AN ENVIRONMENTAL ANALYSIS OF PROPOSED EFFICIENCY IMPROVEMENTS FOR THE EDWIN L. JONES CANCER RESEARCH BUILDING

by

Christopher Benonis
Dr. Lincoln Pratson, Advisor
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Abstract

In the fall of 2009 Duke University initiated an energy audit of the Edwin L. Jones Cancer Research Building. The Jones Building was selected due to its age and energy consumption profile. Rising energy prices and maintenance costs associated with building operation were key motivations. Skanska USA Building, Inc. and Griffin Engineering & Technical Services were contracted to conduct the audit. Final audit results included a series of recommendations for potential efficiency improvements, using energy cost reductions as the primary decision criteria. The final report did not incorporate potential environmental impacts in the decision-making process.

This project investigates the potential impact of the proposed improvements on Duke's climate neutrality goals by quantifying the associated greenhouse gas emission reductions. I estimate potential emissions impact using energy savings estimates from the audit and emissions rates calculated using University utility data. The project also evaluates mechanisms for pricing these benefits and prioritizing other campus facilities for future audits. Pricing of projected emissions reductions is conducted using an avoided cost assumption for carbon offsets. I evaluate the Energy Performance Standard Calculation Toolkit (EPSCT) as an alternative method for prioritizing buildings for future audits.

Project results indicate that implementing the proposed improvements could reduce total non-transportation campus emissions by approximately 1% and that similar improvements to all research facilities could reduce campus emissions by more than 10%. The estimated value of emissions reductions from the Jones Building is $27,000-$30,000 per year, based on current offset price estimates. Results of the evaluation of the EPSCT suggest that further study is required.

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Introduction

In the fall of 2009 Duke University Medical Center initiated an energy audit of the Edwin L. Jones Cancer Research Building ("Jones Building"). The Jones Building was constructed in 1972 as part of the Duke Comprehensive Cancer Center. The building has substantial laboratory resources. Engineering staff and the Medical Center's architects' office selected the Jones Building to be audited due to its age and energy consumption profile.

Skanska USA Building, Inc. ("Skanska") and Griffin Engineering & Technical Services ("Griffin Engineering") were contracted to conduct the audit. The process included several site visits and a thorough analysis of building energy usage data provided by the University. As part of the audit Skanska and Griffin Engineering recommended a series of energy and cost-saving efficiency measures to be implemented in the Jones Building.

Several key motivations led Duke Med to initiate the evaluation of energy usage at the Jones building. The rising costs of energy and building systems' operations and maintenance were a primary concern. The environmental impact of greenhouse gas emissions ("GHGs") was also an important factor as the University looks to meet its GHG reduction goals. Duke Med and University staff considered the potential for this audit process to serve as a template for replication across campus.

This research paper is an analysis of the results of the audit conducted by Skanska and Griffin. Using the energy reduction and cost-saving estimates developed by Skanska and Griffin Engineering I begin by analyzing the environmental impacts of the proposed efficiency improvements. The analysis includes an investigation into alternative methods of prioritizing buildings for an energy audit.

This analysis focuses primarily on the carbon dioxide reduction potential of a range of proposed improvements. Potential is characterized both in terms of absolute emissions and environmental payback. Using these results, recommendations can be prioritized across three key decision criteria; cost reduction, energy reduction, and emissions reduction.

In the investigation into alternative methods of initiating an energy audit I focus on building energy performance software developed at the Georgia Tech School of Architecture. The Energy Performance Standard Calculation Toolkit (EPSCT), developed by Drs. Godfried Augenbroe and Cheol-Soo Park, employs user-generated building parameter data and energy usage algorithms to estimate energy consumption. By benchmarking buildings with the EPSCT using existing data, and with the help of University employees, critical buildings and building systems could be prioritized for further evaluation.

The EPSCT is tested as an intermediate step in the characterization of building energy usage and the prioritization of formal energy audits. Efficiency improvements are also characterized to test the robustness of the EPSCT as an initial means of identifying potential projects.

The results of the environmental analysis have implications for next steps with respect to the Jones Building and for policies and procedures for future campus energy audits. The environmental considerations that were not incorporated into the audit conducted by Skanska and Griffin Engineering have relevance to the University's Climate Action Plan. These considerations represent an alternative method of selecting improvements for implementation.

The analysis of the EPSCT as an intermediate building energy use evaluation tool represents a potential cost-reduction and resource maximization opportunity. Utilizing the EPSCT to identify priority buildings for detailed audits could speed the pace of energy use and emission reductions on campus. More targeted efficiency improvements would enhance the cost-effectiveness of formal audits.

Background

Motivation

Duke Med initiated the Jones Building energy audit as part of a larger goal of reducing energy usage in facilities on campus. This goal is motivated primarily by energy cost and environmental impact considerations. Skanska and Griffin give significant attention to energy cost implications in the audit while the treatment of environmental implications is limited.

The primary consideration in the treatment of the Jones Building audit by Skanska and Griffin Engineering is the cost of energy usage. The University traditionally utilizes simple payback from energy savings as the primary decision criteria for implementing efficiency projects. All efficiency improvement recommendations in the audit are presented in terms of annual energy cost savings and simple payback period. An estimate of the life of each project recommendation is not included in the report.

Electricity costs in North Carolina and across the country have increased in recent years and are predicted to continue this rise in the future. In October 2009 Duke Energy announced rate increases of 3.8% in 2010 and 3.2% in 2011 (Duke Energy 2009). University facilities have already seen a 3.5% increase in electricity costs between 2008 and 2009. These increasing electricity costs reduce the payback period for energy efficiency improvements and increase the potential for significant cost savings, thereby making efficiency improvements more financially attractive.

Among facilities on the University campus, laboratory facilities including the Jones Building tend to have large energy consumption profiles. Current estimates of energy usage on Duke's campus suggest an annual energy intensity (energy usage per square foot of occupied space) of 600kBTU/GSF for laboratory facilities, or approximately twice the energy intensity of housing and office/classroom space (Duke CAP 2009). As a proportion of the total consumption on campus, laboratory and research facilities account for approximately 30% of chilled water and steam usage and 16% of electricity usage (see table). These buildings represent about 12% of the total gross square footage of facilities on campus (Palombo 2009).

Campus Energy Data FY 2009				
	Chilled Water	Steam	Electricity	GSF
	ton-hrs	lbs.	kWh	ft.^{2}
Campus	95,518,648	1,145,124,473	442,545,169	15,425,489
(%)	100.0%	100.0%	100.0%	100.0%
Jones Building	1,247,671	24,639,045	6,213,005	91,768
(%)	1.3%	2.2%	1.4%	0.6%
Research Buildings	27,529,336	331,729,806	68,795,177	1,842,557
(%)	28.8%	29.0%	15.5%	11.9%

The energy intensity for the Jones Building is approximately 660kBTU/GSF, or 10% higher than the average for University laboratory facilities (Skanska 2009). Facility energy use is equal to approximately 60 billion BTU per year. Annual energy costs for fiscal year 2009 were $800,000. This high energy intensity, coupled with rising energy costs, has made the Jones Building increasingly expensive to operate with its current building system technology. These costs have prompted the investigation into potential efficiency improvements.

Cost considerations also include the optimization and utilization of existing building and campus energy systems. The Jones Building heating and cooling systems are currently outdated and inefficient. The Alexander H. Sands, Jr. Building is a nearly identical facility located adjacent to the Jones Building. According to Medical Center Staff Engineer John Kramer, the Sands Building was recently updated with modern heating and cooling technology and uses approximately half of the annual heating and cooling energy of the Jones Building (personal communication, October 6, 2009). Replacing outdated equipment and upgrading equipment controls increases the efficiency of system service delivery while also reducing operations and maintenance costs.

The audit by Skanska and Griffin Engineering, though motivated in part by environmental considerations, offers only limited treatment of the subject. The report includes an explanation of the LEED certification process for Existing Buildings and recommendations for meeting certification thresholds. Additional discussion of potential environmental implications is not included. The analysis of potential efficiency improvements does not attempt to quantify potential carbon emissions reductions. This is an important consideration given the University's climate reduction commitments.

In October 2009, Duke University published its Climate Action Plan for achieving campus carbon neutrality by 2024. This goal is part of the institution's submission to the American College and University Presidents' Climate Commitment (ACUPCC). This plan calls for a 15% reduction in campus facility energy use between 2010 and 2030 through the implementation of Energy Conservation Measures. Campus growth projections suggest that 68% of future construction will be laboratory facilities (Duke CAP 2009). This, coupled with the energy intensity of laboratory buildings, means that many of the Energy Conservation Measures will need to be directed to this segment of the campus built environment.

