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Deep Energy Retrofits Using the Integrative Design Process: Are they Worth the Cost

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1. Introduction

In the United States, existing commercial buildings account for about 40% of the total energy consumed nationwide (Zhai, J., LeClaire, N., & Bendewald, M. 2011). According to the Rocky Mountain Institute, commercial sector energy consumption will expand by 2.7% each year in the United States unless existing commercial building energy retrofits are progressively applied. At the current rate of existing commercial building retrofits in the U.S., 2.2% of buildings are retrofitted each year, achieving an average of 11% energy savings annually (Olgyay and Seruto 2010). If this trend continues, by 2030 retrofit projects will have averted 13.5 million metric tons (MMt) of CO_2(eq) from entering the atmosphere (Olgyay and Seruto 2010). California, Illinois, Minnesota, and New Mexico, as well as numerous local governments and organizations including ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) have adopted a commercial sector green house gas (GHG) emissions reduction goal of 179 MMt of CO_2(eq) by 2030 (Mazria, E., Kershner, K., 2009)(Olgyay and Seruto, 2010). This goal is part of the Architecture 2030 Challenge, a set of goals and guidelines that aim to reduce GHG emissions in the building sector by 50% and to plateau the increase of GHG emissions from the expanding commercial building sector (Mazria & Kershner, 2009). Energy efficiency retrofits present a low-cost opportunity to save energy and reduce GHG emissions, however, to accomplish the goals set by the Architecture 2030 challenge, energy retrofits need to be applied more frequently and achieve more aggressive energy savings (Olgyay and Seruto, 2010).

The term *Deep Energy Retrofit* refers to a whole building retrofit that can reduce energy consumption in an office building by 30-50%+ (Bendewald et al 2012). The key to this radical energy savings is the *Integrative Design Process*, where all systems in a building are analyzed congruently to find synergies between these systems (Lovins, 2010). This holistic approach to energy retrofits allows design teams to identify energy efficiency retrofit measures that can produce multiple benefits from single expenditures instead of single benefits (Lovins, 2010).

This paper hopes to address the question, can Deep Energy Retrofits be a cost-effective option for office buildings, and if so, under what conditions? When it comes to energy efficiency, the orthodox way of thinking generally assumes that the more energy saved, the higher the required cost becomes (Lovins, 2010). While this is often true in conventional energy retrofits, Deep Energy Retrofits using an Integrative Design Process can provide means by which higher energy savings can provide lower payback periods, a higher return on investment, and improved cost-effectiveness through operational cost savings and avoided capital costs (Bendewald et al 2012). Moreover, there are additional benefits that Deep Energy Retrofits provide beyond cost savings such as improved working environment for occupants, and enhanced reputation of the building owner and tenants (Bendewald et al 2012). Moreover, this paper will offer recommendations that could be useful to improve the cost-effectiveness of Deep Energy Retrofits, ultimately expanding the frequency of which they are used.

2. Methodology

Case studies were used to explore how Deep Energy Retrofits can be cost-effective while still yielding huge energy savings. The Rocky Mountain Institute and the New Buildings Institute provide a wide variety of Deep Energy Retrofit case studies. In all, 8 case studies were used in the analysis of this paper. Furthermore, research papers on Deep Energy Retrofits, the Integrative Design Process, and other energy-related topics were used to provide supporting information in all sections of this paper.

Deep Energy Retrofit case studies were chosen for this study based on multiple and (to some degree) diverse criteria. Possibly the most important factor was the overall success in energy reduction achieved by each project. Another critical factor was the availability of financial information. For many Deep Energy Retrofit case studies, this information is not disclosed. It is important to keep in mind that the expenses of energy efficiency measures implemented in a Deep Energy Retrofit are rarely disaggregated from other non-energy related expenses (Bendewald et al 2012). This makes analyzing the cost-effectiveness of energy efficiency measures alone difficult to explore. In addition to energy and financial data, case studies were chosen based off of additional, sometimes non-monetary benefits achieved by the retrofit. An example of this is the improvement to the indoor air quality or the reputation of the building. Finally, a few case studies were chosen based on the innovation in the use of the Integrative Design Process.

To analyze the cost-effectiveness of a Deep Energy Retrofit, energy savings data is needed that include electricity, natural gas, propane, and other fossil fuels. In the energy efficiency industry, Energy Usage Intensity (EUI) is the most commonly used benchmarking unit to define a building's an annual energy use. This unit is defined as: Energy Use Intensity = kBTU/sf/yr (www.energync.net). The EUI was used to provide information about how much the energy is saved, as well as to benchmark these case studies to the national EUI average for office buildings of 93 kBTU/sf/yr.

3. Overview of Energy Retrofits for Office Buildings

In order to explore the financial viability of Deep Energy Retrofits, it is important to understand the process, and how the Integrative Design Process is used to achieve *deep* energy savings. Moreover, it is important to differentiate the Integrative Design Process from other types of retrofits like retrocommissioning and the standard retrofit design process. Currently, these two methods are the most commonly used to improve energy efficiency and improve the overall operations of commercial buildings in the United States (Moser et al. 2012).

3.1 Retrocommissioning and Standard Retrofits

Retro-commissioning, also know as Existing Building Commissioning, is commonly used to improve a building's systems to meet energy or operational requirements using little capital costs with relatively low risk (Moser et al. 2012). Retocommissioning focuses on investigating and improving a buildings operations and maintenance procedures to optimize performance, which doesn't require replacement of equipment. Retro-commissioning is a practical way to achieve energy savings, in some cases up to 16% reduction in energy consumption (Moser et al. 2012).

Today, standard retrofits are commonly used to provide energy efficiency upgrades for building owners who are committed to making incremental upgrades with the hopes of achieving cost effective results. Often, in a standard energy efficiency retrofit, Energy Service Companies (ESCOs) will replace substandard equipment with equipment that operates with greater energy efficiency, while using the same or greater capacity (i.e. heating load or cooling load for HVAC systems) (Moser et al. 2012). Furthermore, tenant spaces are often not touched in a standard retrofit, mainly because of the inconvenience placed on the tenant (Fluhrer, Maurer, & Deshmukh 2010).

In a Standard Energy Retrofit, energy efficiency measures are implemented one after another, where after one system is renovated, unforeseen impacts are often discovered to effect different building systems (Moser et al. 2012). This makes the sequence of energy efficiency measure implementation paramount for a successful standard retrofit (Moser et al. 2012). Furthermore, the Standard retrofit design process requires less effort in the early stages of design and more effort in the later stages, which is due to the linear nature of the standard retrofit framework (Harvey, 2012).

3.2 Deep Energy Retrofits using the Integrative Approach

Deep Energy Retrofits using the Integrative Design Process combines Operations and Maintenance commissioning with whole-building retrofit design

(Moser et al. 2012). The overall objective of a Deep Energy Retrofit is to provide the client with multiple design options that provide elevated energy efficiency that provide enhanced cost-effectiveness. Energy efficiency measures are developed with an in-depth understanding of the synergies between systems before any implementation takes place, which requires more time and effort than standard retrofits, and especially retrocommissioning (Moser et al. 2012).

The Integrative Design Process is what drives Deep Energy Retrofits to achieving more energy and operational cost savings than the conventional standard retrofit. This highly collaborative process uses "whole systems thinking", in that, all the components of a building are analyzed and optimized for multiple benefits, not isolated components for single benefits (Lovins 2010). There are specific principles for which the Integrative Design Process is performed, which the Amory Lovins and the Rocky Mountain Institute has clearly defined through years of research and analysis.

1. *Focusing on the desired end-use places purposes and application before equipment, efficiency before supply, passive before active, simple before complex.*
2. *Broadening design scope embraces whole systems and sets end-use performance metrics.*
3. *Designing from scratch, at least initially, creatively harnesses "beginner's mind," spans disciplinary silos, surpasses traditional solutions, and further expands the design space.*
4. *Analyzing gaps between theoretical minimum requirements and typical usage reveals overlooked opportunities for elegant frugality.*
5. *Optimizing systems, not isolated parts, lets single expenditures yield multiple benefits.*
6. *Evidence-based analysis supplants rules of thumb.*
7. *Measurement and prudence replace mindless oversizing and allow operational risks to be managed explicitly and intelligently.*
8. *End-use savings multiply upstream energy and capital savings, so efficiency logic is sequenced in the direction opposite to energy flow.*
9. *Design satisfies rare conditions (making appropriate tradeoffs and engaging end-users), but emphasizes typical conditions to maximize performance integrated over the range.*
10. *Controls and embedded sensors create intelligence and learning, so design can be optimized in real operation and further improved in future applications.*

(Lovins 2010)

Unlike standard retrofits, there is no consensus between retrofit design professionals on a single framework for conducting a Deep Energy Retrofit. For the purpose and scope of this paper, the framework used for the Deep Energy Retrofit of the Empire State Building will be described. This is because of the many innovations that were discovered in the process, its overall success of the project in achieving deep energy savings in a skyscraper sized building, the contribution from many different retrofit design professionals, and its utilization of the Integrative Design Process.

The first stage of the Deep Energy Retrofit, the target and qualification stage, involves the collaboration of Energy Service Companies (ESCOs), property management, and sometimes a third party design team to evaluate the building (Adams et al 2012). The purpose of the third party is to ensure the effectiveness of the ESCO and to offer guidance in energy efficiency measures that otherwise would not be realized (Fluhrer, Maurer, & Deshmukh 2010). In this stage a baseline is calculated, the first step of a Life Cycle Cost Analysis. A Life Cycle Cost Analysis is a multifaceted method to analyze a building's equipment and systems, which allows design teams and stakeholders fully realize the financial implications of the retrofit project, as well as explore what is technologically possible (Fluhrer, Maurer, & Deshmukh 2010). An accurate baseline allows for a clear separation between the businesses-as-usual scenario and multiple deep energy savings scenarios (Buys, Bendewald, & Tupper 2011). In that, capital costs and savings are evaluated, not just to show operational cost savings but to offer potential alternative cost savings beyond energy efficiency. This will play an important part in understanding the financial viability of Deep Energy Retrofits explained later in this paper. In addition, specific end-user needs are identified and defined, such as the desired outcomes required by the building owner/s and tenants (Adams et al 2012).

