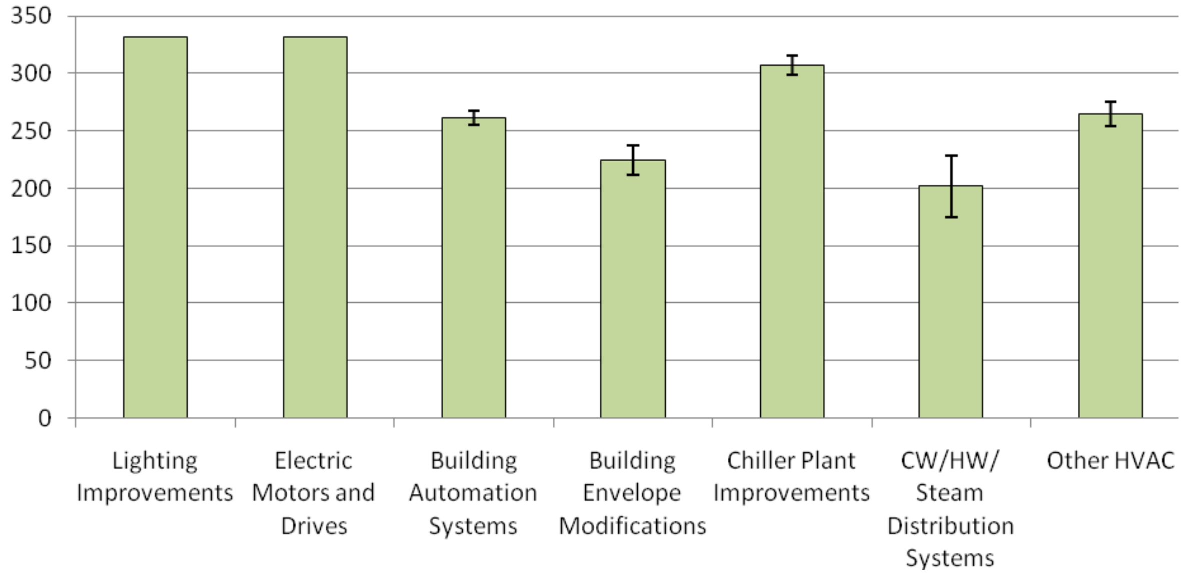

Figure 9. Mean emissions output rate for each technology category (lbs CO_2e/MMBTU) ± SE.

Life-cycle emissions per thousand square feet were calculated to determine total carbon savings and the effect of efficiency technologies on reducing a building's carbon footprint. There was considerable variability within technology categories, particularly in the chiller plant improvement category, which exhibited the highest mean savings per square foot. The BAS technology category had the second highest mean savings due to large energy savings, despite a moderate emissions output rate. The first and third quartile boundaries for the BAS plot indicate high emission savings are typical (Fig. 10). On average, chiller plant improvements cut a building's life-cycle carbon footprint by 40 lbs of carbon dioxide equivalent for every square foot. Individual efficiency measures within the category cut a building's annual carbon footprint by as much as 17%. BAS efficiency measures reduced a building's carbon footprint by up to 28%.

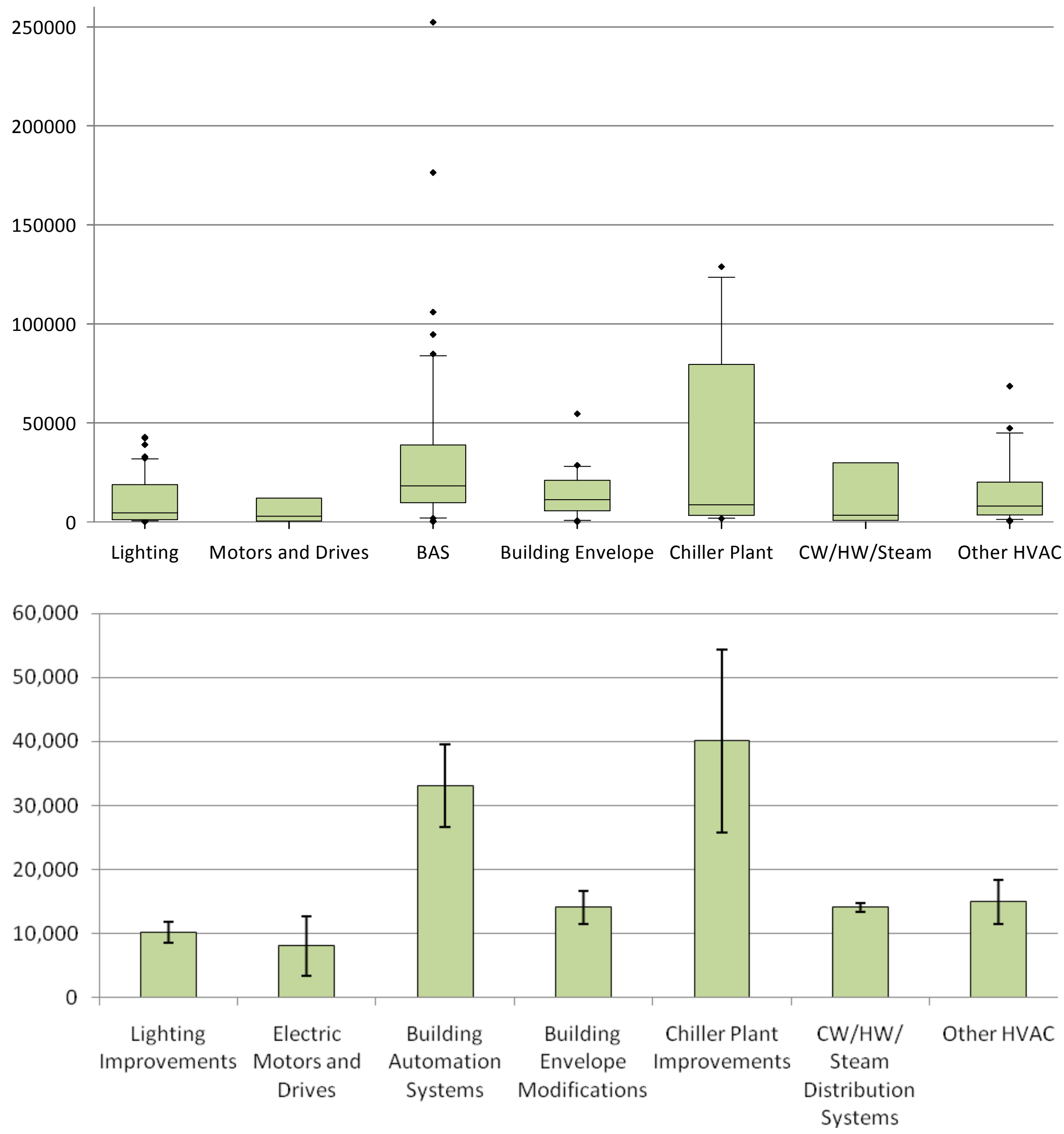

Figure 10. Life-cycle emissions savings (lbs CO_2e) per 1000 sq ft and mean emission savings ± SE.

An emissions savings-to-investment ratio (ESIR) measures the pounds of CO_2e avoided for every dollar spent. A high ESIR indicates that emission savings can be achieved at low costs. Despite varying output rates, mean ESIR followed the same general trend as mean SIR across technology categories.