Research by the National Renewable Energy Laboratory ("NREL") suggests that the energy intensity of laboratory facilities is 5 to 10 times higher than comparably sized office buildings (NREL 2000). These figures are consistent with those published in the University's Climate Action Plan. Laboratory facilities are consequently among the most significant contributors of GHGs in a campus setting.

An EPA study estimates that a 30% reduction in energy usage at American laboratory facilities would reduce total annual energy consumption by 84 trillion Btu. This is equivalent to the annual energy consumption of approximately 840,000 American households. A 30% reduction in energy use would also reduce annual carbon emissions by approximately 19 million tons (NREL 2000).

With laboratory research facilities constituting the majority of projected campus construction, the efficient use of energy in these buildings will become increasingly important in constraining campus energy costs. Building systems within existing facilities will also continue to deteriorate, consuming greater amounts of energy and eventually requiring replacement. The process of designing new facilities and retrofitting existing structures will need to consider the effects of various options on meeting campus climate goals.

Audit Process

The audit conducted by Skanska and Griffin Engineering for the Jones Building relies primarily on building energy usage data to evaluate building performance. The audit was intended to evaluate existing energy performance as well as the efficiency of operations and maintenance practices (Skanska 2009). The results of this analysis were used to make recommendations on efficiency improvements to be implemented within the Jones Building to reduce costs and environmental impact.

The Skanska/Griffin Engineering audit began with a detailed description of current conditions within the facility in the form of occupancy rates, operational profiles, and a summary of all energy-consuming systems including lighting, heating, cooling, ventilation, and building automation and control (Skanska 2009). Duke Med provided all available information and access to architectural and mechanical drawings for the purpose of compiling this information.

The audit included a detailed analysis of energy usage information from utility bills to identify trends and inconsistencies in operation. Calculations of energy intensity were made to benchmark the building against similar facilities both on campus and across the country. Skanska and Griffin used utility data comparisons to determine the estimated consumption of various building systems (lighting, heating, cooling) based on annual operational profiles. A site visit and visual inspection of the facility identified additional potential improvements to the building.

The results of the Skanska audit suggest that many of the building systems are outdated or not operated so as to maximize efficiency. Among the areas identified for potential efficiency improvements were reductions in lighting through re-lamping with energy efficiency bulbs and the installation of occupancy and/or day-lighting sensors to maximize the efficiency of delivered illumination. The results also included behavioral and operational improvements to reduce energy usage and extend system life. No consideration was given to the quantification of emission reductions associated with these improvements.

The final recommendations of the audit included a range of potential technology, behavior, and operational improvements selected based on capital outlay and simple payback period. These recommendations include improved temperature set-point control and improved maintenance scheduling to identify sub-optimal performance in building HVAC systems. Skanska and Griffin Engineering estimated a total capital outlay of $3 million to $4 million and cost savings of $400,000 to $500,000.

The audit conducted by Skanska and Griffin Engineering is an example of a typical primary energy audit. The audit methods go beyond a simple analysis of utility bills to consider building systems and expected operational performance, but stop short of a full-scale characterization of the building using an advanced modeling tool.

This level of audit detail offers a wealth of valuable information, but only for one particular period in time. The time and expense associated with conducting an audit of this scale on a regular basis to reduce temporal inconsistencies is prohibitive. This process also avoids energy usage implications stemming from the integrated nature of building systems. The recommendations made under these conditions are necessarily time-dependent and system-independent.

EPSCT Process

Augenbroe and Park designed the GSA Toolkit (predecessor to the EPSCT) for the purpose of overcoming the temporal and integrative limitations of a traditional energy audit. By developing a normative evaluation tool for building performance, facilities managers could characterize energy usage based on system components. This characterization allows the predicted energy use estimated by the toolkit to be compared to actual energy use, and to benchmark these predictions against other facilities.

Augenbroe and Park benchmarked the toolkit developed for the United States General Services Administration ("GSA") using building performance data from several GSA facilities. The verification methods for this process included a complete characterization of the building using the toolkit. The results of this characterization were then compared to actual building energy usage data to estimate toolkit error. Benchmarking results from an analysis of two years of building usage data at the

Sam Nunn Atlanta Federal Center in Atlanta, GA, produced an error of 2.2% and 15.4% in 2000 and 2001, respectively (Park and Augenbroe 2003).

The authors suggest that a contributing factor to the high error in 2001 was unseasonably cool weather that produced an unusually high heating load for the facility. The authors concluded that the results of the analysis showed that the toolkit could be used as a reliable performance evaluation method for GSA facilities' management (Park and Augenbroe 2003). The GSA has since incorporated the software in its operations on a large scale (Ramkrishnan 2007).

The University of Pennsylvania employed a version of the GSA toolkit to characterize energy usage at 160 facilities on its campus. The goal of this project was to develop an energy cost allocation model for the campus (Ramkrishnan 2007). The campus of the University of Pennsylvania did not utilize energy sub-metering and instead allocated cost based on building area. By characterizing the buildings using the toolkit developed by Augenbroe and Park, the campus was able to allocate energy costs based upon predicted building design usage. This allocation method has allowed the campus to incentivize energy efficiency improvements and reduce energy costs (Augenbroe 2009).

The GSA Toolkit served as the foundation for a revised performance software kit titled the Energy Performance Standard Calculation Toolkit (EPSCT). This revision streamlined the data acquisition and input processes to improve ease of use. The version also incorporated an emissions output component. The EPSCT was expanded to consider indirect energy use effects, in the form of primary energy demand, in order to estimate emissions impacts.

The EPSCT was designed to estimate the normative design and delivered energy requirements for a facility. Assuming proper input of data, the results of the EPSCT analysis are intended to approximate building energy needs. The model estimates the minimum energy necessary to meet design parameters of a facility and the actual energy necessary to deliver these services based on the building systems included. The software does not calculate actual energy usage.

Objective

The audit recommendations submitted by Skanska and Griffin Engineering for the Jones Building offer several potential options for energy efficiency improvements. These improvements are presented in terms of cost savings and payback period, based upon projected energy savings. The treatment of the improvements as cost-saving mechanisms is appropriate but incomplete. Given the objective of University administration to also address the environmental impact of campus operations, the impact of these improvements on emissions should also be considered.

The object of this research is to investigate the environmental impacts of the proposed efficiency improvements. With the University's ACUPCC goals in mind, the analysis is limited to GHG emissions. A secondary objective is to evaluate the feasibility of alternative methods of prioritizing buildings for audit, and of identifying potential efficiency improvements. The method evaluated is the EPSCT developed by Drs. Augenbroe and Park.

The energy efficiency improvements recommended by Skanska and Griffin Engineering represent potential financial savings of as much as $500,000 per year. Their analysis does not consider the environmental impact, either from a quantity or economic value basis, of these reductions in energy usage. This paper attempts to estimate the environmental impact in the form of GHG emissions reductions.

I use estimates of current emissions from building operations and potential reductions associated with proposed improvements to determine the total potential carbon impact of the recommendations. These reductions are contextualized relative to campus reduction goals and potential in other facilities across campus. An estimate of the cost-effectiveness of different recommendations is also calculated, based upon projected cost of implementation and energy usage and GHG reductions, to prioritize environmental efficiency improvements.

I investigate alternative methods of auditing and prioritizing buildings for audit. This evaluation focuses on the building performance characterization software program EPSCT. This tool is used to quantify energy consumption across uses (heating, cooling, ventilation, lighting, and domestic hot water) and through time (monthly and annually).

I use the results of this characterization and the characterization of several potential efficiency improvements to evaluate the robustness of the software as a preliminary audit tool and for prioritization. The characterization data is compared to the audit data provided by Skanska and Griffin Engineering to determine overall efficacy.

Methods

Calculations of the environmental impact of the proposed efficiency improvements focus on the reduction of GHG emissions from building operations. All carbon dioxide emissions associated with the Jones building are indirect emissions. Attributable emissions originate from the University's steam plant and from power plant emissions on the regional electricity grid.

Emissions Quantification

I calculate current emissions using two sets of GHG emissions factors for each of the three primary energy sources (steam plant, chilled water plant, and grid electricity).

CAP emissions factors are calculated using electricity and fuel emissions rates published in the Duke University Climate Action Plan (Duke CAP 2009). Current emissions factors are calculated using FY 2009 data reported by Duke Energy and provided by University Energy Manager Steve Palumbo (see table) (personal communication, February 23, 2010).