The second stage of the Integrative Design Process involves documenting the existing building systems and equipment (Fluhrer, Maurer, & Deshmukh 2010) where the design teams set out to understand the current state of the building and determine if needs are being met (Adams et al, 2012). An emphasis is placed on understanding the building's energy consumption trends (Fluhrer, Maurer, &

Deshmukh 2010). Furthermore, design teams brainstorm different energy efficiency measures to define goals of the retrofit. Throughout this process, stakeholders should be involved at every turn, to ensure that needs are being met (Buys, Bendewald & Tupper 2011).

The third stage of the integrated design approach focuses on creating an accurate and comprehensive energy model. Variables taken into account include but are not limited to: climate conditions, building shape, zoning, building envelope conditions, internal heat gain, and HVAC controls (Fluhrer, Maurer, & Deshmukh 2010). After the appropriate level of calibration, energy efficiency measures that were devised in the previous stage are set through rigorous testing.

The next stage includes the final documentation and synthesis of all energy efficiency measures into energy efficiency measure packages, which is also the final stage of the Life Cycle Cost Analysis. Here, net present value of all energy efficiency measure packages are calculated where the team determines packages that provide the highest net present value, and packages with the highest potential for energy efficiency. Often, these packages are called NVP Max and CO_2 Max (Buys, Bendewald & Tupper 2011). In the case of the Empire State Building, intermediate energy efficiency packages were determined to meet the client's needs. By the end of the fourth stage, recommendations are finalized and final proposals are brought to the client (Fluhrer, Maurer, & Deshmukh 2010). The final stage of the Deep Energy Retrofit is the verification and execution stage, where the implementation of energy efficiency measures takes place, as well as ongoing measurements to identify any barriers (Fluhrer, Maurer, & Deshmukh 2010).

There are several key differences between Deep Energy Retrofits and the standard retrofits processes worth noting. First, the collaboration between ESCOs, the building owner/s, and sometimes a third party allows for more energy efficiency opportunities to be explored by defining more goals and resolutions to achieve these goals (Fluhrer, Maurer, & Deshmukh 2010). In addition, the client is more informed, ensuring that their financial and energy reduction needs are met (Adams et al. 2012). The brainstorming of many energy efficiency measures through the collaboration of different design teams would not take place in a standard retrofit, mainly because the ESCO is not under contract in this early stage of development (Fluhrer, Maurer, & Deshmukh 2010). Secondly, the development of a comprehensive baseline program through the Integrated Life Cycle Cost Analysis, which plays an integral part in identifying alternative cost savings, avoided cost savings, as well as general operations cost savings (Buys, Bendewald, & Tupper 2011). The third key difference is the investigation into the improvement of tenant spaces to improve tenant energy efficiency (Fluhrer, Maurer, & Deshmukh 2010).

4. Review of Case studies

The gross capital cost of a Deep Energy Retrofit to achieve between 30-50%+ energy savings in a commercial building can vary dramatically depending on multiple factors including (but definitely not limited to): age, building size, building use, location, climate conditions, and pre-existing building conditions. Often times, design teams do not disaggregate energy related retrofit expenditures from non-energy retrofit expenditures, creating more variability from case to case (Bendewald et al 2012). Furthermore, the largest determining factor of a Deep Energy Retrofit may be the determination and commitment of the financial decision makers. The average Deep Energy Retrofit of an existing commercial building (of all sizes) in the United States costs $10-$75 per square foot; which will reduce energy consumption by 10-25 KBTUs/sf/year (Kok, Miller, and Morris 2011). However, according to the Rocky Mountain Institute, the average Deep Energy Retrofit of a large commercial office building, 500,000 square foot and 12-stories, will cost anywhere between $25 and $150+ per square foot to reduce energy consumption by 30 KBTU/sf/year to 50 KBTU/sf/year (Bendewald et. al. 2012). On the lower end, this amounts to $12.5 million for the total capital costs of the retrofit project (before incentives), while the higher end can be $75 million or more (Bendewald et. al. 2012).

4.1 The Empire State Building

The Empire State Building is by far the most famous Deep Energy Retrofit to date. Many innovative deep retrofit solutions where created during the retrofit process that serve as an example for what can be done to other large skyscrapers. Before the Empire State Building retrofit in 2009, the annual utility cost for the 2.7 million square foot building was roughly $11 million, or around $4.00/sf/year (Harrington & Carmichael 2009). After the retrofit was completed in 2010, annual utility costs dropped to $6.6 million or approximately $2.50/sf/year (Harrington & Carmichael 2009). By using the Integrative Design Process, the design teams were able to achieve a 38% reduction in energy consumption saving $4.4 million per year in utility costs (Harrington & Carmichael 2009). Furthermore, the payback period for the additional $13.2 million capital costs for the Deep Energy Retrofit was reduced to only 3 years (Harrington & Carmichael 2009).

There were several focal points for the retrofit of the Empire State Building that created financial viability of the project. One of the most important factors included using preplanned expenditures to act as a guideline on what building components to explore first (Fluhrer, Maurer, & Deshmukh 2010). By piggybacking these already allocated expenses, energy efficiency retrofit measures could be planned with little or no additional capital costs, drastically reducing overall expenditure and exponentially increasing the return on investment (Harrington & Carmichael 2009). By focusing in on preplanned expenditures in the Life Cycle Cost Analysis, design teams could identify ways to avoid these expenses, as was the case for the Empire State Building's chiller plant (Fluhrer, Maurer, & Deshmukh 2010). Before the retrofit, building operations required $17.3 million to replace the large office building chiller plant with equipment that matched the cooling capacity of the old, inefficient chiller plant (Harrington & Carmichael 2009). After a Life Cycle Cost Analyses was performed, it was concluded that cooling loads for the building could be reduced with other energy efficiency measures, eliminating the need to replace the chiller plant. Instead, the chiller plant was renovated for $5.1 million in capital expenses, avoiding the high $17.3 million cost of a replacement (not to mention the costs of bringing the large chiller plant into the building, shutting down New York's 5th ave. and disrupting traffic) (Harrington & Carmichael 2009).

In addition, engineers were assigned the task of designing complex and detailed energy models to develop strategies for whole-building energy reduction (Fluhrer, Maurer, & Deshmukh 2010). This allowed the estimated performance of the energy efficiency measures, and subsequently, energy efficiency measure packages to be highly accurate and effective. When it came time for the Empire State Building retrofit design teams to present the Energy Efficiency measure packages for implementation, they decided to use two hybrid packages instead of a NPV Max and Max CO_2 packages (Fluhrer, Maurer, & Deshmukh 2010). To better serve the objectives of the building owner, these new hybrid packages found the balance between energy efficiency and cost-effectiveness (Fluhrer, Maurer, & Deshmukh 2010). The newly developed packages were called the NPV Neutral package and NPV Mild package (Fluhrer, Maurer, & Deshmukh 2010). Ultimately, Malkin decided to implement the NPV Mild package, the more energy efficient of the two. The NVP Mild package provided a solution to meet higher CO_2 goals set out by the building owner with well-adjusted financial constraints (Fluhrer, Maurer, & Deshmukh 2010).

The design teams of the Empire State Building retrofit project went a step further with an in-depth analysis of tenant spaces (Fluhrer, Maurer, & Deshmukh 2010). Here, the team identified 3 opportunities to reduce energy consumption. First, the development of tenant "green-built" spaces and specifications. In that, these energy efficiency measures involved the reduction in electric lighting density, the installation of dimmable ballasts coupled with photosensors, as well as individual plug load meters for individual tenant spaces (for workers to keep track of their own energy consumption) (Fluhrer, Maurer, & Deshmukh 2010). Secondly, tenant "green-space" guidelines were developed. If a tenant wished to hire separate contractors/engineers to remodel their space, the hired design team would be required to comply with these guidelines. Thirdly, energy management control hardware and software was installed to provide tenants with real time, sub-metered energy use data, so that they can track their energy use and adjust behavior accordingly (Fluhrer, Maurer, & Deshmukh 2010). The resulting benefits of these measures included reduced cooling demand (from the reduced internal heat gain caused by electric lighting), reduced energy costs, and improved visual quality (from improved lighting controls allowing daylight to be utilized) (Harrington & Carmichael 2009). Overall, the cost of the tenant space retrofit measure added an additional cost of $6 per square foot to the retrofit project, and it is expected to save $0.70-$0.90 per square foot in energy costs annually (Harrington & Carmichael 2009). Even though this retrofit measure would take anywhere between 6.5 years to 8.5 years for a simple payback, there are valuable non-energy cost related advantages (Harrington & Carmichael 2009). The "green-built" design not only allows for improved energy efficiency, it adds greater occupant comfort levels, which in turn, is likely to reduce tenant turnover, reduce vacancy, and elevate rental premiums (Harrington & Carmichael 2009).