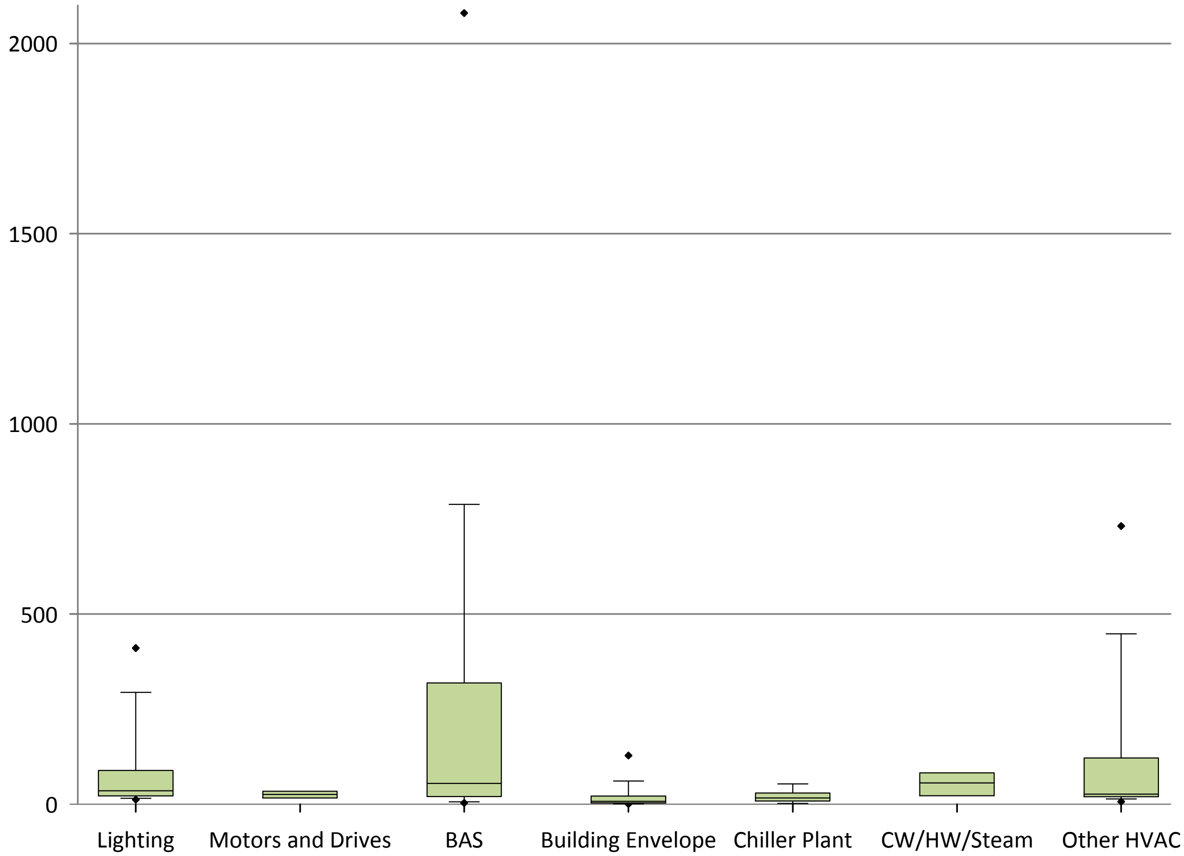

Figure 11. Emissions savings-to-investment ratio.

The BAS technology category had the highest mean ESIR, followed by lighting improvements. Both categories exhibited significant emissions savings through low cost options. Despite significant carbon savings in the chiller plant improvement category, the average ESIR was modest due to high implementation costs.

Additional Analysis of Lighting Improvements

Among individual efficiency measures within the lighting improvement technology category, a positive relationship between cost and savings was evident.

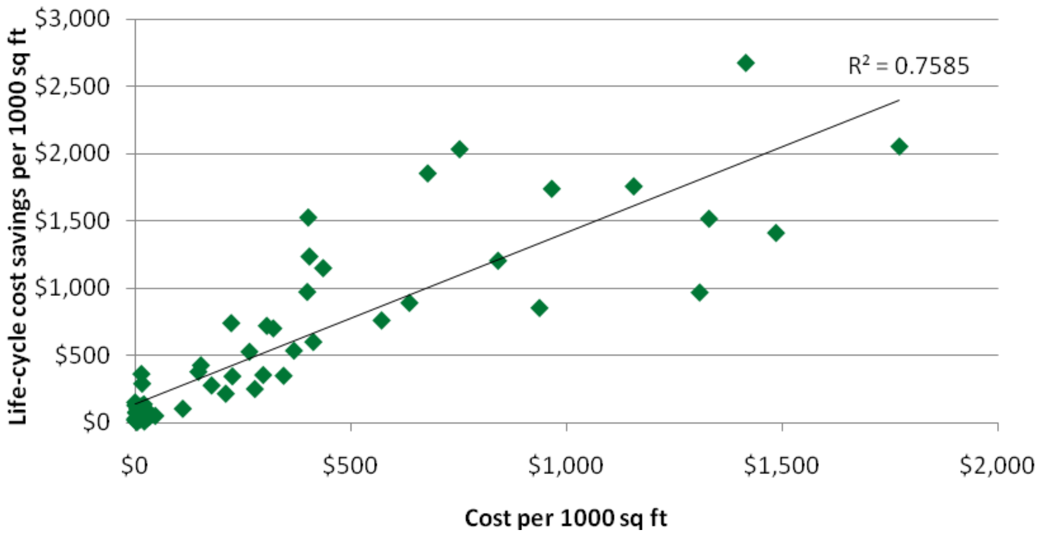

Figure 12. Relationship between cost and life-cycle cost savings per 1000 sq ft among lighting improvement efficiency measures (n = 59).

A graphical representation of ESIR illustrates the relationship between life-cycle greenhouse gas emissions savings and implementation cost.

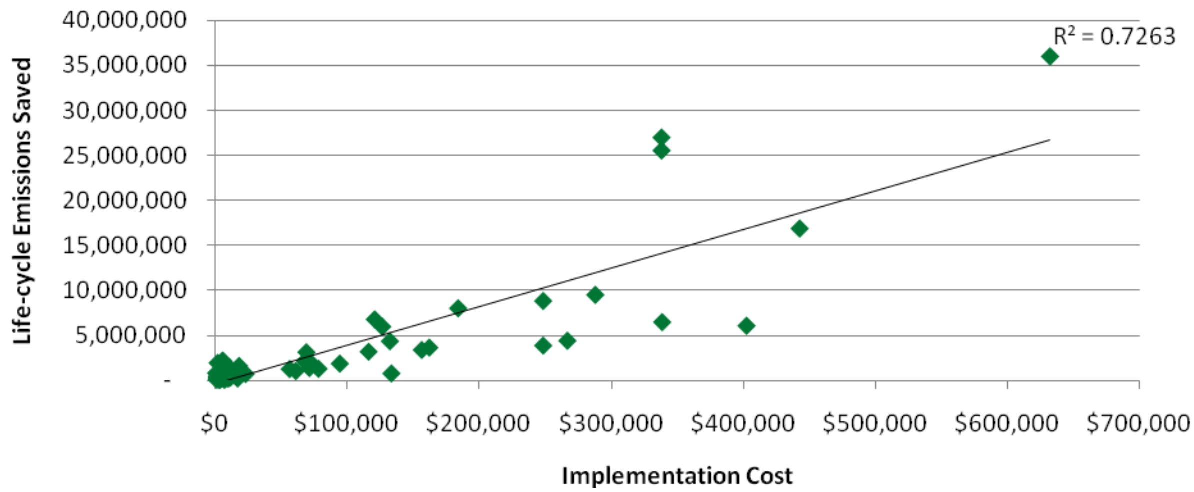

Figure 13. Relationship between emission savings and implementation cost (n = 59).

Within the lighting improvement category, measures were further assigned to one of four lighting technology subcategories: occupancy sensors, daylight harvesting, efficiency replacements, and other controls upgrades and modifications. Figure 14 depicts mean implementation cost per thousand square feet for each of the subcategories and the average for all lighting improvements.

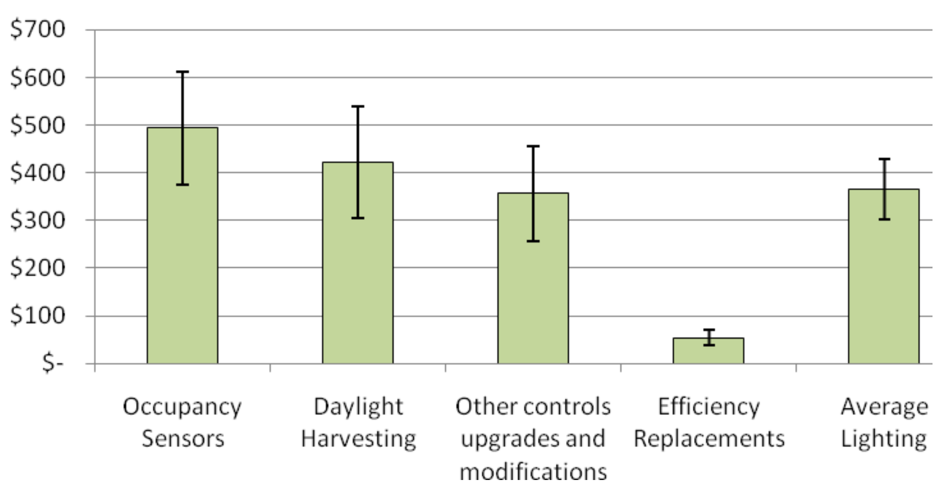

Figure 14. Mean implementation cost for lighting subcategories ± SE.

Efficiency replacements had, as expected, the lowest mean implementation cost, significantly lower than other subcategories. Control technology, including occupancy and daylight controls, exhibited higher installation costs. All subcategories offered a range of energy savings, with daylight harvesting exhibiting the highest mean savings and the fewest samples with low savings (Fig. 15). Energy savings for daylight harvesting averaged 1.82 million BTU per thousand square feet, or roughly $8,400 in annual cost savings.