CO_2-e Emissions Rates (MT/mmBTU)		
	CAP	Current
Electricity	0.146	0.106[1]
Coal	0.094	0.094
Natural Gas	0.053	0.053

I calculate emissions factors using the following equation below, where E represents the emissions rate for fuel *f* (electricity, coal, or gas):

$$\text{Emissions Factor}_f\ (\text{lbs. } CO_2 - e / kWh) = \frac{E_f (MTCO_2 - e)}{1(mmBTU)} \times \frac{2{,}204(lbsCO_2 - e)}{1(MTCO_2 - e)} \times \frac{1(mmBTU)}{293.1(kWh)}$$

The emissions rate for electricity reported in the University Climate Action Plan is 0.046 MT/mmBTU. Converting this value to pounds per kWh yields an emissions factor for electricity 1.098 lbs/kWh. The current electricity emissions factor based on data for FY2009 is 0.98 lbs/kWh.

Chilled water is produced using electricity at a central plant on campus. The seasonal energy efficiency ratio (SEER) of the chilled water plant is calculated as the kBTU of chilled water output per kWh of electrical input. The average SEER of the

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[1] Duke Energy attributes this decrease to a reduction in demand over this period and a higher proportion of electricity produced at its nuclear generating units.

plant is approximately 15 according to the equation below[2]. The emissions factor for chilled water is .878lbs/ton-hr.

$$SEER = \frac{1}{(.8kWh/tonhr)\times(0.083tonhr/kBTU)} = 15kBTU/kWh$$

The emissions rate for steam is dependent upon the proportion of fuel inputs used in the campus steam plant. The fuel mixed assumed in the Climate Action Plan is 90% coal and 10% natural gas. The emissions rate for coal is .279lbs/lb$_{steam}$ delivered to the building while emissions rate for natural gas is 0.113lbs/lb$_{steam}$ delivered. The combined emissions rate for steam is 0.263lbs/lb$_{steam}$ delivered. The equations below are the formulas for calculating the steam emissions rate:

Coal

$$\mathrm{CO_2\ (lbs/lb_{steam})} = (.094MTCO_2/MMBTU \times 2204lbs/MT \times \underset{\text{dist. losses}}{1.11} \times \underset{\text{plant eff.}}{1.25} \times 970lbs/MMBTU)$$

Natural Gas

$$\mathrm{CO_2\ (lbs/lb_{steam})} = (.053MTCO_2/MMBTU \times 2204lbs/MT \times \underset{\text{dist. losses}}{1.11} \times \underset{\text{plant eff.}}{1.25} \times 970lbs/MMBTU)$$

Average

$$\mathrm{CO_2\ (lbs/lb_{steam})} = .9(COAL) \times .1(NATURALGAS)$$

The emissions factors for chilled water and steam can also be expressed in units of lbs/kWh. Chilled water usage is converted from ton-hrs to kWh using the conversion rate of 0.8kWh/ton-hr. Steam is converted using a value of 0.284kWh/lb$_{steam}$. The CAP emissions factor is then 1.098lbs/kWh for chilled water.

The emissions factor for steam based on CAP emissions rates is 0.923lbs/kWh. The University has recently completed the construction of a new steam plant on East Campus that will allow for the production of steam using 70% natural gas and 30%

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[2] Based on information provided by John Kramer and Steve Palumbo (personal communication, February 8, 2010).

coal. The shift in fuel mix for steam generation will reduce the emissions factor for steam from 0.923lbs/kWh to 0.573lbs/kWh. For simplicity and comparability, all subsequent rates are reported as lbs/kWh (see table).

CO_2-e Emissions Rates (lbs/kWh)		
	CAP	Current
Electricity/Chilled Water	1.098	0.980
Steam	0.923	0.573

I estimate the monthly and annual emissions attributable to electricity, steam, and chilled water use at the Jones Building by multiplying reported energy use by the emissions factors. I estimate projected emissions reductions associated with the proposed energy efficiency improvements in the Skanska/Griffin Engineering audit using the same methodology. Projected emissions reductions are calculated separately for each recommendation, based on predicted reductions in energy usage, and aggregated where improvements are not mutually exclusive.

I calculate total annual emissions for laboratory facilities and for the campus as a whole to contextualize the emissions from operation of the Jones Building. These results are presented as a percentage of total campus emissions. I also estimate the contribution of the proposed improvements toward campus carbon reduction goals.

Emissions Valuation

Using carbon reduction projections I calculate the environmental value of each proposed project. This is an estimate of annual avoided cost of carbon offsets associated with CO_2 reductions.

$$\text{EnvironmentalValue}_{\text{Project}} = \text{CO}_2\text{Reduced}_{\text{Project}}\ (tons/year) \times \text{AvoidedCost}_{\text{Carbon Offsets}}(\$/ton)$$

A project's cumulative environmental value cannot be calculated because the audit does not provide estimates of project life. The environmental value of each project or project category is a function of the magnitude of annual emissions reductions. The value does not consider the cost of the proposed improvement. Evaluation of projects for implementation requires a metric that incorporates project cost.

The University uses a simple payback criterion to evaluate traditional energy savings projects for implementation. Simple payback is calculated as the number of years needed to recoup the cost of a project through energy savings, neglecting discount rates. Campus energy efficiency projects typically must meet a payback hurdle of 2-3 years. Projects with a payback period longer than three years are generally not implemented on the basis of energy savings alone.

I calculate an environmentally-adjusted payback period for each project by including the environmental value as a component of total project savings. Each energy efficiency project is then evaluated on the basis of the associated energy savings benefits as well as the projected reductions in greenhouse gas emissions. I present the results in terms of the overall adjusted payback period and the contribution of project environmental value to a reduction in that period.

$$\text{Adj.Payback}\ \ (years) = \frac{\text{EnvironmentalValue}\ \ (\$/year) + \text{EnergySavings}\ \ (\$/year)}{\text{ImplementationCost}\ \ (\$)}$$

Without an estimate of project life, alternative decision criteria such as net present value (NPV) or internal rate of return (IRR) calculations cannot be made. I use the calculations of adjusted payback as the selection metric to prioritize proposed projects for implementation based on environmental impact. Those projects with the shortest environmentally-adjusted payback period are given priority for implementation. I compare these results to a prioritization of projects based simply on economic considerations, as measured by simple payback period.

EPSCT Process

The evaluation of alternative audit methods begins with the characterization the energy performance of the Jones Building utilizing the EPSCT. Major energy-consuming building systems characterized include heating, cooling, ventilation, lighting, and domestic hot water. I also characterize energy usage under several project implementation conditions. I use the relaxation of building temperature set point conditions and lighting efficiency improvements as the projects of study. I compare the results of this series of characterizations to the results of the professional audit conducted by Skanska and Griffin Engineering.

The EPSCT model uses data inputs on building design and building systems to estimate energy usage. This process is based on NEN2916, a Dutch energy performance standard for non-residential buildings (Augenbroe and Park 2005). The standard uses system parameter data to quantify predicted energy consumption necessary to meet building operational demands. Under the Dutch code these energy quantification figures are then normalized based on building size to develop an energy performance coefficient.

The EPSCT model uses this framework to calculate the designed energy use for a building. The designed energy use represents building thermal energy requirements based upon factors such as internal heat gain, occupancy, and ventilation. The model estimates delivered energy use, which represents the quantity of energy necessary to meet the design needs of the building (Augenbroe and Park 2005).

The model also estimates the primary energy consumption at the central steam plant or power plant necessary to deliver energy to the building. The primary energy use is used to calculate the emissions impact of building operation for pollutants including carbon dioxide, nitrous oxide, and sulfur dioxide. All energy use and emissions figures are normalized for building size and type (EPSCT 2009).

To compare the results of the EPSCT output to the Skanska and Griffin Engineering audit I begin by inputting data supplied by the Medical Center Engineering and Operations office. This process, with the help of Staff Engineer John Kramer, entails the quantification of key building parameters including occupancy profiles, building size and construction, energy management controls, and building energy systems. A summary of the input variables can be found in Appendix I.

The output of the model includes monthly and annual energy use estimates for the building heating, cooling, ventilation, lighting, and domestic hot water systems. I compare the predicted energy usage of the EPSCT to the actual usage data provided by the University and compiled in the Skanska/Griffin Engineering audit.

I run a reconfigured iteration of the model with the set point and lighting efficiency recommendations made by Skanska. I compare the EPSCT summary energy usage predictions to the original predicted energy usage and to the projected energy savings calculated by Skanska and Griffin Engineering.

Results

The efficiency improvements recommended by Skanska and Griffin Engineering have the potential to substantially reduce GHG emissions. All potential reductions associated with the operation of the Jones Building operations are indirect. Actual emissions reductions occur at the campus steam plant and at power plants supplying electricity to the University through the regional grid.