One of the more arduous, yet effective Energy Efficiency measures implemented on the empire state building was the whole-building window remanufacturing. In all, approximately 6,500 widows were removed and remanufactured on-site into "superwindows" (Harrington & Carmichael 2009). Each window was taken apart, then an isolative film coating was applied, as well as a gas infill to increase the insulation properties by more than 3 fold (Fluhrer, Maurer, & Deshmukh 2010). Moreover, the remanufacturing of the windows reduced the Solar Heat Gain Coefficient considerably (Harrington & Carmichael 2009). The total capital cost of the windows reconstruction was $4.1 million, while the annual energy savings alone is expected to be $410,000. The simple payback of this measure by itself is approximately 10 years, however, other benefits were achieved through increased occupant comfort (warmer in the winter, cooler in the summer), as well as decreased heat loss and HVAC loads (Harrington & Carmichael 2009). Moreover, the northern façade of the building now receives more daylight, while the southern façade rejects more solar heat gain (Harrington & Carmichael 2009).

The total cost of the energy related retrofit projects of the 2.7 million sf Empire State Building was approximately $106 million (Harrington & Carmichael 2009). Before the a Deep Energy Retrofit was even considered, Anthony Malkin and building management Jones Lang LaSalle had allocated $93 million in capital for standard energy retrofit projects, which, could have saved between 10-20% energy consumption. By using the Integrative Design Process, Johnson Controls inc, the Clinton climate initiative, and the Rocky Mountain Institute were able to reduce the Empire State Building's energy use by 38%, adding only $13.2 million to the total capital expenditures (Fluhrer, Maurer, & Deshmukh 2010). The Empire State Building was given an EPA Energy Star Rating of 90/100, making the pre-WWII historical building in the top 10% of all buildings with regard to energy efficiency (Harrington & Carmichael 2009). This is a prime example of how to piggyback Deep Energy Retrofit measures with preplanned expenses. This increase in capital expenditures for the Deep Energy Retrofit was repaid in only 3.3 years, but that is only taking into account simple payback (Harrington & Carmichael 2009). Other non-energy related cost savings and added value could be taken into account: Increased comfort of the tenant spaces will lower tenant turnover rates in the building (average turnover rate of 40% by 2015) (Harrington & Carmichael 2009); improvement in indoor air quality enhances occupant health, thus reducing sick days (Bendewald et al 2012); Improved lighting and daylighting for enhanced occupant comfort; and the improved reputation of the Empire State Building as a top notch, world class building (Harrington & Carmichael 2009). Once again, this icon of New York City has pushed the boundaries of what was thought to be possible.

4.2 The Joseph Vance Building

The Joseph Vance Building, a 134,000 square foot office building was built in 1929 in Seattle WA. One of the goals of the design team was to seek out energy efficiency measures that were cost-effective and that brought the building up to ASHRAE 62.1-2004 standards (NBI, 2011). Under this, one of the requirements was the fresh air ventilation needed an upgrade. Furthermore, the building was to be occupied during the entire retrofit process, adding complexities to the retrofit project (NBI, 2011).

For a historical building, the Joseph Vance Building achieved extremely high energy savings of 24% to bring the Energy Use Intensity from 51 kBTU/sf/yr to only 39 kBTU/sf/yr (NBI, 2011). This allows the Vance Building to operate with 58% less energy per square foot than the average US commercial office building and now saves $65,000 annually in operational costs (NBI, 2011). Furthermore, the energy star rating of the Vance Building was brought up to 98/100. The cost breakdown for the energy retrofit project came to $6.1 million, which is approximately $43/sf (NBI, 2011). Because of the building owner's desire to achieve LEED-EB certification, as well as the ASHRAE standards for air ventilation, the cost for energy efficiency proved marginal (NBI, 2011). After the Deep Energy Retrofit, occupancy went from 68% to more than 96%, greatly improving the revenue of the building.

4.3 The Aventine Building

The Aventine is a 253,000 square foot office building located in La Jolla CA. The Aventine was designed by the world famous Architect Michael Graves (one of the "New York Five") in 1990, however, in 2006 when the building was only 16 years old, occupancy in the Aventine had plummeted due to a high rate in early lease terminations (NBI). Building owners wanted to revitalize the Aventine to improve its reputation and improve revenue. Because there were occupants still in the building, the design team was faced with the challenge of minimizing tenant disturbance, as to not lower building occupancy any further. Moreover, there were multiple planned expenses for energy efficiency upgrades including the installation of building control systems, converting the cooling tower from potable to reclaimed water, and improvement of daylighting (NBI). Most of the construction for energy efficiency measures was conducted at night and on weekends. Moreover, the design team and building management engaged the building occupants to encourage support and to communicate the benefits of the retrofit project (NBI).

During the first stages of analysis, it became evident that the HVAC system accounted for 50% of the building loads. A Life Cycle Cost Analysis revealed that by upgrading to a variable speed, automated chiller plant, the existing chiller centrifuges could be kept (NBI). This retrofit measure would allow for the lowest incremental costs possible. However, due to the minimal payback period for this retrofit measure, the centrifugal chillers were also renovated to all variable air speed systems, providing the deeper energy savings (NBI).

By the time the Aventine's Deep Energy Retrofit was completed in 2010, the energy use intensity of the building had been reduced from 62 kBTU/sf/yr to only 23 kBTU/sf/yr (NBI). Moreover, this retrofit project only cost $801,540 in additional capital expenses after the preplanned expenses (NBI). The cost of the Deep Energy Retrofit came in at $3.20/sf (before incentives)(NBI). Furthermore, $170,000 in utility incentives was awarded to the Aventine after the retrofit completion, lowering capital investment even further (NBI). In the first year after project completion, 2 million kWh of electricity were saved, $116,000 in operational costs were saved, and 600,000 tons of CO_2(eq) were averted (NBI). The Aventine received an energy star rating of 100/100, which means this is among the top 1% in energy efficient buildings in the US (NBI). Building owners have claimed that the Aventine's Deep Energy Retrofit exceeded expectations by improving not only energy efficiency, but also tenant productiveness with improved indoor air quality and a greater level of comfort (NBI).

4.4 The Christman Building

Built in 1928, the Christman building is a registered historical landmark located in Lansing, MI. This building is owned and operated by the Christman Co., a construction and real estate management firm specializing in sustainable construction, historic preservation of buildings, and integrated project planning. This made the retrofit of their own building a unique opportunity to implement the Integrative Design Process from both a designers perspective and an owners perspective (NBI, 2011) The Christman Co. developed the retrofit project to represent the ingenuity of their company, build team collaboration, to plan design guidelines for other projects, and to create an overall improved environment with optimized comfort and environmental due diligence (NBI, 2011). Moreover, the Christman Co. wanted to prove that the Integrative Design Process could accomplish all the proposed goals while staying within a tight budget. One of the great challenges of the Christman building retrofit was achieving cost-effective deep energy savings on this historical landmark (subject to strict regulations under the historical landmark registry) located in a region faced with extreme climate conditions like Michigan. An extensive Life Cycle Cost Analysis was performed, focusing mainly on the HVAC system and ensuring that the capital costs of the retrofit would not expand beyond the proposed budget (NBI, 2011).

The Christman Co. did not reach their goals after the first retrofit project was completed, so the design teams decided on performing a whole-building re-commissioning project. After the initial retrofit project was completed, the EUI for the Chrisman building was 118 kBTU/sf/yr, roughly the same as when they started and considerably higher than the national average of 93 kBTU/sf/yr (NBI, 2011). After re-commissioning the building, the EUI was brought down to 66 kBTU/sf/yr, a 44% reduction from the first retrofit design and 23% lower than the national average (NBI, 2011). This reduction serves as a testament to the effectiveness of commissioning included into a Deep Energy Retrofit. What's more impressive, the Christman Building received the first ever Triple LEED platinum certifications in the Existing Buildings, Commercial Interior, and Core & Shell categories because of the innovations in energy efficiency, indoor air quality, and occupant comfort (NBI, 2011). This is a prime example of how a Deep Energy Retrofit can be used to pursue value beyond energy cost savings. That total project after significant tax incentives cost $8.9 million ($138/sf), however, the majority of the capital costs went to non-energy related improvements (NBI, 2011). The cost for the implementation of the energy related upgrades was only $22,690 with estimated annual energy savings of $45,659 (NBI, 2011).

4.5 The 1525 Wilson Blvd. Building

The 1525 Wilson Blvd. Building is a 12 story, 313,337 square foot office building in Rosslyn VA. 1525 Wilson is an all-electric building, which means that all the building's mechanical equipment, including the HVAC system, runs solely on electricity (NBI). This made the buildings electricity consumption extremely high compared to other office buildings of similar size and shape. At the time the retrofit project had been proposed, 1525 Wilson was 100% occupied making occupant disruption a major concern for the building's stakeholders and tenants (NBI). The principle ESCO, Glenborough, sought to drastically increase the energy efficiency of the building by focusing on five categories: energy efficiency, water conservation, waste management, tenant education, and operational excellence (NBI). Right away, design teams reached out to tenants to inform them of the benefits of a Deep Energy Retrofit, and encouraged involvement and feedback. This played a crucial roll in the success of this retrofits project (NBI, 2011).

Before the Deep Energy Retrofit project of 1525 Wilson took place, this all-electric building had an Energy Use Intensity of 98 kBTU/sf/yr (NBI). After Glenborough's Deep Energy Retrofit, the EUI was reduced to 64 kBTU/sf/yr, a 35% improvement before the retrofit, and 31% better than the national average. Tenant involvement was key to achieving this energy use reduction, as tenant space plug loads accounted for 7.5-15% of the total electric load of the building (NBI). According to Energy Star, an average comparable building to 1525 Wilson consumes 113 kBTU/sf/yr, making this building highly efficient considering it's size, shape, climate conditions, and age (NBI). Energy improvement capital expenses were kept extremely low at only $3.50/sf with a total cost of $1.1 million, providing a low simple payback period of only 2 years (NBI). The Energy Star Rating for 1525 Wilson jumped from 63/100 to 97/100. Moreover, tenants were highly satisfied with the improved indoor air quality and improved HVAC system, which will ensure the high occupancy of this building will remain high (NBI, 2011).