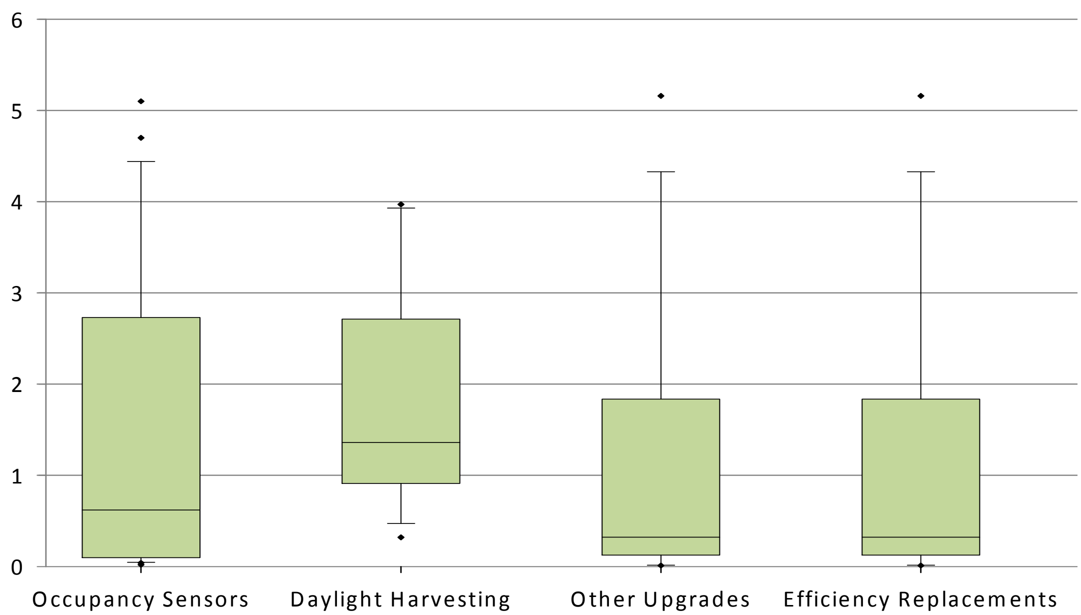

Figure 15. Energy savings (MMBTU) per thousand sq ft.

Return on investment was positive on average for each lighting subcategory; however, there was considerable variation in the efficiency replacement and other control and modification upgrade categories. Daylight harvesting efficiency measures offered the highest mean ROI due to large savings.

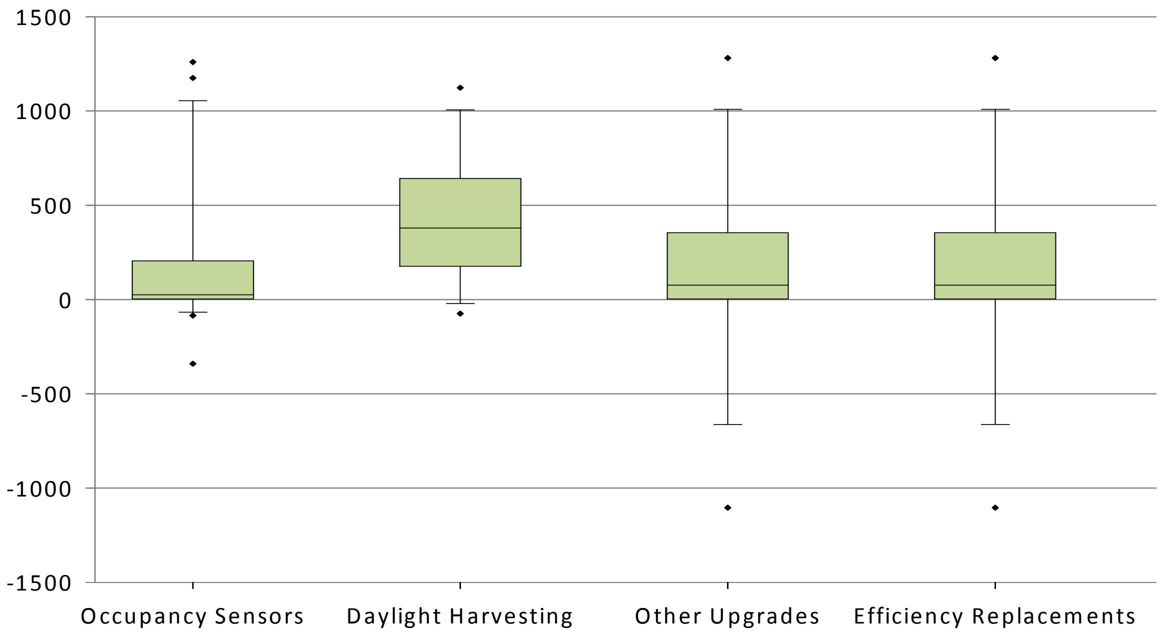

Figure 16. Mean return on investment per thousand sq ft + SE.

Although efficiency replacements presented the lowest mean dollar return, savings were typically several times higher than costs. Mean SIR for efficiency replacements was 4.3, and some measures offered savings up to 16 times higher than investment costs (Fig. 17). Although occupancy sensors and daylight harvesting produced large dollar returns, percentage returns and SIRs were modest compared with other subcategories (Fig. 17). Other controls and modifications included several efficiency measures with significantly high savings-to-investment ratios. These measures were all related to reducing unneeded light using dimming technology or removing excess bulbs. These minimal cost measures offer significant percentage returns compared with control upgrades, although dollar ROI is not substantial.

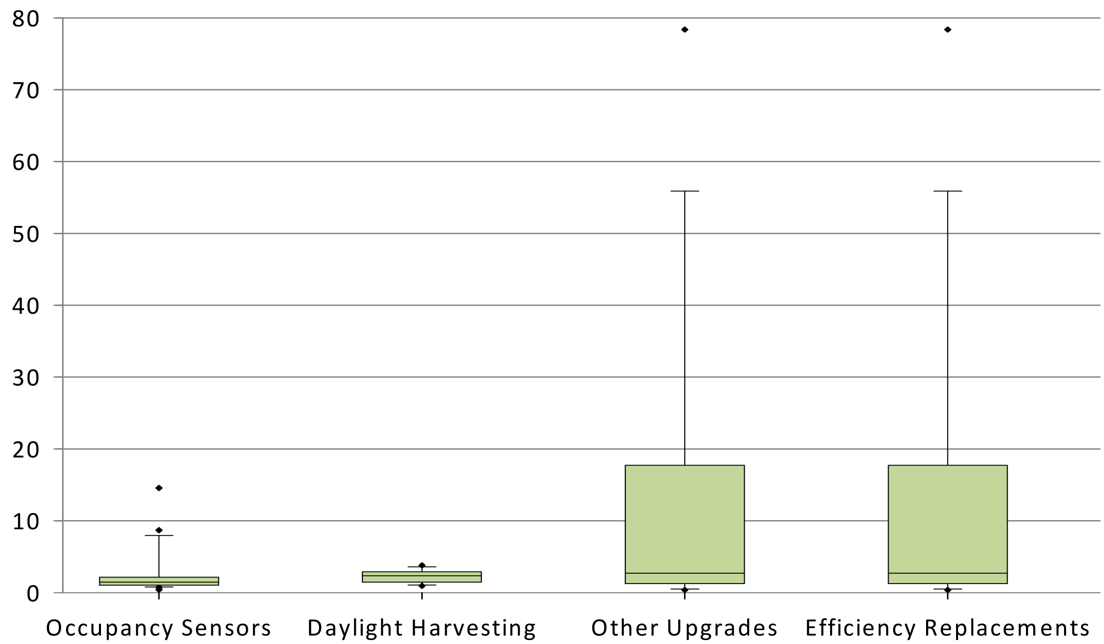

Figure 17. Savings-to-investment ratio.

There was no significant difference in payback period between the four subcategories in lighting improvements. Greenhouse gas emissions saved per square foot followed the same trend as annual and life-cycle energy savings, as all lighting measures affect electricity consumption. Annually, daylight harvesting measures cut a building's carbon footprint by 600 lbs of CO_2e per 1000 square feet on average. Even efficiency measures, which offered the lowest mean savings, cut annual emissions by an average of 140 lbs for every 1000 square feet (Fig. 18). Lighting improvements, overall, resulted in a mean 2% reduction in a building's carbon footprint.

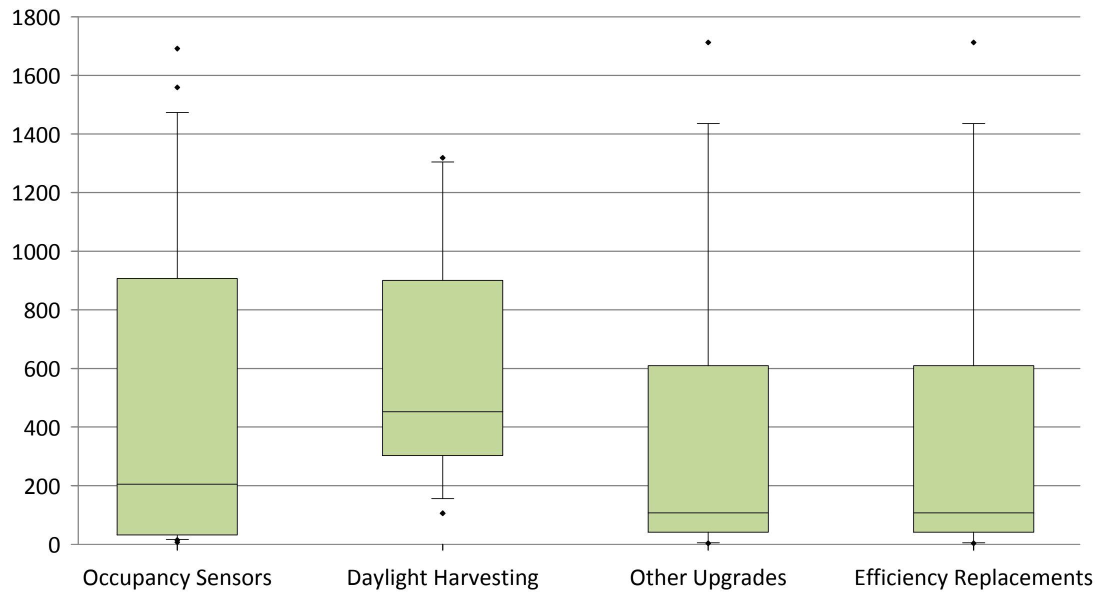

Figure 18. Annual emissions savings (lbs CO2e) per thousand sq ft.