Current Emissions Quantification

The Jones Building has an annual energy intensity of 660kBTU/GSF based on energy usage data for the fiscal year ended June 2009. Building energy consumption for this period included 1.2 million ton-hours of chilled water for building cooling; 24.6 million pounds of steam used for heating, domestic hot water, and sterilization; and 6.2 million kWh of electricity. Monthly energy use for each category is converted to a common unit, one thousand British thermal units (kBTU), in the table below. Total building energy usage for this period was approximately 60 million kBTU.

Jones Building Energy Use FY 2009 (kBTU)

	Chilled Water	Electricity	Steam	Total
Jul	0	2,399,909	1,334,296	3,734,204
Aug	0	2,534,886	1,578,801	4,113,687
Sep	0	2,514,627	873,769	3,388,396
Oct	2,619,840	1,457,808	2,453,140	6,530,788
Nov	1,397,864	1,391,535	2,003,089	4,792,487
Dec	1,515,600	1,318,848	2,536,870	5,371,318
Jan	1,726,099	1,326,848	3,077,897	6,130,844
Feb	1,688,577	1,389,309	3,299,300	6,377,186
Mar	1,203,642	1,264,875	2,605,304	5,073,821
Apr	1,621,569	1,376,197	1,814,695	4,812,461
May	2,671,726	1,467,812	1,341,297	5,480,834
Jun	527,112	2,762,332	981,417	4,270,861
Total	14,972,029	21,204,986	23,899,874	60,076,889

Using emissions rates reported in the Duke University Climate Action Plan, FY 2009 energy use at the Jones Building produced approximately 7,200 tons of GHG. Total emissions included 550 tons (~8%) due to chilled water use, 3,400 tons (47%) from the use of electricity, and 3,200 tons (44%) from steam. A summary of monthly and annual emissions estimates can be found in the table below.

Jones Building Current Estimated Annual Emissions (tons) – CAP Rates				
	CHW	Electricity	Steam	Total
Jul	0	386	180	567
Aug	0	408	214	621
Sep	0	404	118	523
Oct	96	234	332	662
Nov	51	224	271	546
Dec	55	212	343	611
Jan	63	213	416	693
Feb	62	223	446	731
Mar	44	203	352	600
Apr	59	221	245	526
May	98	236	181	515
Jun	19	444	133	596
Annual	547	3,411	3,233	7,191

Estimated total campus GHG emissions in 2007, including transportation and selected Scope III emissions, were 433,361MTCO_2-e or 478,000 tons of carbon dioxide equivalent. Estimated campus emissions from electricity (including chilled water production) and steam usage in 2007 were 386,000 tons CO_2-e (350,000MT) (Duke CAP 2009). Using Climate Action Plan emissions rates (1.098lbs/kWh for electricity/chilled water and 0.923lbs/kWh for steam) and energy usage data for FY 2009 (see table) I estimated current campus emissions from electricity and steam to be approximately 393,000 tons CO2-e (357,000 MT). Using the CAP emissions rates, campus emissions are projected to have increased slightly between 2007 and 2009.

Campus Energy Use FY 2009 (Native and Universal Units)				
	CHW*	Electricity	Steam	Total
Native	ton-hrs	kWh	lbs	--
Universal	kWh	kWh	kWh	kWh
Campus				
Native	95,518,648	442,545,169	1,145,124,473	--
Universal	76,349,767	442,545,169	325,548,282	768,093,451
Jones				
Native	1,247,671	6,213,005	24,639,045	--
Universal	997,286	6,213,005	7,004,652	14,214,943
Research Buildings				
Native	27,529,336	68,795,177	331,729,806	--
Universal	22,004,692	68,795,177	94,307,711	185,107,580

I used the current Duke Energy emissions rates and campus projections for fuel mix in steam production to recalculate total campus emissions for FY 2009. Total emissions for FY 2009 (using current emissions rates) are 310,000 tons (281,000 MT). Of this total, approximately 37,000 tons (12%) are from chilled water, 93,000 tons (30%) from steam, and 179,000 tons (58%) from electricity (excluding chilled water). Total FY 2009 emission for these sectors are 21% lower using current rates than those estimated using CAP emissions rates (see table).

Estimated Campus Emissions FY 2009 (tons)				
	CHW	Electricity	Steam	Total
CAP Emissions Rate*	41,911	242,927	150,307	393,234
Current Emissions Rate**	37,411	216,847	93,350	310,197
Change in Campus Emissions	-10.7%	-10.7%	-37.9%	-21.1%

* Electricity = 1.098lbs/kWh; Steam = 0.923lbs/kWh (90% coal, 10% natural gas)

** Electricity = 0.98lbs/kWh; Steam = 0.573 lbs/kWh (30% coal, 70% natural gas)

Using current emissions rates for electricity and steam, annual emissions from operation at the Jones Building decrease by 23% to 5,540 tons. This is equal to approximately 1.8% of total campus emissions and 7.2% of emissions from buildings classified as research laboratories. Emissions from all research labs represent approximately 23% of the campus total (see table).

Emissions Proportions FY 2009 – Current Rates				
	CHW*	Electricity	Steam	Total
Campus Emissions (tons)	37,411	216,847	93,350	310,197
Research Labs (tons)	10,782	33,710	27,043	71,534
Jones Building (tons)	489	3,044	2,009	5,542
Jones Building (% of Campus Total)	1.31%	1.40%	2.15%	1.79%
Jones Building (% of Research Labs)	4.34%	8.28%	6.91%	7.19%
Research Buildings (% of Campus Total)	28.82%	15.55%	28.97%	23.06%

* Campus chilled water also counted in electricity (Campus Total = Electricity + Steam)

Emissions Reductions Quantification

Using the efficiency improvement recommendations made by Skanska and Griffin Engineering I calculated the potential energy reductions from the implementation of a series of projects. This calculation provides a range of potential energy savings resulting from improvements to lighting, HVAC equipment, and other buildings systems (fans, pumps, motors, etc.). Also included in these calculations are estimates of savings resulting from proper commissioning of new and existing building systems to ensure optimal performance.

Estimated energy savings resulting from the efficiency improvements proposed by Skanska and Griffin Engineering range from 28 to 36 million kBTU (8 million to 10 million kWh) or 46% to 49% of building energy usage. Savings include reductions of 434,000kWh to 884,000kWh per year for lighting depending on the projects implemented. Projected reductions from heating and cooling systems (including hot water) are 15.8 million kBTU per year. Improvements to other building systems including pumps, fans, and motors represent savings of 1.9 million kWh per year (see table). Skanska and Griffin Engineering also project savings of as much as 6.5 million kBTU from system commissioning, though this is not included in total building savings. Building energy intensity drops from 660kBTU/GSF to 335-350kBTU/GSF per year.

Projected Jones Building Annual Energy Savings			
	Energy Savings (kWh/year)	Energy Savings (kBTU/year)	Energy Savings (%)
Total (Current – 60mm kBTU)			
	8,136,769	27,762,657	46%
	8,587,096	29,299,173	49%
Lighting (Current – 1mm kWh)			
Low	434,077	1,481,070	43%
High	884,404	3,017,586	87%
HVAC (Current – 48mm kBTU)			
	4,623,249	15,774,524	33%
Other			
	1,922,559	6,559,1772	--
Commissioning*			
	1,923,076	6,561,538	--

* Commissioning not included in total savings calculations.

Using the energy savings estimates established with the Skanska and Griffin Engineering audit I calculated the projected GHG emissions reductions associated with these improvements. Calculations using CAP emissions rates are included to allow for comparability to CAP figures and objectives. I use reductions estimates based on current emissions for all subsequent data analysis. The proposed efficiency projects are found to result in potential emissions reductions of 2,750-3,000 tons using current emissions rates and 3,400-3,650 tons based on CAP rates (see table).

Projected Jones Building Annual GHG Emissions Reductions				
	CAP Rates		Current Rates	
Current Emissions	(tons)	(%)	(tons)	(%)
Total	7,192	--	5,542	--
Electricity	3,411	47.4%	3,044	54.9%
Steam	3,234	45.0%	2,009	36.2%
Chilled Water	547	7.6%	489	8.8%
	CAP Rates		Current Rates	
Projected Reductions	(tons)	(% reduction)	(tons)	(% reduction)
Total				
Low	3,401	47.3%	2,748	49.6%
High	3,648	50.7%	2,968	53.6%
Electricity				
Low	2,147	62.9%	1,916	62.9%
High	2,394	70.2%	2,137	70.2%
Steam	1,077	33.3%	673	33.5%
Chilled Water	178	32.4%	158	32.4%

Potential emissions reductions from operations at the Jones Building are approximately 50% of building emissions using current emissions rates. This reduction is consistent with the predicted 46%-60% reduction in energy usage. Current emissions rates for campus electricity usage are 70% higher than for steam usage. As a result, both direction and indirect (chilled water) reductions in electricity consumption result in larger emissions reductions than an equivalent reduction in steam usage.