4.6 The Byron G. Rodgers Federal Office Building

The 500,000 square foot Byron G. Rodgers Federal Office Building, located in downtown Denver CO, was selected for a Deep Energy Retrofit under the American Reinvestment and Recovery Act (ARRA) of 2009 (Tupper et. al. 2012). Under this act, the General Services Administration (GSA) was given $129 million to transform the Byron Rodgers Building into a highly efficient green building; and to serve as a paradigm of what is possible for federal office building retrofits throughout the US

(Miller 2009). The Rocky Mountain Institute was brought on to provide guidance for the Integrative Design Process to meet the aggressive goals set out by the GSA.

Before the retrofit in 2009, the Byron G. Rodgers building had a EUI of 91.8 kBTU/sf/year, close to the national average of 93kBTU/sf/year (Tupper et. al. 2012). Built in the 1960's, this federal office building was soon to be subject to historical preservation requirements, which, like the Vance and Christman buildings, limits the retrofit design measures that affect the appearance of the building (Tupper et. al. 2012). Making matters more difficult for the retrofit design team, the southwest orientation of the Byron Rodgers Building allowed little solar exposure, limiting the usable space for renewables like Photovoltaic Solar Panels and Solar Thermal Panels (Tupper et. al. 2012). This made the use of renewable sources of energy negligible to reach the requirements set by the ARRA. To reduce the overall carbon footprint to comply with the ARRA requirements, design teams needed to capitalize on passive retrofit measures rather than renewable energy alternatives. To do so in a cost effective manner, the Integrative Design Process was used to identify these passive design strategies. A Goal Setting Charrette was held focusing only on the technical potential of the retrofit project (Tupper et. al. 2012). In that, retrofit measure ideas were brainstormed with less consideration of cost, construction, and project schedule constraints (Tupper et. al. 2012). This allowed more creative *whole systems thinking*, and to scrutinize the technical feasibility of retrofit measures. By reintroducing cost, construction, and schedule constraints after this Goal Setting Charrette, design teams were able to consider a broader range of cost-effective retrofit measures for an aggressive Deep Energy Retrofit. End user demands (such as lighting and heat load demands) were defined before the equipment and capacity requirements were identified to meet those demands. This allowed all passive retrofit strategies to be identified to meet end-user requirements before identifying the demand for energy consuming equipment (Tupper et. al. 2012).

An example of passive end-user solutions to cost-effectively reduce energy consumption was the development of lighting retrofit strategies to optimize daylight and reduce over-lit spaces. In that, design teams were able to reduce the cooling demand of the Byron Rodgers Building, as well as the energy demand for lighting (Tupper et. al. 2012). The windows were upgraded to provide enhanced illumination from daylighting with reduced heat loss and increased solar heat gain, effectively reducing heating demand in the cooler months (Tupper et. al. 2012). Finally, insulation was installed in the walls, roof, and floor to reduce heating and cooling loads. The combination of these passive strategies allowed the retrofit teams to design an appropriate HVAC system with far less energy demands to provide the required interior comfort level (Tupper et. al. 2012). Because HVAC systems are often the most expensive system in a building, these strategies greatly reduced the cost of the retrofit while providing value beyond cost savings through improved occupant comfort (Tupper et. al. 2012).

The projected result of the Byron Rodgers Retrofit was a reduction in energy consumption by 60-70%, while the EUI after the retrofit is expected to be between 28-38 kBTU/sf/year (Tupper et. al. 2012). This pushes the boundaries of what was thought technologically possible in such a large building that is located in an area where extreme winter temperatures can reach -3°F. Moreover, the projected Net Present Value of the energy cost savings was calculated to be $556,700 over a 20-year period (Miller, 2009). The incremental cost of the Byron Rodgers project is approximately $258/sf, a seemingly high cost for a retrofit. However, not all of the capital cost went to energy efficiency measures, the majority of the costs went to the modernization (repositioning) of the building, asbestos and PCB abatement, as well as non-energy related tenant space improvement (Miller 2009). Because the Deep Energy Retrofit of the Byron Rodgers Building was piggybacked along with these renovations, the operational cost savings at little additional costs provided an attractive return on investment, boosting the overall cost-effectiveness of the project (Tupper et. al. 2012).

4.7 Indianapolis City-County Building

The Indianapolis local government set out to address energy efficiency in commercial office buildings. To spark citywide interest and to promote energy retrofits for existing commercial buildings, the Indianapolis Office of Sustainability decided to undertake a Deep Energy Retrofit of the Indianapolis City-County building, a 731,119 square foot government office building constructed in 1962 (Torbert, 2012). At the time before the retrofit, the City-County building had an EUI of 113 kBTU/sf/year and an energy star rating of 52 (Torbert, 2012). This building's energy performance was about 22% higher than the average US commercial office building, making it a prime target for a Deep Energy Retrofit to drastically reduce energy consumption and lower operational costs (Torbert, 2012).

The SustainIndy Program, a division of the Office of Sustainability, with help from the Rocky Mountain Institute set out aggressive energy efficiency goals to reduce energy consumption of the City-Country building by 40%, as well as to produce attractive financial returns to serve as an example for other buildings in Indianapolis (Torbert, 2012). During the Design Charrette, design teams proposed that a Deep Energy Retrofit could save approximately $700,000 in operational costs and reach an Energy Star rating of 95, all while operating with a budget of approximately $10 million ($13/sf) (Torbert, 2012). Furthermore, the design teams identified an innovative energy and cost saving opportunity in the naturally high groundwater table found under the building. The building had already been pumping 225 gallons of water per minute out of the lower parking garage to keep water from intruding (Torbert, 2012). With this in mind, the design team implemented a heat exchange and cooling system that utilized water from the high water table (Torbert, 2012). This energy efficiency measure now serves two purposes, to reduce heating and cooling loads in the building while eliminating a liability to the building (Torbert, 2012). Another liability had to be addressed in the retrofit design was the asbestos used in the original construction of the building. Energy efficiency retrofit measures were implemented in conjunction with the asbestos abatement (Torbert, 2012). Because the building was at full capacity (with over 2000 occupants), the timing of the occupant space renovations, as well as the cooperation of the occupants themselves was key to minimizing the cost of the project (Torbert, 2012). A retrofit project of this scale typically requires a building to empty out for a year or more, however, through scheduling and occupant cooperation, the retrofit project allowed the building to continue operations (Torbert, 2012).

In total, 8 energy efficiency measures were implemented and the Indianapolis City-County Building saw energy consumption reduced by 46%, while only spending $8.19 million in capital costs ($11.17/sf) (Torbert, 2012). This was about $1.8 million under the proposed budget while producing 6% more energy reductions than expected. The annual energy cost savings was calculated to be $776,674 for a 10.5-year simple payback period, 4.5 years less than the 15-year payback goal (Torbert, 2012). If other benefits to the Deep Energy Retrofit had been taken into account, such as maintenance cost savings or avoided cost savings, the financial metrics of this project would show even better cost results (Torbert, 2012). Furthermore, the occupants of the Indianapolis City-County building could benefit from increased indoor air quality and a more comfortable working environment. The SustainIndy program could also use this Deep Energy Retrofit case to estimate energy and cost savings potential for other local government office buildings in the county's portfolio (Torbert, 2012).

4.8 The Beardmore Building

The Beardmore Building is a 28,800 square foot mixed-use commercial office building in Priest River, ID. Originally built in 1922, this building is registered under the National Register of Historic Places (Better Bricks). For years, the Beardmore has been neglected by building owners, and was in poor condition when it changed ownership in 2006 (Better Bricks). The new owner (and great grandson to the original owner Charles Beardmore) set out to improve the overall condition of the building, improve energy efficiency, while still keeping the historical building status (Better Bricks). An intensive cost-benefit analysis was performed to define the financial constraints and most cost-effective design strategies for a Deep Energy Retrofit, as well as the pursuit of a LEED certification (Better Bricks).

In all, the retrofit design teams identified, and ultimately implemented 8 energy efficiency measures (Better Bricks). Energy consumption data was not released, however, due to the poor condition and age of the building, it is safe to say that the EUI was close to, or higher than the national average for office buildings (93 kBTU/sf/year) (Better Bricks). The cost of the Deep Energy Retrofit of the Beardmore Building came to $2.6 million or $105/sf, while the resulting EUI was only 32 kBTU/sf/year (Better Bricks). The 92-year-old Beardmore now has an Energy Use Intensity 66% better than that of the average US office building (Better Bricks). The annual operational cost savings came to $23,370, which provides a 111-year payback period. While the return on investment through operational cost savings seems to be minor, the owner had other objectives for the retrofit project like improved reputation, historical preservation, and increased lease rates (Better Bricks). The Beardmore building is one of the small number of buildings that is both LEED-NC Gold certified and registered under the National Register of Historic Places (Better Bricks). This allowed for tax incentives from the National Parks Service of $336,571, as well as $71,000 from the local utility company. After the Deep Energy Retrofit was completed, the Beardmore saw an increase in rental premiums, which are about 35% higher than other office buildings in the immediate area (Better Bricks). Moreover, occupancy of the Beardmore was expected to be at full capacity shortly after the renovations were complete, fulfilling one of the goals of the owner.

5. Case Studies Summary

Table 1 (below) clearly shows how the total capital cost, cost per square foot, annual energy savings, and payback period of a Deep Energy Retrofits can vary between each case study. Because not all of the case studies revealed the same level of financial detail, analyzing the cost of the case studies can only be accomplished by splitting them up into two categories: Case studies that disclosed the cost of the entire retrofit project and case studies that only disclosed energy efficiency upgrade costs. The Empire State Building and the Christman building disclosed both, and therefore can fit into both categories.