Conclusions

Results indicate that there are a variety of NPV positive options available for building owners hoping to reduce their costs, energy consumption, and carbon footprint. Of the 183 samples, 136 (74.3%) resulted in a positive return on investment. When potential tax incentives and market-based benefits are included, the likelihood of an energy efficiency investment paying for itself over time increases. Amongst samples within technology categories, 100 percent of CW/HW/steam distribution system upgrades, 88.1 percent of lighting improvements, and 80 percent of BAS improvements were NPV positive. Only 36 and 35 percent of chiller plant and building envelope plant improvements were NPV positive, respectively.

Payback period results were consistent with current trends in efficiency investments. Lighting and HVAC improvements are the most popularly employed efficiency techniques because they exhibit the shortest payback periods, which, amongst NPV positive investments, is typically the most important criteria for choosing an investment.[70] Several NPV positive investments that could save considerable amounts of energy over time have prohibitively high payback periods due to high implementation costs. Internal rate of return and SIR are also important determiners, however, SIR does not take into account potential capital constraints of building owners.[71]

In addition to cost savings, efficiency measures cut a building's carbon footprint. While it is evident that major carbon savings can be achieved through NPV positive

[70] Siemens, "Economics of Energy Upgrades," *Buildings Operations Management* (2010).
[71] Ibid.

investments, maximizing saving will require building owners to bundle costly, but effective improvements with those with high returns and quick payback periods. Chiller plant improvements, for example, offer substantial carbon savings but only four of eleven samples analyzed were NPV positive.

Despite significant barriers to large-scale reductions in building-related energy use and carbon dioxide emissions; new regulation, incentives, voluntary behavioral shifts, and potential energy cost savings will continue to promote more investments in energy efficiency measures. New technologies will improve options, reduce costs, and increase the prevalence of these investments. Tremendous potential and opportunity exists for sustainable building to dramatically influence how buildings affect the environment outside their walls and the people within them.

Appendix

Gross Square Footage (Thou.)	Annual Energy Use (Site Billion Btu)	ECM Title	Category	Construction Cost	Estimated *Annual* Energy Savings (Million Btu/yr)	Estimated *Life-Cycle* Energy Savings (Million Btu)	Estimated Present Value *Life-Cycle* Cost Savings ($)	Estimated *Annual* Cost Savings ($)
298	20	Add variable frequency drives to air handlers	Electric Motors and Drives	See ECM M1	See ECM M1	See ECM M1		See ECM M1
298	20	Parking lot lighting fixture upgrades	Lighting Improvements	$7,935	27	675	$12,854.70	$1,400
298	20	Add photocell control to parking lot lighting	Lighting Improvements	$1,150	46	1,150	$21,884.50	$1,200
298	20	Add occupancy controls to stairwells	Lighting Improvements	$6,900	6	150	$2,898.00	$150
298	20	Add occupancy controls to all small rooms	Lighting Improvements	$287,960	1,143	28,575	$518,328.00	$29,500
298	20	Disconnect the exist cove lighting in elev lobbies	Lighting Improvements	$575	96	2,400	$45,057.00	$2,500
298	20	Add occupancy controls to elevator lobbies	Lighting Improvements	$11,500	38	950	$17,710.00	$1,000
298	20	Provide daylight harvesting at exterior windows	Lighting Improvements	$120,750	815	20,375	$368,287.50	$21,000
298	20	Eliminate need for personal space heaters	Energy Related Process Improvements	See Mech ECMs	3	75		$80/heater
298	20	Replace T12 with T8 Ballasts in Lighting Fixtures	Lighting Improvements	$10,350	27	675	$12,834.00	$700
298	20	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$118,278	-	-	$4,731.12	$311
298	20	Low Flow Aerators and Showerheads	Water and Sewer Conservation Systems	$3,004	-	-	$18,955.24	$1,071
298	20	VFDs for Air Handling Unit Fans	Electric Motors and Drives	$402,500	1,381	34,525	$623,875.00	$38,600
298	20	VFDs for Cooling Tower Fans	Electric Motors and Drives	$23,000	54	1,350	$25,300.00	$1,500
298	20	VAV Minimum Air Set-points	Building Automation Systems/EMCS	$46,000	2,375	59,375	$605,360.00	$34,000
298	20	Building Automation System Upgrade	Building Automation Systems/EMCS	$345,000	715	17,875	$324,300.00	$20,000
298	20	Evaluation of Lab Fume Hood Oper. and Control	Other HVAC	$23,000	285	7,125	$134,320.00	$8,000
298	20	Air Handling Unit Cooling Coils Cleaning	Other HVAC	$296,700	715	17,875	$323,403.00	$20,000
298	20	Fan Powered Box Inspection, Cleaning	Other HVAC	$345,000	250	6,250	$113,850.00	$7,000
298	20	Thermostat Inspection and Replacement	Building Automation Systems/EMCS	$51,750	179	4,475	$84,352.50	$5,000
298	20	Replace Three-Way Valve on Cooling Tower	CW/HW/Steam Distribution Systems	$6,900		-	$0.00	

Gross Square Footage (Thou.)	Annual Energy Use (Site Billion Btu)	ECM Title	Category	Construction Cost	Estimated *Annual* Energy Savings (Million Btu/yr)	Estimated *Life-Cycle* Energy Savings (Million Btu)	Estimated Present Value *Life-Cycle* Cost Savings ($)	Estimated *Annual* Cost Savings ($)
298	20	Replacement of Domestic Water AC Units	Water and Sewer Conservation Systems	$17,250	46	1,150	$67,965.00	$4,000
298	20	Replace Membrane Roof and Roof Insulation	Building Envelope Modifications	$470,350	58	1,450	$9,407.00	$700
298	20	Repair Penthouse Masonry Walls	Building Envelope Modifications	O&M $30,000				
298	20	Replace Curtain Wall / Windows	Building Envelope Modifications	$2,187,300	2,772	69,300	$940,539.00	$56,500
298	20	Exterior Door Modifications	Building Envelope Modifications	O&M $110,000				
298	20	Site Improvements - Replace Side Walk and Parking Lot	Other	O&M $360,000				
288	26	Apply Solar Window Film	Building Envelope Modifications	$276,000	1,053	21,062	$1,854,720.00	$75,900
288	26	Apply Interior Windopw Blinds	Building Envelope Modifications	Not Being Pursued				
840	53	Re-wiring of lighting system from receptacle panel to independent lighting panel	Lighting Improvements	$1,495,000	1,421	35,536	$568,100.00	$36,000
840	53	Update of lighting controls	Lighting Improvements	$632,500	4,333	108,322	$1,707,750.00	$109,700
840	53	Sub-metering of lights by tenant	Lighting Improvements	Not Pursued		-		
840	53	Provide daylight harvesting at exterior windows	Lighting Improvements	$338,100	3,248	81,206	$1,281,399.00	$83,000
840	53	Point-of-use domestic hot water system	Energy Related Process Improvements	$92,000	382	9,554	$123,280.00	$9,700
840	53	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$792,293	-	-	$110,921.00	$13,169
840	53	Low Flow Faucet Fixtures	Water and Sewer Conservation Systems	$3,364	-	-	$100,045.00	$7,088
840	53	Solar Hot Water Heating	Renewable Energy Systems	$230,000	326	8,146	$112,700.00	$8,300
840	53	Chiller Retrofit	Chiller Plant Improvements	$977,500	3,327	83,168	$1,309,850.00	$92,700
840	53	VFDs for chilled water pumps to primary variable system	Electric Motors and Drives	$460,000	1,433	35,826	$565,800.00	$36,300
840	53	Built-up Air Handlers Control Upgrade	Building Automation Systems/EMCS	$264,500	2,286	57,151	$901,945.00	$57,900
840	53	Additional control sensors tied back to BMS	Building Automation Systems/EMCS	$373,750	2,184	54,592	$859,625.00	$55,300