Projected emissions reductions for the Jones Building are equal to 1% of total campus emissions. The proposed reductions also constitute 4% of emissions from campus research laboratories. Of the 17 facilities classified as research buildings, 13 (including the Jones Building) have energy intensities of at least 270kBTU/GSF and the average energy intensity for these buildings is 495kBTU/GSF. Reaching an average building energy intensity of 335-350kBTU/GSF for these 13 facilities could reduce annual GHG emissions from research facilities by 44-49.5%. Total campus emissions from electricity and steam consumption would also be reduced by 10-11.5% (see table).

Research Building Emissions Reduction Potential (Excluding Research Park I-IV)*					
		Energy Intensity Reductions (kBTU/GSF)		Emissions Reductions (tons/year)	
Target Energy Intensity		335	350	335	350
Target Intensity Reductions		159.5	144.5	159.5	144.5
	Proposed Reductions				
Electricity					
Low	69.72%	111.2	100.7	28,535	25,851
High	72.00%	114.8	104.0	29,467	26,696
Steam					
Low	24.49%	39.1	35.4	5,865	5,314
High	22.68%	36.2	32.8	5,431	4,920
Chilled Water					
Low	5.75%	9.2	8.3	535	484
High	5.32%	8.5	7.7	495	449
Total					
Low				34,935	31,649
High				35,393	32,064
Total (% of Research)				48.8%	44.2%
Low				49.5%	44.8%
High					
Total (% of Campus)					
Low				11.3%	10.2%
High				11.4%	10.3%

*Research Park I-IV have energy intensities of 50-200kBTU/GSF and are unlikely to realize similar efficiency gains. Total GSF excluding Research Park I-IV: 1,786,831

Emissions Reductions Valuation

Using the emissions reductions estimates, I calculate the environmental value of the proposed efficiency improvements. Valuation of emissions reductions assumes an avoided cost of $10/ton. This is the projected price of a carbon offset used in the University's Climate Action Plan. Assuming the University intended to meet its goal of climate neutrality in the current year, the predicted cost to purchase the necessary carbon offsets would be $10/ton. Any reductions in campus emissions through energy efficiency projects can then be valued at this avoided cost.

Using a price of $10/ton, the cumulative environmental value of the proposed improvements is $27,500 to $29,700 per year in the current year. Among project categories, the projects to improve building systems including pumps, fans, and motors have the highest environmental value of $15,000 per year in the current year. The hot water project has an annual environmental value of $160 per year (see table).

Projected Environmental Value FY 2009 ($) ($10.02/ton CO_2-e)	
Project Category	Estimated Environmental Value CAP ($/year)
Total	
Low	27,501
High	29,710
Lighting	
Low	2,129
High	4,338
Other (Fans, Pumps, DDC)	15,103
Hot Water	156
Heating/Cooling	10,113
Commissioning	9,432

The single project with the largest environmental value, $16,000, is the upgrade of the building HVAC system.[3] Additional projects with a high environmental value include modifications to the building's fume hoods. These improvements are designed to reduce building ventilation volumes, thereby reducing fan and motor electricity usage. A ranking of the projects based on environmental value is given below in Appendix II.

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[3] Note: The upgrade of the building HVAC system is comprehensive. It includes improvements to air handling units, heat exchange equipment, DDC temperature set point controls, and exhaust fan VFD's. Some of these components fall under different project categories.

I estimate adjusted payback periods for each project by aggregating project environmental value and energy savings. Several projects offer instantaneous payback, as there are no costs associated with implementation. Improvements to the building HVAC system, with an estimated cost of $3,000,000, have the longest payback period of 13.9 years. This period is reduced by 1.1 years by incorporating the environmental value of the project in the calculation. The period reduction for the HVAC system is the largest reduction for any project.

The adjusted paybacks for lighting improvements range from 1.7 to 10.7 years, and are reduced between .15 and 1 years through the incorporation of environmental value. Improvements to pumps, fans, and motors all have adjusted payback periods between 0 and 1.3 years. Each of these projects passes the University's hurdle rate for implementation. Only one project that did not initially meet the University's hurdle rate passed the hurdle rate when adjusted for the project's environmental value. See Appendix III for a ranking of projects based on payback period.

A comparison of the two environmental metrics for evaluating efficiency projects shows that improvements to building pumps, fans, and motors rank high on both lists. The building HVAC improvements have a high environmental value due to the magnitude of projected emissions reductions but also have a long payback period because of the high capital cost of the project. In both cases, the most aggressive lighting retrofit, replacing all T12 (42 watt) lamps with T5 (28 watt) lamps and removing three of the four lamps in each fixture, is ranked highest.

EPSCT Output

After calculating the environmental impact of the proposed efficiency improvements to the Jones Building I evaluate an alternative method of quantifying building energy performance. The results of the building performance analysis using the EPSCT suggest that the system may not be adequate for modeling the complex energy usage characteristics of the Jones Building.

With the help of John Kramer in the Medical Center Engineering and Operation Office I characterized building energy systems including heating, cooling, ventilation, lighting, and domestic hot water. The building data inputs included in the analysis can be found in Appendix IV. The results of this analysis suggest that, per the design parameters of the building, the annual thermal energy requirements are approximately 8.3 million kBTU for heating and 2.6 million kBTU for cooling (see table). The predicted thermal energy requirements are approximately 35% of the actual steam energy usage and 11% of actual chilled water usage.

EPSCT Output -- Thermal Demand		
	Heating (kBTU)	Cooling (kBTU)
Jan	1,960,702	11,911
Feb	1,630,881	12,522
Mar	1,065,309	25,617
Apr	379,802	55,697
May	11,039	154,714
Jun	0	546,282
Jul	0	838,912
Aug	0	630,115
Sep	0	283,612
Oct	529,666	46,707
Nov	1,020,838	22,843
Dec	1,764,734	13,580
Total	8,362,972	2,642,512
% of Actual	35%	11%

The model output for delivered energy performance suggests that total annual energy consumption for the building is 43.1 million kBTU. Of this total, approximately 37.4 million kBTU is for heating and domestic hot water, 681,000 kBTU for cooling, and 2.1 million kBTU for lighting. The predicted energy usage is approximately 113% of actual steam usage, 12% of actual chilled water usage, and 62% of actual electricity usage for lighting (see table).

EPSCT Output -- Predicted Energy Usage		
	Predicted Usage (kBTU/year)	Proportion of Actual Usage (%)
Heating	37,448,696	113.1%*
DHW	92,673	
Cooling	681,615	12.4%
Lighting	2,155,087	62.1%
Fan	2,286,518	
Pump	108,539	
Equip	391,834	
Total	43,164,960	77.5%

* Includes domestic hot water

To evaluate the robustness of the toolkit as a method of identifying or analyzing potential efficiency improvements I used the Skanska and Griffin Engineering recommendation for changes to the building temperature set points. The recommendation calls for relaxing the temperature set points by 2°F (~1°C) for heating and cooling. Increasing the temperature set points by 1°C in the summer and reducing by 1°C in winter results in an annual thermal energy requirement of 7.4 million kBTU of heating and 2 million kBTU of cooling (see table).

The predicted decrease in heating and cooling demand for the relaxed set point condition is approximately 1.5 million kBTU per year. This reduction in heating and cooling corresponds to a decrease in input energy of 4.2 million kBTU. The decrease is almost entirely the result of a reduction in heating demand and is approximately 13% of the initial thermal demand and 10% of input energy.

EPSCT Output -- Thermal Demand Under Set Point Control		
	Heating (kBTU)	Cooling (kBTU)
Jan	1,821,935	10,929
Feb	1,505,878	11,440
Mar	930,462	22,690
Apr	267,277	46,550
May	0	116,039
Jun	0	410,535
Jul	0	698,638
Aug	0	489,840
Sep	0	200,284
Oct	405,775	39,675
Nov	890,079	20,185
Dec	1,626,351	12,386
Total	7,447,758	2,079,198
% of Actual	31.2%	8.6%

The absolute magnitudes of the predicted reductions in thermal energy demand from the EPSCT are approximately 60% lower than the projected reductions reported in the Skanska and Griffin Engineering audit. The audit projections for energy usage reductions associated with the relaxed set point condition are approximately 3.6 million kBTU. As a percentage of initial usage, the predicted decrease of 13% of energy demand by the EPSCT is larger than the decrease in energy usage projected by Skanska and Griffin Engineering. The audit reduction projections for this recommendation represent about 7.5% of thermal energy use. Additionally, the audit assumes the project reduces both heating and cooling demand, as annual energy usage for thermal needs is split evenly between heating and cooling demand.