The high cost of the retrofit case studies that combined energy efficiency measures and other retrofit measures into one lump sum had an average payback period of 106 years. That means in most cases, energy savings from the Deep Energy Retrofit would not pay back the cost for the modernization or non-energy related retrofit measures within a reasonable amount of time. However one case study, the Indianapolis City-County Building, was able to implement modernization and non-energy retrofit upgrades and produced enough annual energy savings to recoup the entire cost of the project in only 10.5 years (Torbert, 2012). While the cost per square foot of the Indianapolis City-County case is lower than other case studies, it still proves that a Deep Energy Retrofit can be used to recoup capital expenses for a whole-building renovation with energy savings in a short time period.

	Building	Total Capital Costs of the Retrofit Project	Annual Utility Cost Savings	Payback Period
EEM Costs Only	The Aventine (1990)	*$801,500 ($3.20/sf)	$116,000	*4-6 years
	1525 Wilson (1987)	*$1,100,000 ($3.50/sf)	$283,000	*< 2 years
Total Project Costs + EEM Costs	Empire State Building (1931)	$550,000,000 ($204/sf) *$106,000,000 ($39.25/sf) for all energy efficiency upgrades **$13,200,000 ($4.89/sf) additional capital for the Deep Energy Retrofit	$4,400,000	125 years for total retrofit costs *24 years for the total cost of the planned energy efficiency upgrades **3 years for additional Deep Energy Retrofit capital costs
	The Christman (1928)	$8,913,200 ($138/sf) *$22,690 ($0.35/sf) for the cost of the energy efficiency upgrades	$46,000	193 years for the total retrofit costs *6 months for energy efficiency measures
Total Project Costs Only	Joseph Vance Building (1929)	$6,100,000 ($43/sf)	***$65,000	***93 years
	Byron G. Rodgers Federal Office Building (1965)	$129,000,000 ($258/sf)	***$1,270,000	***101 years
	Beardmore Building (1922)	$2,600,000 ($105/sf)	$23,400	111 Years
	Indianapolis City-County Building (1962)	$8,900,000 ($11.17/sf)	$776,674	10.5 Years

Table 1: Shows the total capital cost, the annual energy savings, and simple payback period of each case study. Green rows contain data from case studies that included energy efficiency upgrade costs only. Purple rows contain data from case studies that disclosed both the total cost of the retrofit and energy upgrade costs. Red rows contain data from case studies that only disclosed the total cost of the retrofit project.
*Total capital cost and payback period for the energy efficiency upgrades
**Additional capital cost and payback period for just the Deep Energy Retrofit
*** Annual Energy Savings based off of $0.04/kBTU-yr

Even though the Indianapolis City-County Building provided evidence that a Deep Energy Retrofit can be cost effective while coupling energy retrofit measures with non-energy measures, it is not clear exactly how much was spent on energy compared to other non-energy upgrades. The Empire State Building and the Christman Building provide financial data that shed light on the improved value that Deep Energy Retrofits can provide to a project with non-energy related measures. The total cost of the Chrisman Building Retrofit came to $8.9 million, however, the cost of the energy efficiency upgrades was only $22,700; about 0.25% the cost of the entire retrofit project. The high cost of the overall project could be attributed to the large capital costs required for the non-energy retrofit measures to obtain a triple LEED-Platinum certification (NBI, 2011), as well as the modernization of the building. Because this Deep Energy Retrofit resulted in an annual energy savings of $46,000 per year, the energy efficiency upgrades were paid back in only 6 months (NBI, 2011). The Christman Building was able to achieve the most cost-effective energy retrofit out of all the case studies based purely on capital costs and energy savings achieved. Even though this Deep Energy Retrofit was not a viable option to provide a return for the entire project within a practical time period (193 years), it provided an attractive return for the energy-related expenses.

The Empire State Building went a step further and disclosed the additional cost for the Deep Energy Retrofit of $13.2 million, the total cost of the energy upgrades of $106 million, as well as the overall cost of the retrofit project, totaling $550 million (Harrington & Carmichael, 2009). The total cost of all energy efficiency upgrades was 19% of the cost of the entire retrofit. Furthermore, the cost of the additional capital required for the Deep Energy Retrofit only accounted for 12.4% of the total cost of the energy efficiency measures and 2.4% of the cost of the entire project. Given the tremendous annual operational cost savings of $4.4 million (Harrington & Carmichael, 2009), the additional cost of the Deep Energy Retrofit was paid back in only 3 years. Moreover, all energy-related renovations will be paid back in approximately 24 years. Because the owner of the Empire State Building already planned many of these energy efficiency upgrades, more likely than not, this project would have ended up costing the owner more capital in the long run if a Deep Energy Retrofit had not been used. This is because a standard retrofit would not have been able to provide an energy reduction of 38%.

The Aventine Building and the 1525 Wilson Building only disclosed capital expenditures for the energy efficiency upgrades. Because these are the newest buildings from all the case studies, we can assume that the cost of the energy efficiency upgrades might have been accounted for the majority, if not all of the capital spent on the retrofit project. Both the Aventine and 1525 Wilson were able to attain a Deep Energy Retrofit for under $4 per square foot for annual operational cost savings of $116,000 and $283,000 respectively. Even though the Aventine and 1525 Wilson case might not have achieved the most cost-effective energy retrofit, they might have been the most successful. This is based on the extremely large amount of capital costs for just the energy retrofit measures and the short payback period of 4-6 years (Aventine) and less than 2 years (1525 Wilson). The Christman Building did achieve the lowest payback period (6 months) for the energy-related retrofit measures; however, only $26,700 was spent on these upgrades. The Aventine and 1525 Wilson Buildings spent a considerable amount more and still achieved relatively short payback periods.

Before exploring the cost-effectiveness of the case studies further, Table 2 (below) provides an easy comparison of the result for each Deep Energy Retrofit using the Energy Use Intensity before and after the retrofit, as well as the resulting energy reduction percentage and the percent below the baseline average (93 kBTU/sf/year). By looking solely at the energy reduction data, The Aventine and the Byron G. Rodgers Building achieved the greatest level of success by reducing energy consumption by 60% or more. While the Byron G. Rodgers energy reduction has yet to be calculated based on actual utility data, for the purposes of this paper, it can be assumed that the projected percent energy reduction range is accurate. Furthermore, the Aventine achieved the lowest EUI of any case study with only 23 kBTU/sf/year.

Building	Pre-Retrofit EUI (KBTU/sf/year)	Post-Retrofit EUI (KBTU/sf/year)	Percent Energy Reduction	Percent Below Baseline Average for US Office Buildings (93 kBTU/sf/year)
The Aventine	62	23	63%	75%
1525 Wilson	98	64	35%	30%
Empire State Building	88	60	38%	35%
The Christman	118	66	44%	29%
Joseph Vance Building	51	39	24%	58%
Byron G. Rodgers Federal Office Building	91	28-38*	60-70%*	60-70%*
Beardmore Building	n/a	32	n/a	66%
Indianapolis City-County Building	113	59	46%	37%

Table 2: Shows the Energy Use Intensity before and after each retrofit, percent energy reduction, and percent below baseline average. *Based in projected energy reduction data

The resulting EUI of the Deep Energy Retrofit case studies can be used to benchmark these buildings to a baseline Energy Use Intensity. For this paper, benchmarking will be done using the baseline average for US office buildings, 93 kBTU/sf/year. Figure 1 (below) shows the pre-retrofit EUI and the post-retrofit EUI for each study. The red dotted line indicates the EUI baseline average for US office buildings. Before the Deep Energy Retrofit, the Indianapolis City-County Building, the Christman Building, and the 1525 Wilson Building had a higher EUI than the national average for office buildings. Even though the Beardmore Building did not disclose energy consumption data before the retrofit, there is a high likelihood that the EUI for this building was above the national average based on the age (built in 1922) and the extremely poor condition of the building before the retrofit. The percentage below the US office building baseline for each case study can be seen in Table 2, where the Aventine, the Byron G. Rodgers, and the Beardmore Building have the lowest EUI percentage below the national average with 75%, 60-70%, and 66% respectively.