Gross Square Footage (Thou.)	Annual Energy Use (Site Billion Btu)	ECM Title	Category	Construction Cost	Estimated *Annual* Energy Savings (Million Btu/yr)	Estimated *Life-Cycle* Energy Savings (Million Btu)	Estimated Present Value *Life-Cycle* Cost Savings ($)	Estimated *Annual* Cost Savings ($)
840	53	Low leakage outside air dampers for Built-up Air Handlers	Other HVAC	$331,200	819	20,472	$324,576.00	$20,800
840	53	Built-up air handler cooling coil upgrades to primary variable system	Other HVAC	$172,500	478	11,942	$188,025.00	$12,100
840	53	VFDs for Fitness air handling system	Electric Motors and Drives	$17,480	53	1,331	$21,850.00	$1,400
840	53	Demand controlled ventilation for Lobby unit	Building Automation Systems/EMCS	$53,360	379	9,477	$155,811.00	$9,600
840	53	Upgrade to DDC system from pneumatic	Building Automation Systems/EMCS	$2,587,500	1,228	30,708	$491,625.00	$31,100
840	53	Damper replacement for emergency generator exhaust system	Building Automation Systems/EMCS	$4,600	14	341	$5,612.00	$400
840	53	VFDs for stair and fireman elevator pressurization system	Electric Motors and Drives	$161,000	21	537	$8,050.00	$600
840	53	VFDs for transformer room exhaust fans	Electric Motors and Drives	$23,000	15	384	$6,210.00	$500
840	53	Replacement of the windows	Building Envelope Modifications	$11,271,000	1,832	45,800	$676,260.00	$41,300
840	53	Installation of a green roof at the lower roof	Building Envelope Modifications	Not Pursued				
316	25	Add occupancy sensor controls to stairwells	Lighting Improvements	$5,520	29	725	$13,137.60	$700
316	25	Add occupancy sensor controls to all areas	Lighting Improvements	$71,760	244	6,100	$109,075.20	$6,000
316	25	Provide daylight harvesting at exterior windows	Lighting Improvements	$126,500	717	17,925	$307,395.00	$17,600
316	25	Decrease lighting output in over-lit areas	Lighting Improvements	$5,175	256	6,400	$114,678.00	$6,300
316	25	Add occupancy sensor controls to building elevators	Lighting Improvements	ECM Completed		-		
316	25	Space Temperature Set-Points	Building Automation Systems/EMCS	$6,900	889	22,225	$296,286.00	$16,000
316	25	VAV Minimum Air Flows	Building Automation Systems/EMCS	$46,000	1,131	28,275	$272,780.00	$14,969
316	25	Thermostat Calibration or Replacement	Building Automation Systems/EMCS	O&M Issue		-		
316	25	BAS Upgrade	Building Automation Systems/EMCS	$345,000	1,421	35,525	$779,700.00	$22,000
316	25	Fan Powered Box Inspection, Cleaning, and Repair/Replacement	Other HVAC	$23,000	182	4,550	$38,870.00	$2,000

Gross Square Footage (Thou.)	Annual Energy Use (Site Billion Btu)	ECM Title	Category	Construction Cost	Estimated *Annual* Energy Savings (Million Btu/yr)	Estimated *Life-Cycle* Energy Savings (Million Btu)	Estimated Present Value *Life-Cycle* Cost Savings ($)	Estimated *Annual* Cost Savings ($)
316	25	Chiller Replacement (Centrifugal compressor)	Chiller Plant Improvements	$440,519	3,618	90,450	$246,690.64	$6,000
316	25	Chiller Replacement (Screw compressor)	Chiller Plant Improvements	$657,506	3,491	87,275	$302,452.76	$12,000
316	25	Geothermal Heating and Cooling	Renewable Energy Systems	$5,405,000	9,414	235,350	$2,324,150.00	$110,000
316	25	Boiler Controls Upgrade	Building Automation Systems/EMCS	$23,000	329	8,225	$70,380.00	$3,850
316	25	VFDs for Cooling Tower Fans	Chiller Plant Improvements	$34,500	61	1,525	$27,255.00	$1,500
316	25	Testing and Balancing	Other HVAC	$115,000	246	6,150	$105,800.00	$6,000
316	25	Toilet Exhaust Control	Building Automation Systems/EMCS	$11,500		-	$0.00	
316	25	Cooling Tower Draining	Chiller Plant Improvements	$17,250		-	$0.00	
316	25	Replace Domestic Water Heaters	Water and Sewer Conservation Systems	$17,250		-	$0.00	
316	25	Air Handler Fan Control	Energy Related Process Improvements	$16,675	85	2,125	$38,185.75	$2,100
316	25	Low Flow Fixtures	Water and Sewer Conservation Systems	$1,271		-	$495.69	$30
316	25	Rain Water Harvesting	Water and Sewer Conservation Systems	$264,500		-	$13,225.00	$1,103
316	25	Solar Window Film	Building Envelope Modifications	$145,100	212	5,300	$91,413.00	$3,624
772	39	Add occupancy sensor controls to all areas	Lighting Improvements	$266,800	529	13,225	$269,468.00	$15,500
772	39	Provide daylight harvesting at exterior windows	Lighting Improvements	$248,400	1,061	26,525	$541,512.00	$31,000
772	39	Add reflectors to down light fixtures in lobby	Lighting Improvements	O&M				
772	39	Remove need for portable fans cooling equipment enclosures	Other HVAC	O&M				
772	39	Replace existing transformers with new general purpose transformers	Energy/Utility Distribution Systems	$32,200	259	6,475	$137,816.00	$7,500
772	39	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$788,900		-	$134,113.00	$9,081
772	39	Low Flow Lavatory Aerators	Water and Sewer Conservation Systems	$3,184		-	$16,780.00	$1,088

Gross Square Footage (Thou.)	Annual Energy Use (Site Billion Btu)	ECM Title	Category	Construction Cost	Estimated *Annual* Energy Savings (Million Btu/yr)	Estimated *Life-Cycle* Energy Savings (Million Btu)	Estimated Present Value *Life-Cycle* Cost Savings ($)	Estimated *Annual* Cost Savings ($)
772	39	Low Flow Work/Kitchen Sink Aerators and Showerheads	Water and Sewer Conservation Systems	$2,243		-	$13,279.00	$860
772	39	Building Automation System Upgrade	Building Automation Systems/EMCS	$2,012,500	1,678	41,950	$623,875.00	$35,500
772	39	AHU Replacement (Multi-Zone and 100% Outdoor Air)	Other HVAC	$2,990,000	4,736	118,400	$2,093,000.00	$120,150
772	39	Domestic Water Cooled Unit Replacement	Other HVAC	$345,000		-	$279,450.00	$20,000
772	39	Chiller Replacement	Chiller Plant Improvements	$828,000	802	20,050	$405,720.00	$23,500
772	39	Replace Three-Way Chilled Water Valves	CW/HW/Steam Distribution Systems	$23,000	181	4,525	$96,140.00	$5,300
772	39	Demand Control Ventilation	Building Automation Systems/EMCS	$195,500	4,588	114,700	$1,327,445.00	$89,000
772	39	HVAC Zone Occupancy Control	Building Automation Systems/EMCS	$97,750	3,316	82,900	$1,444,745.00	$79,400
772	39	Temperature Control Air Compressor Revision	Other HVAC	$3,450	82	2,050	$43,574.00	$2,400
772	39	Fan Coil Unit Control	Other HVAC	$172,500	601	15,025	$248,400.00	$14,300
190	7	Add occupancy sensor controls to all areas	Lighting Improvements	$248,400	464	11,600	$183,816.00	$10,500
190	7	Provide daylight harvesting at exterior windows	Lighting Improvements	$70,150	246	6,150	$101,718.00	$5,500
190	7	Add lighting controls to second floor corridors	Lighting Improvements	$9,200	24	600	$9,752.00	$550
190	7	Add occupancy sensor controls to stairwells	Lighting Improvements	$2,760	12	300	$4,940.00	$270
190	7	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$76,590		-	$78,888.00	$4,685
190	7	Low Flow Electronic Lavatory Faucets and Aerators	Water and Sewer Conservation Systems	$553		-	$26,760.00	$1,596
190	7	Low Flow Sink Aerators and Showerheads	Water and Sewer Conservation Systems	$509		-	$4,942.00	$295
190	7	Building Automation System Upgrade	Building Automation Systems/EMCS	$80,500	190	4,750	$48,300.00	$3,000
190	7	AHU-4 Replacement	Other HVAC	$87,400	296	7,400	$72,542.00	$4,200
190	7	AHU-5 through AHU-8 Replacement	Other HVAC	$540,500	1,567	39,175	$351,325.00	$21,300
190	7	Eliminate Concurrent Heating and Cooling	Other HVAC	Not Recommended				