EPSCT Output -- Predicted Energy Usage Under Set Point Control		
	Predicted Usage (kBTU/year)	Proportion of Adjusted Actual Usage (%)
Heating	33,317,545	108.9%
DHW	542,228	10.7%
Cooling	2,155,087	62.1%
Lighting	2,286,518	
Fan	108,539	
Pump	391,834	
Equip	92,673	
Total	38,894,422	73.7%

* Includes domestic hot water

I also evaluated the range of potential lighting improvements proposed by Skanska and Griffin Engineering using the EPSCT. These lighting improvements include the replacement of T12 bulbs with T5 bulbs and the removal of lamps in multi-lamp fixtures. The results of this analysis can be found below.

Opt.	Description	Audit Estimate (kWh/yr)	Audit Estimate (%)	EPSCT Estimate (kWh/yr)	EPSCT Estimate (%)	EPSCT Estimate (% of actual)
1a	Replace 4-lamp bulbs	248,269	7.2%	119,625	5.6%	3.4%
1b	Replace 4-lamp bulbs, remove 1 lamp	372,404	10.7%	191,400	8.9%	5.5%
1c	Replace 4-lamp bulbs, remove 2 lamps	496,538	14.3%	263,175	12.2%	7.6%
1d	Replace 4-lamp bulbs, remove 3 lamps	620,692	17.9%	311,025	14.4%	9.0%
2a	Replace 2-lamp bulbs	155,788	4.5%	23,925	1.1%	0.7%
2b	Replace 2-lamp bulbs, remove 1 lamp	233,692	6.7%	71,775	3.3%	2.1%
3	Replace 1-lamp bulbs	8,538	0.2%	0	0.0%	0.0%

The results of the EPSCT lighting improvement analysis show that the predicted reductions are significantly smaller than the reductions predicted in the audit. The EPSCT-predicted reductions are between 30% and 50% of the audit predictions. The proportional reductions from the initial EPSCT-estimated lighting energy usage, however, are similar to the proportional reductions in the audit. This is due to the lower EPSCT initial predicted energy use for lighting.

Discussion

The environmental analysis of the proposed energy efficiency improvements for the Jones Building shows the potential for significant reductions in GHG emissions. Implementing all recommended projects would result in a reduction in GHG emissions of 2,750-2,950 tons CO_2-e annually. This represents a decrease in total campus emissions of 1% and a decrease in emissions from research buildings of 4%.

Economic Value of Emissions Reductions

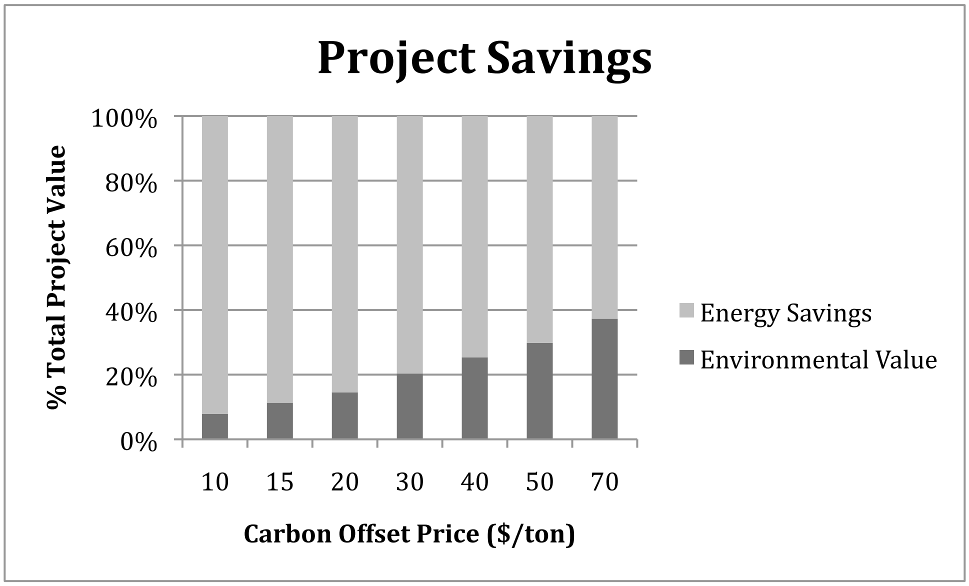
The environmental value of these projects is estimated at $27,500 to $30,000 per year assuming an avoided cost of $10/ton for carbon offsets. The total environmental value of proposed projects is equal to 8% of the aggregate economic and environmental value. The table below reports the environmental value of a project per kWh of energy saved.

Emissions Cost Savings ($/kWh) Through Avoided Offsets			
Estimated Price of Offsets	$10.02/ton		
	Chilled Water	Steam	Electricity
CAP	0.0055	0.0046	0.0055
Current/FY09	0.0050	0.0029	0.0050

Assuming a carbon offset price of $10/ton, environmental savings for electricity and chilled water projects are equal to approximately $0.005/kWh while steam efficiency projects save approximately $0.0029/kWh in avoided carbon costs. Current energy prices are $0.055/kWh for electricity and $0.036/kWh for steam.

This confirms that value of the energy savings far outweigh the current environmental value of reducing consumption.

Assuming emissions from the central steam plant and from the electrical grid remained unchanged, an increase in the avoided cost of carbon offsets would increase the environmental value of an efficiency project. A carbon offset price of $20, equal to the Nicholas School predicted price for the University's target date of 2024, would increase the environmental value of the project to approximately 15% of total project value under constant energy prices (see table).



Though the University Climate Action Plan assumes a 5% annual increase in the cost of carbon offsets, the expected price by 2050 under this assumption is only $73/ton. At the same time, Duke Energy projects a general decline in the emissions rate of grid electricity out to 2050, as it decarbonizes its generation portfolio. This trend would reduce the environmental value of reductions in campus electricity usage.

Rising energy costs would also mitigate the effect of increasing offset prices in increasing the proportional environmental value of a project. As a result, the environmental value of energy efficiency projects is unlikely to be the primary economic driver of project implementation in the future. The cost savings associated with reductions in energy use will continue to offer the primary economic incentive to implement energy efficiency projects on campus going forward.

Though the environmental value of efficiency projects at the Jones Buildings is small compared to their overall economic value, the total estimated environmental value of the proposed projects is nearly $30,000 per year. While not a primary driver for implementation, the environmental value still reduces the estimated payback period of a given project. If the University wishes to encourage efficiency improvements on campus, incorporating the environmental value into the payback period calculations may make marginal projects more attractive.

The University might also consider budgeting this cost as part of the cost of energy on campus. Though the University currently does not allow facility managers to retain the savings associated with energy efficiency improvements, allowing the managers to retain the environmental value of such projects would encourage further investment in efficiency. The approval process for financing efficiency projects can at times be restrictive. Allowing managers greater flexibility in securing financing would promote the adoption of capital-intensive projects. Further study into the development of such an incentive process is warranted.

Total emissions reductions associated with the proposed improvements represent 1% of total campus emissions from electricity and steam use. The Jones Building is one of 17 buildings identified as research laboratory facilities. Replicating these gains at all research facilities on campus would have significant impacts on the University's goals of achieving carbon neutrality by 2024. A rough estimate of potential reductions from research facility improvements suggests that campus emissions from electricity and steam usage could be reduced by 10-11.5%. Additional work to quantify the magnitude of these potential reductions would be a valuable resource for planning and budgeting future building system retrofits.

EPSCT Process

The results of the EPSCT evaluation suggest that, as currently configured, the toolkit may not be appropriate for evaluating complex building systems like those in the Jones Building. The model offers value in estimating the designed energy demand based on input parameters and how that demand would be met given the building systems in place. The model accounts for building use in only the broadest sense (the model classifies the Jones Building as an office building) and does not fully account for behavioral impacts on energy usage. This is particularly important in a facility like the Jones Building where researchers have control over temperature set points and regularly set sub-optimal temperature ranges to suit personal preferences.

Predicted energy usage for cooling was particularly inaccurate. The toolkit as it is currently designed does not offer explicit parameters for characterizing cooling supply from a central chilled water plant. Calculations of heating energy use also do not include considerations for central plant configurations. This model insufficiency coupled with unique behavioral characteristics of the Jones Building complicate its energy use characterization. Revisions to the model would be necessary to properly characterize the energy systems in the Jones Building. These revisions would clarify the dominant source of model error as either improper parameterization or building behavioral characteristics.

Similar difficulties arose in using the model as a tool for evaluating potential energy efficiency improvements. The EPSCT-predicted energy usage reductions from the relaxation of building set point controls were only 40% of the projected reductions from the Skanska and Griffin Engineering audit. As a proportion of initial predicted energy use, the model predicted a reduction of 13% versus a 7.5% reduction in total energy use based on audit projections.