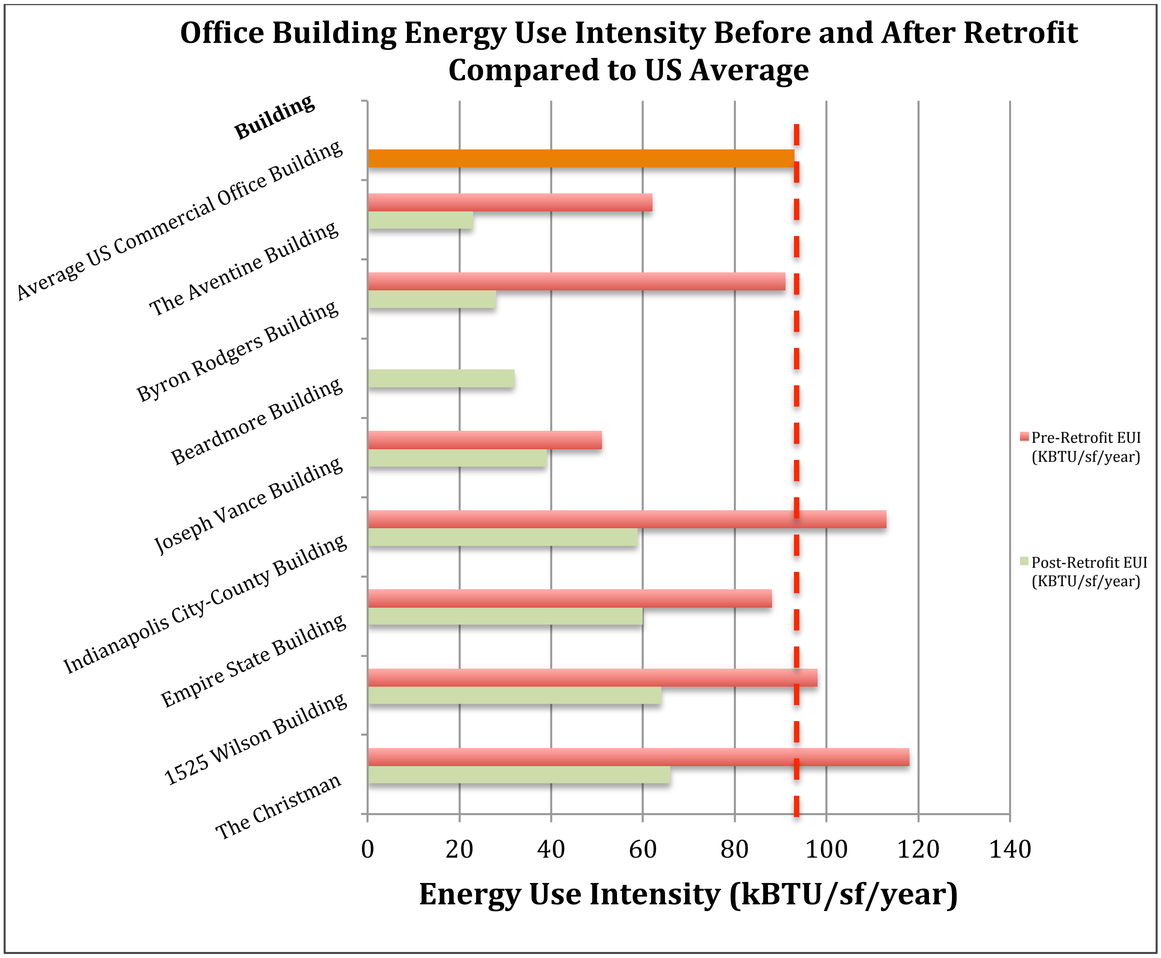

Figure 1: Shows the pre-retrofit and post-retrofit Energy Use Intensity compared to the national average. Red dotted line indicates the baseline average of 93 kBTU/sf/year.

To explore the cost-effectiveness of the retrofits examined in the case studies, it is important to know how much capital was spent reducing a single unit of energy. Table 3 (below) shows the capital cost spent to reduce the building's energy consumption by 1000 BTUs annually (kBTU/yr). As expected, out of the case studies that disclosed energy-related expenses (highlighted in green), the Christman Building achieved the lowest cost to reduce every kBTU/yr at only $0.01. Even though the Empire State building had a higher cost of $1.40 per kBTU saved annually, the Empire State Building dwarfed all other buildings that disclosed energy upgrade costs. This may show that bigger buildings require more capital to reduce every unit of energy annually, which will be explored later in this section.

Building	Cost for every kBTU reduced annually ($/kBTU-yr)
The Aventine	$0.08
1525 Wilson	$0.10
Empire State Building	$1.40
The Christman	$0.01
Joseph Vance Building	$3.58
Byron G. Rodgers Federal Office Building	$4.10
Beardmore Building	n/a
Indianapolis City-County Building	$0.21

Table 3: Shows the cost for every 1000 BTUs saved annually for each case study. Highlighted in green is calculated from energy related costs only. Highlighted in red is calculated from total project costs.

For the case studies that disclosed the total cost of the Deep Energy Retrofit projects coupled with other non-energy related expenditures, the Indianapolis City-County Building achieved the most cost-effective energy reduction of just $0.21 per kBTU saved annually. This may be because more energy efficiency measures were implemented, providing more energy cost savings, and more energy savings for each dollar spent on the project. The Joseph Vance Building and the Byron G. Rodgers Building had the highest cost per kBTU saved annually. Both buildings undertook major non-energy related renovations, lowering the overall return on investment from energy savings. This must be especially true for the Byron G. Rodgers case, where energy reductions are projected to be as high as 70% with annual operational cost savings over $1.2 million.

To examine the cost-effectiveness of the Deep Energy Retrofit case studies even further, reports and how-to guides provide useful information to help explain the results. Table 4 shows the average incremental cost and subsequent EUI reduction for five of the most common energy efficiency strategies used (in conjunction with other measures) in Deep Energy Retrofits: Plug load, Lighting, Ventilation, Cooling, and Heating (Kok, Miller, and Morris 2011). Moreover, this table provides a cost comparison and EUI savings comparison between an average US office building and an average large commercial building that is approximately

500,000 square feet in size (Bendewald et. al. 2012). All of these metrics were derived from the same study conducted by Davis Langdon Global Construction Managers, where multiple buildings from five US cities (Houston, San Francisco, New York, Chicago, and Anchorage) were analyzed before and after retrofit projects (Kok, Miller, and Morris 2011).

Energy Efficiency Retrofit Measure	Capital Costs per Square Foot for Average Commercial Building [1]	EUI reduction (KBTU/sf/year) for Average Commercial Building [1]	Capital Costs per Sqaure Foot for Average 500,000 sf office building [2]	EUI Reduction (KBTU/sf/year) for Average 500,000 sf office building [2]
Plug Load	Negligible	6 - 15	Negligible	6 - 15
Lighting	\$3 - \$5	6 - 8	\$3 - \$5	6 - 8
Ventilation	\$2 - \$5	4 - 5	\$2 - \$5	4 - 5
Cooling	\$3 - \$7	10 - 15	\$10 - \$75	10 - 25
Heating	\$1 - \$2	3 - 10	\$10 - \$75	3 - 10
Total	\$10 - \$75	30 - 50	\$25 - \$150+	30 - 50

Table 4: Costs and EUI Reductions for Individual Energy Efficeincy Retrofit Measures for the Average Office Builing and the Average 500,000 sf office Building [1] Kok, Miller, and Morris [2] Bendewald et al 2012

Table 4 clearly shows the difference in cost between an average sized office building and the average 500,000 square foot office building. Interestingly, this table shows that a large office building has a higher potential, on average, to save energy through a cooling system retrofit (Bendewald et. al. 2012). The total cost of the 500,000 square foot large office building can be anywhere from \$25 and \$150 per square foot or more, far higher than the average office building that should cost somewhere between \$10 and \$75 per square foot. This explains why the cost per square foot for the larger commercial office buildings is proportionally higher than smaller office buildings, as was the case for the Empire State Building and the Byron G. Rodgers building. However, the other large office building examined, the Indianapolis City-County Building, actually achieved a less expensive retrofit (\$11.17/sf) than what is shown in Table 4, indicating that it is technologically possible to achieve an extremely cost-efficient Deep Energy Retrofit in a large office building.

The case studies presented in this paper explore how Deep Energy Retrofits can be both cost-effective and cost-intensive. For the Empire State Building, the Christman Building, the Vance Building, the Byron Rodgers Building, and the Beardmore Building, the cost of the non-energy related retrofit measures exponentially drove up the cost of the overall project. In these cases, relying on energy savings alone is not a viable option to provide a return on investment for all retrofit measures within a reasonable amount of time. Although, the Empire State Building and the Christman Building showed evidence of how the energy efficiency measures alone can provide short payback periods, and an overall better return on investment for the entire retrofit project. Moreover, in the case of the Aventine Building, the 1525 Wilson Building, and the Indianapolis City-County Building, the energy savings resulting from the entire project showed evidence that Deep Energy Retrofit measures can provided an attractive payback period and return on investment for the entire project.

6. Discussion of the Benefits of Deep Energy Retrofits

Some of the benefits of Deep Energy Retrofits are not as clear as others, however, that doesn't mean they are less advantageous. The most obvious benefit of a Deep Energy Retrofit is the operational cost savings that can be achieved. In addition, the avoidance of capital costs resulting from Deep Energy Retrofits can often be easily quantified, however, the value of Deep Energy Retrofits beyond cost savings is much harder to define. This section will explore the benefits of Deep Energy Retrofits using research papers and guides. Moreover, additional benefits received from the buildings in the case studies will provide useful examples of these benefits when applied in the real world.

6.1 Operational Cost Savings

As stated previously, the goal of a Deep Energy Retrofit is to reduce operational costs by 30%-50%+ (Bendewald et al 2012). Using the potential for energy cost savings is the most commonly used method to spur interest in Deep Energy Retrofits from building owners because it provides an easy way to prove cost-effectiveness through return on investment and net present value metrics (Buys, Bendewald, & Tupper 2011). This is especially true when a building has particularly high energy bills, or when it is located in an area with higher energy costs and/or carbon regulations. According to Bendewald et. al. (2012), most commercial office buildings require $2-$3/sf/year in utility costs to maintain operations. However, large commercial buildings account for the greatest energy use intensity of any building, and can reach costs far greater (Shapiro 2009).

The Rocky Mountain Institute provides an order of magnitude estimate based on the US EPA's Energy Star Rating to predict operational cost savings from a Deep Energy Retrofit. If the Energy Star rating of a building is greater than 75/100 you can estimate operational cost savings of 25%. This estimate can be considered conservative, as there are some cases that exceed this estimate. For example, in 2007 the Aventine Building obtained an Energy Star rating of 85/100 (NBI). After the retrofit project was completed, the Aventine reduced operational costs by 63%, consequently scoring an Energy Star rating of 100/100 (NBI). If the energy star rating ranges from 50-75, you can estimate 35% energy cost reductions. This was the case for the 1525 Wilson Blvd. Building, which had a pre-retrofit Energy Star Rating of 63/100, and ultimately reduced operational costs by 35% post-retrofit (NBI, 2011). Lastly, if the building has an Energy Star rating of 50 and below (the lower 50% energy efficient buildings in the country) you can estimate that a building can reduce energy costs by 50% or more from a Deep Energy Retrofit.