Gross Square Footage (Thou.)	Annual Energy Use (Site Billion Btu)	ECM Title	Category	Construction Cost	Estimated *Annual* Energy Savings (Million Btu/yr)	Estimated *Life-Cycle* Energy Savings (Million Btu)	Estimated Present Value *Life-Cycle* Cost Savings ($)	Estimated *Annual* Cost Savings ($)
190	7	Multi-Zone Unit Retrofit	Other HVAC	Not Recommended				
190	7	AHU-20 Revisions	Other HVAC	Not Recommended				
190	7	Demand Control Ventilation	Other HVAC	$40,250	738	18,450	$127,995.00	$9,500
190	7	HVAC Zone Occupancy Control	Building Automation Systems/EMCS	$40,250	2,035	50,875	$476,963.00	$27,700
190	7	Review and Revise Chilled Water Distribution System	CW/HW/Steam Distribution Systems	Not Recommended				
190	7	District Steam Service	Energy/Utility Distribution Systems	Not Recommended				
190	7	Insulate Suspended Ceiling	Building Envelope Modifications	$120,900	215	5,375	$41,106.00	$2,500
190	7	Perform Thermal Scan	Building Envelope Modifications	O&M				
190	7	Replace Skylight with Insulated Roof	Building Envelope Modifications	$609,400	401	10,025	$79,222.00	$4,950
112	6	Add occupancy sensor controls to all areas	Lighting Improvements	$71,300	164	4,100	$99,820.00	$5,500
112	6	Provide daylight harvesting at atrium windows	Lighting Improvements	$17,250	78	1,950	$47,783.00	$3,000
112	6	Add timeclock lighting controls	Lighting Improvements	$94,300	222	5,550	$134,849.00	$7,400
112	6	Replace T12 ballasts with T8 ballasts in stairwell lighting fixtures	Lighting Improvements	$1,150	7	175	$4,048.00	$230
112	6	Add occupancy sensor controls to stairwells	Lighting Improvements	$3,220	11	275	$6,698.00	$370
112	6	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$134,378		-	$12,094.00	$2,100
112	6	Low Flow Lavatory Faucets	Water and Sewer Conservation Systems	$12,478		-	$5,740.00	$1,038
112	6	Low Flow Sink Aerators and Showerheads	Water and Sewer Conservation Systems	$160		-	$363.00	$67
112	6	Building Automation System Upgrade	Building Automation Systems/EMCS	$373,750	236	5,900	$78,488.00	$4,400
112	6	HVAC Equipment and System Upgrade	CW/HW/Steam Distribution Systems	$189,750	329	8,225	$89,183.00	$5,100
112	6	Automate AC-1 Relief Air	Other HVAC	Not Recommended				
112	6	Demand Control Ventilation	Other HVAC	$34,500	638	15,950	$164,220.00	$9,000
112	6	Replace Domestic Water Cooled AC Units	Chiller Plant Improvements	Not Recommended				

Gross Square Footage (Thou.)	Annual Energy Use (Site Billion Btu)	ECM Title	Category	Construction Cost	Estimated *Annual* Energy Savings (Million Btu/yr)	Estimated *Life-Cycle* Energy Savings (Million Btu)	Estimated Present Value *Life-Cycle* Cost Savings ($)	Estimated *Annual* Cost Savings ($)
112	6	Terminal Unit Heating Coil Cleaning	Other HVAC	$11,500	92	2,300	$31,050.00	$1,700
112	6	Post Office Service Vestibule	Other HVAC	Not Pursued				
112	6	HVAC Zone Occupancy Control	Building Automation Systems/EMCS	$23,000	631	15,775	$158,240.00	$8,700
112	6	Eliminate Boiler Stack Warm-Up Sequence	Boiler Plant Improvements	Not Recommended				
112	6	Heat Recovery	Other HVAC	Not Pursued				
112	6	Airside Test & Balance	Other HVAC	Not Recommended				
112	6	Replace Secondary Exterior Doors	Building Envelope Modifications	$14,260				
112	6	Perform Thermal Scans on Facility Envelope and Study	Building Envelope Modifications	$50,000 - O&M				
280	16	Add occupancy sensor controls to all areas	Lighting Improvements	$78,200	154	3,850	$70,380.00	$3,800
280	16	Provide daylight harvesting at exterior windows	Lighting Improvements	$116,150	382	9,550	$168,418.00	$9,600
280	16	Add occupancy sensor controls to stairwells	Lighting Improvements	$6,210	84	2,100	$38,564.00	$2,100
280	16	Building Automation System Upgrade	Building Automation Systems/EMCS	$287,500	568	14,200	$238,625.00	$10,900
280	16	Replace AHU Coils and Bypass Sections	Other HVAC	$115,000	371	9,275	$155,250.00	$7,100
280	16	HVAC Temperature Control Zones	Building Automation Systems/EMCS	Not Being Pursued		-		
280	16	Demand Control Ventilation	Building Automation Systems/EMCS	$80,500	1,704	42,600	$577,990.00	$30,600
280	16	District Steam Service	Energy/Utility Distribution Systems	$287,500	1,350	33,750	$560,625.00	$23,700
280	16	HVAC Zone Occupancy Control	Building Automation Systems/EMCS	$34,500	786	19,650	$345,345.00	$15,700
280	16	Heat Recovery	Energy Related Process Improvements	Not Being Pursued		-		
280	16	Perimeter Radiation Control	Building Automation Systems/EMCS	$75,900	366	9,150	$160,149.00	$6,900
280	16	Replace Roof Access Doors	Building Envelope Modifications	$11,000				
280	16	Replace Window Sealants and Flashings	Building Envelope Modifications	$249,000	1,097	27,425	$458,160.00	$26,140
280	16	Insulate Exterior Soffit	Building Envelope Modifications	$65,100	188	4,700	$81,375.00	$4,450

Gross Square Footage (Thou.)	Annual Energy Use (Site Billion Btu)	ECM Title	Category	Construction Cost	Estimated *Annual* Energy Savings (Million Btu/yr)	Estimated *Life-Cycle* Energy Savings (Million Btu)	Estimated Present Value *Life-Cycle* Cost Savings ($)	Estimated *Annual* Cost Savings ($)
280	16	Perform Thermal Scan of Building Exterior	Building Envelope Modifications	O&M $50,000				
280	16	Low Flow Aearators	Water and Sewer Conservation Systems	$1,510		-	$3,579.00	$212
280	16	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$342,068		-	$10,262.00	$577
49	5	Add occupancy sensor controls to all areas	Lighting Improvements	$69,000	229	5,725	$130,410.00	$7,100
49	5	Provide daylight harvesting at exterior windows	Lighting Improvements	$14,950	61	1,525	$35,133.00	$1,900
49	5	Add timeclock lighting controls	Lighting Improvements	$56,350	150	3,750	$85,652.00	$4,800
49	5	Building Automation System	Building Automation Systems/EMCS	$345,000	288	7,200	$82,800.00	$4,800
49	5	HVAC Equipment and System Upgrade	Other HVAC	$1,380,000	1,093	27,325	$358,800.00	$21,000
49	5	Replace Domestic Water Cooled AC units	Water and Sewer Conservation Systems	$28,750		-	$24,438.00	$1,800
49	5	Steam Trap Replacement	CW/HW/Steam Distribution Systems	$25,300	326	8,150	$63,756.00	$3,400
49	5	VFD for Cooling Tower Fan	Chiller Plant Improvements	$8,625	17	425	$9,401.00	$550
49	5	Chiller Replacement	Chiller Plant Improvements	$264,000	720	18,000	$134,640.00	$7,500
49	5	HVAC Zone Occupancy Control	Building Automation Systems/EMCS	$20,700	1,238	30,950	$282,141.00	$15,650
49	5	Demand Control Ventilation	Building Automation Systems/EMCS	$23,000	664	16,600	$148,120.00	$8,500
49	5	Ultra Low Flow Water Closets and Urinials	Water and Sewer Conservation Systems	$93,955			$68,587.00	$4,409
49	5	Low Flow Lavatory Faucets	Water and Sewer Conservation Systems	$9,660	11	275	$13,427.00	$2,420
49	5	Kitchen Sink Aerators	Water and Sewer Conservation Systems	$13	1	25	$313.00	$56
49	5	Insulate underside of 1933 Roof Structure	Building Envelope Modifications	$194,350	62	1,550	$17,492.00	$875
49	5	Install new Weather Stripping on Entrance Doors	Building Envelope Modifications	$5,060 O&M				
49	5	Perform Thermal Scans on Facility Envelope and Study	Building Envelope Modifications	Not Pursued				

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74	11	Add occupancy sensor controls to all areas	Lighting Improvements	$69,000	375	9,375	$62,790.00	$3,400
74	11	Replace 2nd Floor Column Lighting with Fluorescent Lighting	Lighting Improvements	$10,925	167	4,175	$27,859.00	$1,500
74	11	Building Automation System Remote Access	Building Automation Systems/EMCS	Not Recommended				
74	11	MEP and Control System Check Test and Start	Building Automation Systems/EMCS	Not Recommended				
74	11	Primary Inspection Booth Occupancy Control	Other HVAC	$9,200	248	6,200	$41,308.00	$2,250
74	11	Demand Control Ventilation	Building Automation Systems/EMCS	$25,300	1,122	28,050	$138,644.00	$10,950
74	11	HVAC Zone Occupancy Control	Building Automation Systems/EMCS	$31,050	2,672	66,800	$473,513.00	$26,000
74	11	Supplemental Unit Heat Rejection	Renewable Energy Systems	Not Recommended				
74	11	BAS Sequence of Operation Revisions	Building Automation Systems/EMCS	$4,255	236	5,900	$41,274.00	$2,250
74	11	Return Air Path Review	CW/HW/Steam Distribution Systems	Not Recommended				
74	11	Wind Power	Renewable Energy Systems	Not Recommended				
74	11	Revise Boiler Fuel	Boiler Plant Improvements	$258,750	1,127	28,175	$194,063.00	$11,150
74	11	New Vegetated Green Roof	Building Envelope Modifications	$2,420,000	238	5,950	$48,400.00	$2,350
74	11	Exterior Wall Insulation Improvements	Building Envelope Modifications	$11,400	284	7,100	$51,186.00	$2,810
74	11	Low Flow Aerators	Water and Sewer Conservation Systems	$75		-	$1,507.00	$1,533
74	11	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$44,160		-	$9,715.00	$2,603
739	67	Disonnect courtroom lobby cove lighting	Lighting Improvements	$1,725	232	5,800	$95,013.00	$3,800
739	67	Reduce emergency lighting in Judge's Reception Areas	Lighting Improvements	$4,025	17	425	$7,004.00	$279
739	67	Law Library lighting modification	Lighting Improvements	$6,785	90	2,250	$37,046.00	$1,481
739	67	Reprogram night lights in entire building	Lighting Improvements	Not Pursued				
739	67	Replace dock area lighting with high-bay fluorescent	Lighting Improvements	$17,940	191	4,775	$78,218.00	$3,130