This is in part the result of the systematic underestimation of initial building thermal energy demand. The EPSCT output suggests that, based on the design parameters, operational profile, and occupancy rate of the building, the annual thermal energy demand is approximately 11 million kBTU. Actual thermal energy consumption for the building in FY2009 was more than 48 million kBTU. The model-predicted thermal energy demand, estimated based on optimal operational characteristics, is not reflective of actual building performance. This is attributable to model parameter constraints and/or the unique behavioral characteristics of the Jones Building.

Estimations of reductions in energy use resulting from lighting efficiency improvements are also inaccurate. Though proportional reductions from the baseline were similar for both the audit and model estimates, the absolute reductions in electricity consumption estimated using the EPSCT are approximately half of those predicted by Skanska and Griffin Engineering. This may be attributable to particular model specifications accounting for daylight effects on lighting usage. It is more likely in this case that the model fails to account for behavioral considerations that result in unusually high lighting usage.

While the model does not properly characterize actual building energy usage or estimate reductions associated with efficiency improvements specifically for the Jones Building, the calculations of designed energy need are a potentially valuable resource. If properly configured, the model could provide information beyond that currently available through campus energy use data for prioritization of future energy efficiency projects.

The model also considers the dynamic effects of efficiency improvements to one building system on all other systems. For example, a reduction in lighting energy consumption can also be expected to reduce the waste heat output from the operation of the lighting fixtures. In doing so, the thermal demand profile of the building is altered, reducing cooling loads in the summer and increasing heating loads in winter. The audit conducted by Skanska and Griffin Engineering fails to consider these dynamic effects in the energy reduction estimates for proposed projects.

As the campus seeks to meet the efficiency component of its climate reduction goals, it will be necessary to expand the auditing process conducted at the Jones Building across campus. A targeted expansion of this process will be needed to minimize the cost outlays associated with building audits. By prioritizing buildings according to their potential for energy use reductions, the University can maximize the potential reductions from each audit. One potential method for prioritizing campus facilities would be a comparison of energy consumption data with the design energy use as estimated by the EPSCT or a similar software tool. Further research is needed to determine the true feasibility of such a program.

Conclusions

Using the recommended efficiency improvements proposed by Skanska and Griffin Engineering for the Jones Building I was able to estimate associated potential greenhouse gas reductions from project implementation. I estimated reductions from the proposed projects of 2,750 to 2,950 tons CO_2-e. Using an avoided carbon offset cost I calculated the environmental value of these reductions. The total predicted environmental value is $27,500 to $29,500 per year.

The cumulative impact of similar efficiency projects implemented in all campus research facilities could significantly reduce campus GHG emissions. A proportional reduction in energy intensity at all research buildings could reduce annual campus emissions from steam and electricity10-11.5%.

The predicted environmental value of the proposed improvements is small relative to the associated energy savings. In the case of the Jones Building, the additional environmental value did not alter project payback periods so as to change project selection. Increases in offset prices could increase the environmental value of a project and might materially affect the payback period of future efficiency projects on campus. However, future increases in energy prices and reductions in grid emissions rates will mitigate this increase.

Formally recognizing and budgeting for the environmental value of efficiency projects could potentially catalyze additional improvements. If the administration were to allocate environmental savings to facilities managers for the purpose of funding additional facility audits and efficiency projects, the University may be able to replicate the Jones Building audit process across campus.

I attempted to characterize energy usage at the Jones Building using the Energy Performance Standard Calculation Toolkit. The results of this analysis indicated that the EPSCT was not configured to properly characterize building usage for this facility. The toolkit inadequately modeled potential energy reductions associated with proposed efficiency improvements. The inaccuracies in the reduction estimates are likely attributable to the improper characterization of baseline conditions and unique behavioral conditions in the Jones Building. Further research would be necessary to determine whether the model can adequately predict energy use reductions from an accurate baseline.

The model may still offer valuable information for prioritizing campus facilities for future energy audits. Unlike the audit conducted by Skanska and Griffin, the EPSCT model accounts for the dynamic effects of proposed efficiency improvements to one building system on the performance of other systems. A comparison of the EPSCT-predicted energy demand based on building design and building systems to actual building energy use could aid in the identification of buildings with the greatest potential for efficiency improvements. Additional research would also be necessary to determine applicability.

Citations

Augenbroe, G. and C. S. Park (2005). "Quantification methods of technical building performance." *Building Research and Information* 33(2): 159-172.

Conversation with Dr. Godfried Augenbroe. November 17, 2009.

Duke Climate Action Plan (2009). *Growing Green: Becoming a Carbon Neutral Campus.* Duke University.

Duke Energy (2009). “Duke Energy Carolinas Reaches Proposed Settlement in Its Request to Raise Base Rates in North Carolina” http://www.duke-energy.com/news/releases/2009102002.asp

Georgia Tech (2009). *Energy Performance Standard Calculation Toolkit: Introduction to the Project.* http://www.epsct.org/?id=402.

Kramer, John. “Re: Overall SEER of CHW Plants.” Email to Christopher Benonis. February 8, 2010.

National Renewable Energy Laboratory (2000). *Laboratories for the 21st Century: An Introduction to Low-Energy Design*. DOE/GO-102000-1112.

Palombo, Steve. *Building Energy Usage Dataset*. Accessed October 19, 2009. Duke University Facilities Management.

Palumbo, Steve. “Re: Campus Energy Usage for Masters Project.” Email to Christopher Benonis. February 23, 2010.

Park, Cheol-Soo and Godfried Augenbroe (2003). *Benchmarking of the Building Performance Toolkit for GSA*. Georgia Institute of Technology, College of Architecture.

Ramkrishnan, K. (2007). *Optimal Investment Strategy for Energy Performance Improvements in Existing Buildings*. Georgia Institute of Technology.

Skanska USA Building, Inc. and Griffin Engineering and Technical Services (2009). *Jones Building LEED & Energy Audit Report.*

Appendix I

General Information	
1.1	Weather Zone
1.2	Shielding Type
1.3	Exposed Façade
1.4	Weekly Occupancy (days/week)
1.5	Daily Occupancy (hours/day)
1.6	Summer Setpoint °C
1.7	Winter Setpoint °C
1.8	Temperature Setback (Y/N)
1.9	Occupants (m^2/person)
Building Materials	
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2.2	Window Glazing
2.3	Wall Material
2.4	Material Heat Capacity (J/(Km^2)
Building Geometry	
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3.2	Roof Area (m^2)
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4.7	Mechanical Ventilation System
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4.26	Type of PV Module
4.27	Type of Building Integration of PV Module
Primary Energy and Emissions	
5.1	Primary Energy and Emission Analysis Location
5.2	Energy Carrier 1 for Building Electric Services
5.3	Energy Carrier 2 for Domestic Hot Water
5.4	Energy Carrier 3 for Heating

Appendix II

Proposed Projects Environmental Value		
	HVAC System Upgrade	$16,049.45
23	Utilize a more practical energy recovery system.	$5,892.86
24c	Modify fume hoods from bypass to restricted bypass and adding VFD's on exhaust fans	$5,673.88
13	Control HVAC temperature set points for the entire facility, instead of having local room controls. Say for example if every space requests 2 deg F higher temperature.	$2,338.43
14	New air handling units and terminal units that are more efficient. Clean ductwork during renovations or replace. Utilize UV lights in new AHU. Assume a 5 to 10% improvement on efficiency.	$1,882.07
15	Convert entire control system to DDC when replacing new units and terminal boxes, remove air compressor. Considerable air leaks.	$262.21
34	During renovation work utilize commissioning services to assure that energy savings is incorporated correctly. Utilize Measurement & Verification testing to confirm.	$9,431.63
24b	Lower fume hood sash height from 18" to 12"	$4,964.90
1d	Existing 4', 4 lamp fixtures (labs and offices) remove 3 lamps and convert the remaining T12 lamps (42 watts) to high efficiency T5 lamps (28 watts) with electronic ballasts. Assume operation is 12 hours day or 4368 hours per year. Assume energy cost is $0.055 / kwh. Total of 1015 fixtures.	$3,044.15
24a	Reduce fume hood face velocity from 100 FPM to 80 FPM	$2,978.98
1c	Existing 4', 4 lamp fixtures (labs and offices) remove 2 lamps and convert the remaining T12 lamps (42 watts) to high efficiency T5 lamps (28 watts) with electronic ballasts. Assume operation is 12 hours day or 4368 hours per year. Assume energy cost is $0.055 / kwh. Total of 1015 fixtures.	$2,435.25
1b	Existing 4', 4 lamp fixtures (labs and offices) remove 1 lamp and convert the remaining T12 lamps (42 watts) to high efficiency T5 lamps (28 watts) with electronic ballasts. Assume operation is 12 hours day or 4368 hours per year. Assume energy cost is $0.055 / kwh. Total of 1015 fixtures.	$1,826.43
1a	Existing 4', 4 lamp fixtures (labs and offices) convert the remaining T12 lamps (42 watts) to high efficiency T5 lamps (28 watts) with electronic ballasts. Assume operation is 12 hours day or 4368 hours per year. Assume energy cost is $0.055 / kwh. Total of 1015 fixtures.	$1,217.62
2b	4', 2 lamp fixtures (corridors) remove 1 lamp and convert the remaining T12 lamps to high efficiency T5 lamps with electronic ballasts – 647 fixtures total	$1,146.13
18	Investigate why both hot water pumps are operating at the same time (25hp motor).	$873.37