6.2 Avoided Capital Costs

In a Deep Energy Retrofit, there is cost savings that can be achieved from avoiding expenses that otherwise would be mandatory for a building to maintain functionality or to comply with government mandates (Bendewald et al 2012). Often, a building's system or equipment can be downsized once passive energy efficiency strategies are implemented, consequently avoiding the higher cost for the replacement with the same or greater capacity. This was the case with the Empire State Building retrofit, where renovations on the windows and cooling load systems allowed for a renovation of the old chiller plant, rather than a replacement (Harrington & Carmichael 2009). This saved the building owner $17 million in capital costs for the replacement, not to mention the cost of having to shut down 5th avenue to bring in the new massive chiller plant replacement (Harrington & Carmichael 2009).

Another way Deep Energy Retrofits can avoid capital costs is through lowering the maintenance cost for existing mechanical equipment. By thinking of a building as one system, there are multiple pathways to reduce the stress of individual mechanical systems by reducing their demand (Lovins, 2010). If the mechanical systems no longer have to work as hard, often they will require less maintenance. The 1525 Wilson Building was able to reduce annual maintenance costs by $75,000+ after the retrofit project by improving lighting fixtures, providing more daylighting to reduce electric lighting demand, improving the HVAC control systems, as well as retro-commissioning the building (NBI, 2011).

6.3 Value Beyond Operational Cost Savings

There are multiple factors that can provide added benefit from Deep Energy Retrofits that go beyond operational and avoided cost savings. By using a Deep Energy Retrofit to make a building more "green", there are opportunities to substantially promote the reputation and enterprise of the building owners, investors, and/or tenants. This can include improved corporate social responsibility (Nelson and Rakau 2010), as well as international recognition through credentials such as LEED certifications and high Energy Star Portfolio Scores (Kok, Miller, and Morris 2011). Table 5 (below) shows the LEED certifications and Energy Star ratings that each case study achieved after a Deep Energy Retrofit.

Building	LEED Certifications	Energy Star Rating
The Aventine	LEED - EB Platinum	100
1525 Wilson	n/a	97
Empire State Building	LEED EB - Gold	90
The Christman	LEED - EBOM Platinum LEED - C&S Platinum LEED - CI Platinum	81
Joseph Vance Building	LEED - EB Gold	98
Byron G. Rodgers Federal Office Building	TBD	TBD
Beardmore Building	LEED - NC Gold	90
Indianapolis City-County Building	n/a	n/a

Table 5: Shows the LEED certifications and Energy Star Score for each case study examined

Most case studies examined were able to achieve LEED certifications and high Energy Star scores that added to the reputation of the buildings and the building owners investment. The Christman building achieved the recognition of being one of the first triple LEED-platinum buildings in the nation (NBI, 2011). This recognition is one of the highest that can be achieved through the United States Green Building Council. Moreover, the Beardmore Building is one of the only buildings in the nation to achieve both a LEED- NC Gold certification and to be inducted into the National Register of Historic Places (BETTER BRICKS). The owner of the Beardmore Building stated that since the Building achieved these credentials, rental premiums for the Beardmore have risen 35% higher than other buildings in the area (NBI, 2011).

The certifications that the building in the case studies achieved likely increased the revenue of the building owner, as well as increased the property value. This is because in recent years, there has been an increase in companies that view sustainability as a way to differentiate their product/services and increase their reputation to consumers and investors (Nelson and Rakau 2010). In that, there is higher demand for green building space, raising the market value and rental premiums (Nelson and Rakau 2010). This is commonly referred to as *Social Responsibility Investing*, where many companies seek to invest in, or lease real estate that fulfills the *triple bottom line*. This takes into account environmental impact factors, social impact factors, and traditional financial returns (Nelson and Rakau 2010). By pursuing credentials like LEED certifications and/or high Energy Star ratings, building owners can publicize their building's accomplishments from a Deep Energy Retrofit to increase reputation and enhance revenue. According to Kok, Miller, and Morris (2012), office buildings that have LEED certifications or a high Energy Star score have 6% higher rental premiums and 16% higher sale prices (per square foot) than buildings without these credentials. Furthermore, occupancy rates are 3-8% higher in buildings with "green" or energy-efficient certifications (Nelson and Rakau 2010). Deep Energy Retrofits provide a means by which building owners can improve a building's environmental and social reputation, making their building more attractive to investors and tenants; in turn, providing added value to the retrofit project through rental premiums and competitive market positioning (Bendewald et al 2012).

In addition to improving the reputation of a building through certifications and recognition, there is considerable value in Deep Energy Retrofits from the increased health and wellbeing of occupants. Often, a Deep Energy Retrofit will provide improved indoor air quality and thermal comfort, which promotes occupant performance and productivity, as well as reducing sick time taken by workers (Miller, et al. 2009). Every case study examined for this paper describes a healthier more comfortable work environment as a direct result of the Deep Energy Retrofit. Whether or not this was one of the goals set out by the design teams and the building owner, an improved working environment was an additional benefit achieved through each retrofit project.

Energy efficiency measures that provide fresh air ventilation, such as demand control ventilation or natural ventilation, increase the indoor air quality in conjunction with saving energy (Bendewald et al. 2012). Health is invariably linked with worker productivity, making indoor air quality paramount to tenants. One study shows that there is a 20-70% linear relationship between poor indoor air quality and decreasing worker productivity, where the effects of air quality on productivity can be as high as 6-9% (Miller et al. 2009). Realizing the value of increased indoor air quality for occupants can allow building owners to capitalize from higher market demand, while tenants can improve their company's productiveness, a mutually beneficial arrangement for both parties. Deep Energy Retrofits provide a way for a building to improve the indoor environment for building occupants, thus improving the cost-effectiveness and overall value of a retrofit project through increased rental premiums (Miller et al. 2009).

Greater control over thermal comfort is another benefit of a Deep Energy Retrofit that increases tenant productivity (Miller et al. 2009). Passive energy efficient strategies like added insulation, envelope sealing, and white roofs can reduce the amount of heat loss or gain, which allows for the indoor temperature to remain more constant without having to increase heating or cooling load (Bendwald et al, 2012). Often, buildings with low energy performance are drafty in the cooler months or contain hot spots in the warmer months due to air leakage and poorly performing HVAC systems (Adams et al 2012). Deep Energy Retrofits provide an opportunity to control temperatures providing increased thermal comfort and increasing worker productivity (Bendewald et al, 2012). According to Miller et al (2009), a study that examined the affects on temperature and worker productivity showed a performance gradient that increased from 69-72° F, and decreased from 73-75° F, while the optimal temperature was observed to be 71.6° F. Furthermore, at temperatures of 86 degrees F, an 8.9% reduction in performance was observed, concluding that temperature does influence productivity (Miller et al 2009).

It is clear that "healthier" buildings increase productivity, thus increasing the value and cost effectiveness of Deep Energy Retrofits through higher demand on the real estate market. In addition, green buildings can reduce the amount of sick days taken by employees, subsequently increases the overall productivity of businesses that operate in the building (Miller et al 2009). A widely used study released by the Sustainability Building Task Force (a collaboration of over 40 California state agencies) in 2003 examined the economic relationship of 33 green buildings and increased worker productivity (from fewer sick days and increased worker performance). What they found was that the added benefits on worker productivity from better lighting, ventilation, and the overall environment increased the net present value of the commercial office space anywhere from $37-$55 per square foot (Kats et al 2003).

To put the potential value of worker productivity into perspective, the Rocky Mountain Institute provides a breakdown of the average energy, salary, and mortgage/rent expenditures of a typical US company that operates in an office building. Because the average company spends 100 times more on employee salaries than on energy, a 1% increase in employer productivity amounts to the value that an average company spends on energy (Bendewald et al 2012). Moreover, because the average mortgage/rent prices account for about 10% of the total cost of employee salaries, a 5% increase in worker productivity will result in the value of approximately half the cost of the mortgage/rent (Bendewald et al 2012).

There is overwhelming evidence that supports how a healthier environment can have a positive affect on reputation, worker productivity, and commercial real estate value (Kok, Miller, and Morris 2011)(Miller et al 2009)(Kats, 2003). All of these factors have a profound affect on the financial viability of Deep Energy Retrofits. Ultimately, the most important benefit beyond operational cost savings from a financial standpoint is that tenants will pay more rent for a building that provides a healthier and more comfortable work environment (Nelson and Rakau 2010). Moreover, environmental health and comfort offers an excellent way for building owners to increase their property's value, reduce vacancy, and lease quicker, making the overall investment in a Deep Energy Retrofit more cost-effective (Bendewald et al 2012). Building owners are not just paying for renovations that will help them save on their utility bill, they are investing in a better building that can increase revenue and reduce vacancy.

7. Conclusions

By examining the 8 case studies used in this paper, as well as the other reports and guides, there is proficient evidence that Deep Energy Retrofits using the Integrative Design Process can drastically reduce carbon emission for existing office buildings. They certainly provide an effective way to help reach the goals set by the

Architecture 2030 challenge to reduce commercial sector energy consumption by 50% in the next 15 years. Every case study resulted in an Energy Use Intensity far below the national average of 93 kBTU/sf/year; proof of the energy reduction potential of a Deep Energy Retrofits. Even though Deep Energy Retrofits provide an excellent way to reduce our societies contribution to climate change, are they a cost-effective and financially viable option for office buildings in the United States? The answer to this question depends on the objectives and the available resources of a building owner. Deep Energy Retrofits, while cost-effective in many cases, can be financially undesirable for building owners that do not have the required capital, do not require major renovations, and do not need to drastically improve the energy efficiency of the building. In some cases, Retrocommissioning or a standard retrofit could be the most cost-effective option because they require drastically less capital to reach the threshold of cost-effectiveness. However, under the right circumstances, a Deep Energy Retrofit can be the most financially viable solution to improve the entire building as a whole and to achieve value beyond just cost savings, such as improved reputation.