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739	67	Add occupancy sensors to dock area	Lighting Improvements	$1,495	32	800	$12,992.00	$520
739	67	Add occupancy sensors to basement circulation	Lighting Improvements	$1,438	51	1,275	$20,944.00	$838
739	67	Corridor lighting modifications	Lighting Improvements	O&M $3,450	-	-		
739	67	Replace or relamp non-fluorescent lighgting fixtures	Lighting Improvements	$132,250	522	13,050	$204,988.00	$11,500
739	67	Provide workstation lighting as described in the GSA SOW	Lighting Improvements	Implemented				
739	67	Add occupancy sensor controls to all areas and upgrade existing occupancy sensor wallboxes	Lighting Improvements	$156,400	406	10,150	$159,528.00	$9,200
739	67	Electrical peak control	Electrical Peak Shaving/Load Shifting	$25,300	3,564	89,100	$839,454.00	$80,000
739	67	Add contols to escalators to avoid continuous operation	Other	Not Recommended				
739	67	HVAC Zone Occupancy Control	Other HVAC	$79,350	1,695	42,375	$1,888,530.00	$71,413
739	67	Demand Control Ventilation	Other HVAC	$264,500	2,010	50,250	$2,793,120.00	$67,708
739	67	On-Site Chiller Replacement	Chiller Plant Improvements	$3,240,125	11,471	286,775	$12,085,666.00	$439,583
739	67	Closed Circuit Fluid Coolers	Chiller Plant Improvements	$198,375	348	8,700	$1,755,619.00	$9,600
739	67	MUA Preheat with Return Chilled Water	Chiller Plant Improvements	Not Recommended				
739	67	Ventilation Control	Building Envelope Modifications	$529,000	3,035	75,875	$1,549,970.00	$78,054
739	67	Humidification Reset Schedule	Other HVAC	$13,225	1,348	33,700	$1,849,252.00	$34,292
739	67	Snow Bypass	Other HVAC	O&M		-		
739	67	Heat Recovery	Energy Related Process Improvements	$79,350	406	10,150	$385,641.00	$14,000
739	67	Chilled Water Bypass	Chiller Plant Improvements	Not Recommended				
739	67	Modify hot water loop operation	Other HVAC	O&M $0	75	1,875		$2,200
739	67	Lavatory and Sink Aerators and Low Flow Showerheads	Water and Sewer Conservation Systems	$6,378		-	$49,748.00	$3,067
739	67	Install New Insulated Membrane Roof	Building Envelope Modifications	$499,100		-	$-	
739	67	Curtain Wall/ Window Improvements	Building Envelope Modifications	$2,243,650	1,384	34,600	$605,786.00	$23,846
739	67	Insulate Exterior Envelope Walls	Building Envelope Modifications	$583,050		-	$-	

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739	67	Adjustment to Lobby Sliding Entrance Door Delay Interlock Controls	Building Envelope Modifications	O&M $40,000		-		
542	78	Add Occupancy Sensor controls to all courtrooms	Lighting Improvements	Not Pursued		-		
542	78	Add Occupancy Sensor controls to offices	Lighting Improvements	Not Pursued		-		
542	78	Reduce lighting level in first floor lobby and corridor	Lighting Improvements	Not Pursued		-		
542	78	Provide daylight harvesting at exterior windows	Lighting Improvements	Not Pursued		-		
542	78	Low Flow Aerators	Water and Sewer Conservation Systems	$2,054	20	500	$34,096.40	$1,363
542	78	Reduce VAV Minimum Air Set-points	Building Automation Systems/EMCS	$258,750	390	9,750	$517,500.00	$29,631
542	78	Demand Control Ventilation	Building Automation Systems/EMCS	$69,000	28	700	$58,650.00	$3,207
542	78	Optimize Space Controls	Building Automation Systems/EMCS	$57,500	2,969	74,225	$637,675.00	$34,316
542	78	Optimize Economizer Control	Building Automation Systems/EMCS	$39,100	933	23,325	$1,948,744.00	$105,860
542	78	Building Pressurization	Building Automation Systems/EMCS	$402,500	2,442	61,050	$603,750.00	$34,491
542	78	Filter Replacement	Other HVAC	O & M Issue	212	5,300		$3,335
542	78	EMS Separation - operational improvement	Building Automation Systems/EMCS	$34,500		-	$0.00	
542	78	Chilled Water and Steam Distribution Isolation and Metering - operational improvement	Building Automation Systems/EMCS	Op. Improvement				
542	78	Steam pressure Reset - operational improvement	Advanced Metering Systems	$11,500		-	$0.00	
542	78	EMS Overhaul - operational improvement	Building Automation Systems/EMCS	$86,250		-	$0.00	
254	19	Add occupancy sensor controls to all areas	Lighting Improvements	$338,560	778	19,450	$385,958.00	$22,000
254	19	Relamp decorative chandeliers and wall sconces	Lighting Improvements	$4,600	136	3,400	$73,922.00	$4,500
254	19	Provide daylight harvesting in corridors near atrium	Lighting Improvements	$67,850	259	6,475	$134,343.00	$7,400

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254	19	Replace lighting in the parking garage with fluorescent lighting and add timeclock control	Lighting Improvements	$3,450	41	1,025	$21,045.00	$1,200
254	19	Add dimming controls to historic courtrooms	Lighting Improvements	$1,265	40	1,000	$20,708.00	$1,100
254	19	Add occupancy sensor controls to stairwells	Electric Motors and Drives	$5,520	10	250	$5,134.00	$300
254	19	Supplemental Cooling for US Marshalls Command Center	CW/HW/Steam Distribution Systems	$14,088	212	5,300	$172,290.00	$9,522
254	19	VAV Minimum Air Set-points	Building Automation Systems/EMCS	$8,625	2,803	70,075	$1,222,594.00	$67,000
254	19	Fin Tube Radiation as Primary Heat Source	Building Automation Systems/EMCS	$8,625	2,402	60,050	$839,385.00	$46,000
254	19	Volumetric Tracking for Air Handler Fans	Other HVAC	$27,600	79	1,975	$41,124.00	$2,250
254	19	Remove Electric Supplemental Heat in Basement	Other HVAC	$28,750		-	$25,013.00	$2,900
254	19	Isolate Basement Steam Line During Cooling Season	CW/HW/Steam Distribution Systems	$5,664	34	850	$11,894.00	$654
254	19	Steam Pipe Insulation	CW/HW/Steam Distribution Systems	$2,300	144	3,600	$50,324.00	$3,500
254	19	Crawl Space Piping Insulation	CW/HW/Steam Distribution Systems	$2,300	14	350	$4,899.00	$420
254	19	Sidewalk Elevator Machine Room Ventilation	Other HVAC	$6,900		-	$0.00	
254	19	Electrical Closet Temperatures	Building Automation Systems/EMCS	$3,450	11	275	$16,802.00	$920
254	19	Shut Off Heating Water Pump	CW/HW/Steam Distribution Systems	$27,514	187	4,675	$96,848.00	$5,481
254	19	Hot Water Availability in Restroom Sinks	Other HVAC	$138,000			$0.00	
254	19	BAS Hardware Upgrade	Building Automation Systems/EMCS	$57,500			$0.00	
254	19	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$226,550			$58,903.00	$381
254	19	Low Flow Lavatory Faucets	Water and Sewer Conservation Systems	$897			$1,668.00	$201