2a	4’, 2 lamp fixtures (corridors) Convert the remaining T12 lamps to high efficiency T5 lamps with electronic ballasts – 647 fixtures total	$764.06
4	Trim impellers on water side instead of closing down valves. For example butterfly valves on condenser water pumps (50 hp) is 20% closed.	$349.63
25	Cleanout heating hot water and domestic hot water converters that have never been replaced or cleaned. Assume you can improve efficiency by 2-3%.	$156.05
20	Replace incandescent with LED for exit signs – 65 total	$95.92
8	4’, 1 lamp fixtures (basement, mech) Convert the remaining T12 lamps to high efficiency T5 lamps with electronic ballasts – 71 fixtures total	$41.88
3	De-lamp vending machines (savings per vending machine)	$9.43

Appendix III

	Project	Simple Payback (Years)	Adjusted Payback (Years)	Change in Payback (Years)
24a	Reduce face velocity from 100 FPM to 80 FPM	0.0	0.0	NA
18	Investigate why both hot water pumps are operating at the same time (25hp motor).	0.0	0.0	NA
33	Delamp vending machines (savings per vending machine)	0.0	0.0	NA
25	Trim impellers on water side instead of closing down valves. For example butterfly valves on condenser water pumps (50 hp) is 20% closed.	0.3	0.2	(0.05)
20	Cleanout heating hot water and domestic hot water converters that have never been replaced or cleaned. Assume you can improve efficiency by 2or 3%.	0.7	0.7	(0.02)
34	During renovation work utilize commissioning services to assure that energy savings is incorporated correctly. Utilize Measurement & Verification testing to confirm.	1.0	0.9	(0.09)
24b	Lower sash height from 18” to 12”	1.4	1.3	(0.11)
8	Replace incandescent with LED for exit signs – 65 total	1.9	1.8	(0.15)
1d	Existing 4’, 4 lamp fixtures (labs and offices) remove 3 lamps and convert the remaining T12 lamps (42 watts) to high efficiency T5 lamps (28 watts) with electronic ballasts. Assume operation is 12 hours day or 4368 hours per year. Assume energy cost is $0.055 / kwh. Total of 1015 fixtures.	2.5	2.3	(0.20)
1c	Existing 4’, 4 lamp fixtures (labs and offices) remove 2 lamps and convert the remaining T12 lamps (42 watts) to high efficiency T5 lamps (28 watts) with electronic ballasts. Assume operation is 12 hours day or 4368 hours per year. Assume energy cost is $0.055 / kwh. Total of 1015 fixtures.	3.1	2.9	(0.23)
1b	Existing 4’, 4 lamp fixtures (labs and offices) remove 1 lamp and convert the remaining T12 lamps (42 watts) to high efficiency T5 lamps (28 watts) with electronic ballasts. Assume operation is 12 hours day or 4368 hours per year. Assume energy cost is $0.055 / kwh. Total of 1015 fixtures.	4.2	3.8	(0.37)
2b	4’, 2 lamp fixtures (corridors) remove 1 lamp and convert the remaining T12 lamps to high efficiency T5 lamps with electronic ballasts – 647 fixtures total	4.3	3.9	(0.41)
1a	Existing 4’, 4 lamp fixtures (labs and offices) convert the remaining T12 lamps (42 watts) to high efficiency T5 lamps (28 watts) with electronic ballasts. Assume operation is 12 hours day or 4368 hours per year. Assume energy cost is $0.055 / kwh. Total of 1015 fixtures.	6.3	5.7	(0.55)

2a	4’, 2 lamp fixtures (corridors) Convert the remaining T12 lamps to high efficiency T5 lamps with electronic ballasts – 647 fixtures total	6.4	5.8	(0.56)
3	4’, 1 lamp fixtures (basement, mech) Convert the remaining T12 lamps to high efficiency T5 lamps with electronic ballasts – 71 fixtures total	12.0	11.0	(1.04)
54	HVAC System Upgrade	15.0	13.9	(1.11)
13	Control HVAC temperature set points for the entire facility, instead of having local room controls. Say for example if every space requests 2 deg F higher temperature.			
14	New air handling units and terminal units that are more efficient. Clean ductwork during renovations or replace. Utilize UV lights in new AHU. Assume a 5 to 10% improvement on efficiency.			
15	Convert entire control system to DDC when replacing new units and terminal boxes, remove air compressor. Considerable air leaks.			
23	Utilize a more practical energy recovery system.			
24c	Modify fume hoods from bypass to restricted bypass and adding VFD’s on exhaust fans			

Appendix IV

General Information		
1.1	Weather Zone	RDU Intl Airport
1.2	Shielding Type	City Center Average Height, Forests
1.3	Exposed Façade	More than one Exposed Façade
1.4	Weekly Occupancy (days/week)	7
1.5	Daily Occupancy (hours/day)	24
1.6	Summer Setpoint °C	23
1.7	Winter Setpoint °C	21
1.8	Temperature Setback (Y/N)	N
1.9	Occupants (m^2/person)	20
Building Materials		
2.1	Roof Material	Membrane, sheathing, insulation board, 100mm LW concrete (U: 0.304, HC: 134.9kJ/m^2K)
2.2	Window Glazing	Single Glaze 6mm acrylic/polycarb (U: 5, Tsol: 0.69)
2.3	Wall Material	100 mm LW concrete, board insulation, gypsum board (U: 0.673, HC 124.7kJ/m^2K)
2.4	Material Heat Capacity (J/(Km^2)	Heavy (260,000kJ/m^2K)
Building Geometry		
3.1	Building Gross Area (m^2)	9,570
3.2	Roof Area (m^2)	2,183
3.3	Building Height (m)	19.2
3.4	Ventilated Volume (m^3)	204,185
3.5	Window Area (m^2) and Shading Control (N, S, E, W)	N: 207, S: 239, E: 13.3, W: 13.3, No Controls
3.6	Opaque Wall Area (m^2) (N, S, E, W)	N: 1,175, S: 1,235, E: 513, W: 513
Building Systems		
4.1	Cooling System SEER Value	4.4
4.2	Heating System COP	0.25
4.3	HVAC System Type	Variable Air Volume/Water or Water & Air/Water/Yes

4.4	Ventilation Type	Mechanical Ventilation
4.5	Mechanical Ventilation Fresh Air Flow Rate	85,000
4.6	Ventilation Operational Time Fraction	0.3
4.7	Mechanical Ventilation System	All other cases
4.8	Exhaust Air Recirculation Percentage	No exhaust air recirculation
4.9	Air Leakage Level	High
4.10	Heat Recovery System Type	No heat recovery
4.11	Lighting Power Intensity (W/m^2)	24
4.12	Constant Illumination Control	No Constant Illumination Control (Control Factor: 1)
4.13	Daylight Control	Manual (Factor: 1)
4.14	Occupancy Impact Control	Manual (Factor: 1)
4.15	Hot Water Flow Control	All Other Cases
4.16	Cool Water Flow Control	Automatically Operating Speed Control
4.17	Electricity Usage Intensity	Typical (Office: 230kWh/workplace/year
4.18	Domestic Hot Water Distribution	Taps more than 3m from heat generation
4.19	Domestic Hot Water Generation	VR-boiler
4.20	Solar Hot Water Module Surf. Area (m^2)	0
4.21	SHW Module Angle (°)	N/A
4.22	SHW Module Orientation	N/A
4.23	PV Module Surface Area (m^2)	0
4.24	PV Module Angle (°)	N/A
4.25	PV Module Orientation	N/A
4.26	Type of PV Module	N/A
4.27	Type of Building Integration of PV Module	N/A
Primary Energy and Emissions		
5.1	Primary Energy and Emission Analysis Location	US: Eastern
5.2	Energy Carrier 1 for Building Electric Services	Electricity: Total Primary Energy
5.3	Energy Carrier 2 for DHW	Fuel: Anthracite Coal
5.4	Energy Carrier 3 for Heating	Fuel: Anthracite Coal