If the financial decision maker wishes to dramatically improve the energy efficiency of the building and reduce operational costs by 30% or more, a Deep Energy Retrofit can be more cost-effective solution than a standard energy retrofit or Retrocommissioning. This is because the Integrative Design Process used in the Deep Energy Retrofit can result in a higher energy savings with lower return rates and shorter payback periods. The Aventine Building and the 1525 Wilson Building provide a superb example of how a Deep Energy Retrofit can be used to drastically reduce the energy consumption of a building and provide relatively marginal payback periods.

Deep Energy Retrofits are particularly cost-effective when a building has large preplanned expenditures for energy or non-energy related renovations. This Empire State Building had allocated $93 million for renovations, which, had a Deep Energy Retrofit not been used, would have resulted in a drastically lower rate of return and a greater payback period (Fluhrer, Maurer, & Deshmukh 2010). The Deep Energy Retrofit only cost an additional $13.2 million, which was paid back in only 3 years through operational savings alone (Fluhrer, Maurer, & Deshmukh 2010).

For a building owner that want to improve the reputation of the building to achieve competitive repositioning in the market, a Deep Energy Retrofit allows for a cost-effective way for the *triple bottom line* to be reached to appeal to the Socially Responsible Investment Market. The Integrative Design Process used in the energy retrofit can provide both the needed renovations to reach the elevated LEED/Energy Star standards and provide a wide range of cost savings, lowering the payback period for the project. The Beardmore Building is an example of how a near-dilapidated building can achieve a LEED Gold credential to gain a competitive position in the real estate market, while achieving an EUI of 66% below the national average (BETTER BRICKS).

Finally, a building that has relatively poor indoor environmental conditions can use a Deep Energy Retrofit to cost-effectively improve these conditions. Because these upgrades can be costly and disruptive to tenants, Deep Energy Retrofits by comparison, can be inexpensive and done with little additional effort. Every building in this case study claimed to have improved indoor working environments as a direct result of the Deep Energy Retrofit. Occupants of these buildings can now benefit from healthier and more comfortable space, while building owners can charge higher rental premiums for these improvements.

To help reach the goals set by the Architecture 2030 Challenge, Deep Energy Retrofits offer a cost-effective way to reduce energy consumption under the right circumstances. Because the stabilization of climate change is one of the greatest challenges we face as a society, Energy Service Companies, Architects, Engineers, as well as all forms of government should facilitate the widespread use of Deep Energy Retrofits using the Integrated Design Process. This will require more advances in retrofit technology, more refined Deep Energy Retrofit Framework, as well as new policies and incentives to help finance these projects.

8. Recommendations

The purpose of the recommendations section in this study is to propose new ways in which the market for commercial building Deep Energy Retrofits can expand throughout the United States. Because Deep Energy Retrofits using the Integrative Design Process has the potential to drastically reduce GHG gas emissions from existing buildings, it is paramount that Deep Energy Retrofit project framework and policies evolve in a way that can unlock enhanced cost-effectiveness potential.

8.1 Framework to Balance Incentives

For the Deep Energy Retrofit market to expand, a framework needs to ensure that both the party that pays for the Deep Energy Retrofit, as well as tenants should receive incentives. Depending on the leasing structure of a particular building, many times the building owner, who responsible for making the investment for a Deep Energy Retrofit, is not the one receiving the economic benefit from the improvements made in tenant spaces (Olgyay & Seruto 2010)(Wagner 2012). This happens when tenants are responsible for paying their own utility bills, thus receiving the operational cost savings from the retrofit that they did not invest in (Wagner 2012). Furthermore, the building owner's economic gain is less obvious through higher rent prices and other benefits beyond energy savings (Wagner 2012). By not addressing this split incentives challenge, building owners may choose to forgo energy efficiency measures that are implemented in tenant spaces (Olgyay & Seruto 2010).

By optimizing the benefits to both the building owner and the tenant, it is possible to overcome this split incentives barrier. Olgyay and Seruto (2010) suggest that in order to ensure all parties are properly incentivized, an in-depth analysis of tenant space, as well as tenant participation in the financial discussion is required at the beginning stages of the retrofit. During the retrofit implementation stage, submeters can be installed in tenant spaces allowing the tenants and building management to track energy consumption (Olgyay & Seruto 2010). A "green lease" structure can then be implemented with benefits and the incentives clearly defined in the framework (Olgyay & Seruto 2010). This ensures that the incentives received by the tenant and the financial gains by the owner are fair (Olgyay & Seruto 2010). This solution to the split incentives problem was applied in the Empire State Building retrofit, where it was calculated that around 58% of the available savings could be found in tenant spaces (Fluhrer, Maurer, & Deshmukh 2010). The design team was able to cost-effectively mitigate this issue with the green leasing stucture and provide satisfying incentives for the owner and tenants of the Empire State Building (Fluhrer, Maurer, & Deshmukh 2010).

8.2 New Incentive Programs for Deep Energy Retrofit Projects

Enhanced incentive programs in the US could potentially contribute to driving the Deep Energy Retrofit market by making projects more financially viable for building owners. Smith and Bell (2011) propose a simple and theoretically effective program that can provide the additional incentives needed to help building owners finance Deep Energy Retrofits. The *Deep Energy Efficiency Pays* (DEEP) program is designed to provide incentives to Deep Energy Retrofit projects with funds from external sources like utility companies and ratepayer funds (Smith & Bell 2011). Utility companies could use funds that are allocated for Demand Side Management (DSM) projects, as the DEEP program fits the criteria for DSM initiatives (Smith & Bell 2011). Incentives will only be awarded to projects that achieve 30% savings; ensuring deep energy reductions are achieved from the project. The exact percentage of the total cost of the retrofit project would be based upon the energy savings potential (Smith & Bell 2011). The DEEP program, or a program similar, would allow building owners to adequately finance a project that meets their payback period threshold, where without these incentives, the project would be financially unattainable (Smith & Bell 2011). Programs like the one presented by Smith and Bell could allow more Deep Energy Retrofits to get off the ground and should be widely instated throughout the US.

8.3 Commercial Sector Inclusion into a US Carbon Trading Market

If the US develops a national carbon trading market that included indirect commercial building GHG emissions reductions, Deep Energy Retrofits for commercial office buildings would proliferate at a faster pace due to greater incentives (Nock & Wheelock 2010). In the US, there is currently no green house gas (GHG) Cap and Trade structure that allows commercial office buildings to participate using indirect GHG emissions reductions (Simon, 2014). The term *indirect* refers to GHG emissions reductions achieved through activities of an energy end-user, where a *direct* source of GHG emissions reductions is from the primary energy producer, such as a power plant. Because regulators are typically only interested in regulating direct sources of GHG emissions reductions, the commercial sector cannot participate.

Even California, which is viewed as the most progressive state in regards to climate regulations, only allows the industrial and energy sectors to join in the carbon trading market (Simon 2014). This is because under California's Assembly Bill 32 *section 38562(d)(1),* in order for a particular sector to participate in the Cap and Trade system, GHG reductions need to be proven *real, permanent, quantifiable, verifiable, and enforceable by the state board.* Similar requirements are universally applied to carbon trading markets around the US, which takes commercial sector end-use energy efficiency off the table because these requirements are difficult for the commercial sector to prove (Simon, 2014). Regulators in-favor of commercial sector inclusion into the carbon market, as well as stakeholders, will need to find ways to overcome or change these regulations. Furthermore, one of the main reasons why indirect GHG reductions from commercial buildings are not included in most Cap and Trade markets is that the same reductions can be counted twice, once from the commercial building and once from the energy provider (Simon, 2014). This results in both parties profiting from carbon offset credits where only half the credits represent actual GHG reductions (Simon, 2014). The issue of double counting GHG reductions can be circumvented by reducing the number of credits attained from the indirect GHG reductions of commercial buildings from the energy provider's cap (Simon, 2014).

This method to avoiding double counting to include indirect GHG reductions from the commercial sector into the carbon trading market was achieved in New South Wales, Australia. In 2003, New South Wales implemented regulations that allow energy efficiency improvements in the commercial building sector to receive carbon offset credits (Simon, 2014). As of 2007, these regulations combined with other demand side management initiatives have reduced GHG emissions by 18.5 million tons of CO_2(eq). By implementing a similar Cap and Trade program throughout the US, the profitability of Deep Energy Retrofits would reach even higher levels because of the additional profits made from the sale of carbon-offset credits. According to Nock and Wheelock (2010), energy efficiency in commercial office buildings has the highest potential to profit from reduced GHG emissions in a carbon trading structure. Reducing GHG emissions through renewable sources can cost up to $10 in the process of saving one metric ton of GHG emissions, while carbon capture can cost as high as $30. Energy efficiency in commercial buildings has the potential to simultaneously save $40 and reduce one metric ton GHG emissions (Nock & Wheelock 2010). In a high carbon credit value scenario, if the market price for one metric ton of CO_2 (eq) is valued at $20/tonne CO_2(eq), a commercial building has the potential to profit $60 by reducing 1 metric ton of GHG emissions with energy efficiency measures. As of May 2nd 2014, California's carbon price was valued at $11.75/ tonne CO_2(eq) (calcarbondash.org). At this price, a commercial building has the potential to profit just over $50 per metric ton of CO_2(eq) reduced. If the US were to adopt a national carbon trading system that included indirect commercial building activities to reduce GHG emissions, the added incentives to increase profits via carbon offset trading could potentially "tip" Deep Energy Retrofit projects that otherwise would not take place.

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