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254	19	Low Flow Sink Aerators and Showerheads	Water and Sewer Conservation Systems	$635			$5,442.00	$712
254	19	Insulate Underside of Roof	Building Envelope Modifications	$226,550	446	11,150	$167,647.00	$9,560
254	19	Replace Window Gaskets on Floors 2 thru 6	Building Envelope Modifications	O&M $96,700				
254	19	Apply Solar Film on Skylight Glazing	Building Envelope Modifications	$153,200	834	20,850	$1,262,368.00	$17,108
254	19	Replace Exterior Sidewalk Freight Elevator	Other	O&M $40,300				
254	19	Insulate Mechanical Space Exterior Walls	Building Envelope Modifications	$128,600	1,222	30,550	$509,256.00	$29,050
271	17	Add Occupancy Sensor controls to offices and courtrooms	Lighting Improvements	$184,000	963	24,075	$502,320.00	$28,724
271	17	Provide daylight harvesting at exterior windows	Lighting Improvements	$402,500	729	18,225	$382,375.00	$21,760
271	17	Install Low Flow Fixtures	Water and Sewer Conservation Systems	$102,327		-		$4,026
271	17	Implement Rain Water Harvesting	Water and Sewer Conservation Systems	$230,000		-	$216,200.00	$13,595
271	17	Energy Management System (EMS) Replacement	Building Automation Systems/EMCS	$115,000		-		
271	17	Air Handling System and Distribution Upgrade	CW/HW/Steam Distribution Systems	$1,150,000	5,583	139,575	$1,851,500.00	$105,987
271	17	AHU Coil Replacement	CW/HW/Steam Distribution Systems	$51,750		-		
271	17	Demand Control Ventilation	Building Automation Systems/EMCS	$201,250	839	20,975	$100,625.00	$12,584
271	17	Optimize space controls	Building Automation Systems/EMCS	See ECM description.		-		
271	17	Building Pressurization	Building Automation Systems/EMCS	$218,500	1,290	32,250	$338,675.00	$19,360
271	17	Replace Roof/Add Insulation	Building Envelope Modifications	$2,138,000	55	1,375	$21,380.00	$742
271	17	Repair Exterior Walls	Building Envelope Modifications	Not Pursued		-		
271	17	Window Replacement	Building Envelope Modifications	$1,651,000	1,124	28,100	$412,750.00	$23,977
168	15	Building Pressurization	Building Automation Systems/EMCS	$86,250	995	24,875	$221,663.00	$12,171

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168	15	Ultra Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$297,907				$1,977
168	15	Low Flow Sink Aerators and Showerheads	Water and Sewer Conservation Systems	$870	13			$381
168	15	Add Insulation to Exterior Walls	Building Envelope Modifications	$8,000	245	6,125	$67,520.00	$3,686
774	53	Provide daylight harvesting and relamping at windows	Lighting Improvements	$338,100	3,074	76,850	$889,203.00	$51,000
774	53	Decrease lighting output in over-lit areas	Lighting Improvements	$5,750	263	6,575	$79,178.00	$4,300
774	53	Add time-out to courtroom lighting panic button	Lighting Improvements	$1,150				
774	53	Add occupancy sensor controls to all areas	Lighting Improvements	$442,750	2,030	50,750	$588,858.00	$33,500
774	53	Add occupancy sensor controls to stairwells	Lighting Improvements	$23,000	84	2,100	$25,300.00	$1,400
774	53	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$290,090		-	$14,505.00	$854
774	53	Low Flow Aerators	Water and Sewer Conservation Systems	$3,301	51	1,275	$43,903.00	$2,387
774	53	Shut Down Chilled Water During After-Hours and Winter	Building Automation Systems/EMCS	$258,750	1,795	44,875	$520,088.00	$29,700
774	53	VAV Minimum Air Set-Points	Building Automation Systems/EMCS	$11,500	9,437	235,925	$2,845,100.00	$156,000
774	53	Demand Control Ventilation	Other HVAC	$49,450	5,263	131,575	$1,204,108.00	$87,000
774	53	Building Automation System Upgrade	Building Automation Systems/EMCS	$2,070,000	2,632	65,800	$765,900.00	$43,500
774	53	Eliminate Secondary Filters in Air Handling Units	Other HVAC	Not Recommended				
774	53	VFDs for Cooling Tower Fans	Electric Motors and Drives	Not Recommended				
774	53	Elevator Machine Room Temperature	Building Automation Systems/EMCS	$0	37	925		$618
774	53	Kitchen Exhaust Fan Stack	Other HVAC	$2,300 O&M				
774	53	Insulate underside of roof structure	Building Envelope Modifications	$786,600	526	13,150	$149,454.00	$8,680
543	29	Replace T12 ballasts with T8 ballasts in lighting fixtures	Lighting Improvements	$60,950	123	3,075	$56,684.00	$3,100
543	29	Provide daylight harvesting at exterior windows	Lighting Improvements	$162,150	437	10,925	$192,959.00	$11,400

Gross Square Footage (Thou.)	**Annual Energy Use (Site Billion Btu)**	**ECM Title**	**Category**	**Construction Cost**	**Estimated *Annual* Energy Savings (Million Btu/yr)**	**Estimated *Life-Cycle* Energy Savings (Million Btu)**	**Estimated Present Value *Life-Cycle* Cost Savings ($)**	**Estimated *Annual* Cost Savings ($)**
543	29	Replace lighting in the parking garage with fluorescent lighting and add timeclock control	Lighting Improvements	$6,325	33	825	$15,054.00	$800
543	29	Align lighting fixtures with the corridor	Lighting Improvements	$3,450	5	125	$2,346.00	$130
543	29	Chiller Plant Piping	Chiller Plant Improvements	Enables M2				
543	29	VFDs for Chillers	Chiller Plant Improvements	$341,550	213	5,325	$95,634.00	$5,379
543	29	Cooling Tower Sequencing and Operation	Building Automation Systems/EMCS	$8,625	23	575	$10,695.00	$584
543	29	Simultaneous Heating and Cooling	Building Automation Systems/EMCS	$11,500	142	3,550	$36,340.00	$2,000
543	29	Steam Condensate Heat Recovery	Other HVAC	$23,000		-	$109,250.00	$6,886
543	29	Thermostatic Valves for Fin Tube Radiation	CW/HW/Steam Distribution Systems	$5,750				
543	29	Remove Inlet Vanes and Mechanisms	Other HVAC	$17,250	258	6,450	$118,508.00	$6,500
543	29	VAV Minimum Air Flows	Building Automation Systems/EMCS	$8,625	1,437	35,925	$461,524.00	$25,300
543	29	Replace Pneumatic VAV Controls	Building Automation Systems/EMCS	$13,800				
543	29	Space Temperature Adjustment	Building Automation Systems/EMCS	$8,625	987	24,675	$293,681.00	$16,100
543	29	AHU Pipe Penetration Leakage	Building Envelope Modifications	$1,380	1	25	$373.00	$20
543	29	Relief Fan Discharge Duct	Other HVAC	O&M				
543	29	Provide Pipe Insulation	CW/HW/Steam Distribution Systems	O&M				
543	29	Replace AHU Filters	Other HVAC	O&M				
543	29	Exhaust Fan for Hydraulic Elevator Room	Other HVAC	$4,600	21	525	$9,568.00	$525
543	29	Low Flow Water Closets and Urinals	Water and Sewer Conservation Systems	$654,638			$39,278.00	$2,501
543	29	Low Flow Faucets	Water and Sewer Conservation Systems	$67,620			$6,086.00	$530
543	29	Low Flow Aerators and Showerheads	Water and Sewer Conservation Systems	$1,999			$9,875.00	$927

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543	29	Remove Abandoned Skylight - Infill with New Roofing System	Building Envelope Modifications	$938,000	1,056	26,400	$187,600.00	$10,260
543	29	Re-seal existing stone coping	Building Envelope Modifications	$4,800 O&M				
543	29	Window Replacement - South Section	Building Envelope Modifications	$1,651,000	2,050	51,250	$495,300.00	$27,111
75	4	Solar Array	Renewable Energy Systems	$420,000	155	3,875	$84,000.00	$4,799
75	4	Vertical Axial Type Wind Turbines	Renewable Energy Systems	Not Being Pursued		-		
75	4	Provide Daylight Harvesting and Re-lamping at exterior windows	Lighting Improvements	$16,900	24	600	$55,770.00	$738
75	4	Add occupancy sensor controls to all areas	Lighting Improvements	$133,400	91	2,275	$154,744.00	$2,828
75	4	Modification to 25 watt T8 lamps	Lighting Improvements	$1,200	16	400	$9,240.00	$510
75	4	Reduce hours of drink vending operation	Other	Not Being Pursued		-		
75	4	Low Flow Plumbing Water Fixtures	Water and Sewer Conservation Systems	$127,500	-	-	$44,625.00	$2,276
75	4	Low Flow Plumbing Lavatories	Water and Sewer Conservation Systems	$18,113	8	200	$4,891.00	$372
75	4	Low Flow Sink Aerators & Showerheads	Water and Sewer Conservation Systems	$305	6	150	$3,486.00	$260
75	4	Timer/Aquastat for water heater	Water and Sewer Conservation Systems	Not Being Pursued		-		
75	4	VFD's for heating hot water pumps	Electric Motors and Drives	$8,700	37	925	$20,967.00	$1,156
75	4	VAV minimum air set-points	Building Automation Systems/EMCS	$63,250	287	7,175	$161,288.00	$8,906
75	4	Court Room CO2 sensors	Building Automation Systems/EMCS	$15,000	159	3,975	$89,550.00	$4,933
75	4	AHU-1&2 control upgrade	Building Automation Systems/EMCS	$3,800	44	1,100	$24,852.00	$1,370
75	4	VFD for lobby heating air handling unit AHU-3	Electric Motors and Drives	$8,100	51	1,275	$28,512.00	$1,573
75	4	Chilled water project	Chiller Plant Improvements	$402,500	57	1,425	$32,200.00	$1,767
75	4	Window Replacement	Building Envelope Modifications	$700,000	227	5,675	$70,000.00	$4,047

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