Green Building at Duke University: Potential Energy Savings and GHG Benefits Achieved by Renovating Existing Residence Halls

by

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May 2008

Masters project submitted in partial fulfillment of the

requirements for the Master of Environmental Management degree in the

Nicholas School of the Environment and Earth Sciences of Duke University

2008

Common Abbreviations

ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
Btu	British Thermal Unit, a measurement of energy
CDD	Cooling Degree Days
CFE	Duke University Committee on Facilities and Environment
DDC	Direct Digital Control
EMS	Environmental Management System
FMD	Duke University Facilities Management Department
FY	Fiscal Year, beginning July 1 and ending June 30
GHG	Greenhouse Gas
gpf	Gallons per flush, a measurement of plumbing fixture efficiency
gpm	Gallons per minute, a measurement of water flow rate
HDD	Heating Degree Days
HVAC	Heating, Ventilation, and Air Conditioning
IESNA	Illuminating Engineering Society of North America
kWh	Kilowatt-hour, a measurement of electricity consumption
LEED	Leadership in Energy and Environmental Design
LEED AP	LEED Accredited Professional
RLHS	Duke University Residence Life and Housing Services
VAV	Variable Air Volume
VFD	Variable Frequency Drive
USGBC	United States Green Building Council

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Abstract

In the U.S., buildings currently account for 65% of total electricity consumption, 36% of total primary energy use, 12% of potable water consumption and 30% of total greenhouse gas emissions. The growing field of green building encourages non-traditional building designs that reduce energy use and natural resource consumption which in turn minimize adverse environmental impacts. This study assesses the energy and environmental benefits achieved through a recent LEED-certified renovation at Duke University's Kilgo Quad. This renovation was expected to provide 32% better energy efficiency and 20% to 30% better water efficiency than the industry standard design building, while upgrading mechanical systems and electrical wiring and adding central air conditioning for the first time. Data for this analysis was collected by performing a sustainability audit and reviewing utility records to quantify changes in energy and water consumption and associated CO_2-equivalent emissions. The audit results were then compared to a baseline measured at Few Quad, which is slated for a similar renovation in Summer 2008, to gauge relative performance before and after the Kilgo renovation.

Compared to the 2001 baseline, Kilgo Quad experienced significant reductions of 20% in electricity consumption and 35% in water consumption immediately following the renovation in 2004. However, Few Quad experienced greater reductions of 35% in electricity consumption and nearly 50% in water consumption over the same time period, without the benefit of any renovation. Resource consumption in both buildings began to rise again after 2005, but the increases at Kilgo were two to three times larger in magnitude, returning the building to nearly pre-renovation levels by 2006. Over this time period, occupancy levels at each dorm remained stable and each building endured the same weather patterns. Even though air conditioning was fully-operational at Kilgo in 2004, energy consumption levels did not spike until 2006, suggesting that infrastructure modifications were not responsible for changes in consumption either. By 2006, despite having less square footage, fewer people and the benefit of the recently-completed renovations, Kilgo Quad used more energy per square foot and more water per person than Few Quad. Kilgo Quad's overall CO_2-eq emissions actually surpassed the emissions from Few Quad in 2006 as well. While no single explanation accounts for this under-performance, it is my belief that changes in individual demand for resources were a key driver behind the unexpectedly high consumption levels at Kilgo. It is unclear why water consumption is more efficient at Few Quad, despite the Kilgo renovation efforts to improve water efficiency. Upgrades to electrical wiring increased plug-in load capacity by a factor of ten, enabling occupants to use electricity differently and possibly contributing to greater phantom load impacts and a rebound effect, neutralizing any efficiency gains expected after the renovation.

Further study is needed to determine exactly why Kilgo Quad is not performing as well as Few Quad and exerting a larger impact on the environment. Green building offers numerous benefits, and can contribute significantly to Duke University's goal of becoming carbon-neutral in the future, however it should be noted that achieving LEED certification does not necessarily guarantee long-term reductions in energy and water consumption. University planners must consider whether a renovation will change a building's capacity for consuming resources and then seek a good balance between optimal comfort and effective resource management. Occupant education and improved metering strategies are also critical keys to successful green renovations at Duke University.

I. Introduction

This paper will evaluate the impacts of green renovation on the performance of an existing building at Duke University. The analysis will focus on two residential dorms: the recently-renovated Kilgo Quad and Few Quad, which is slated for a similar renovation in Summer 2008.

Through analysis of available utility data and a comprehensive sustainability audit of the building, I will quantify the changes in energy and water consumption and associated greenhouse gas emissions that were observed after renovating Kilgo Quad with the goal of attaining basic certification in the LEED Rating System. Data analysis will incorporate quantitative and qualitative information from numerous sources, including utility records, input from FMD staff, meetings with building managers and engineers, a building walkthrough, previous University energy studies and reports, Operations & Maintenance (O&M) Manuals, and relevant climate data obtained from the National Climatic Data Center. After performing a similar analysis for Few Quad, the performance of both buildings will be compared over the period of time beginning in Fall 2000 and ending in Spring 2007. Data will be organized into academic years; for example, 2001 includes the semesters of Fall 2001 and Spring 2002. The academic year of 2001 would align with the Duke fiscal year of FY 2002.

This study will also evaluate the relative impacts of four key drivers of energy and water consumption to try to determine why consumption levels have changed. These possible drivers are:

1. Effect of outdoor temperatures on heating and cooling loads
2. Number of occupants in the building
3. Changes in building infrastructure

4. Changes in individual demand for the resource (i.e. how are energy and water used?)

Ultimately, this analysis will assess the impacts that LEED-based green renovations have had on Kilgo Quad’s energy use and resulting greenhouse gas emissions and clarify the potential environmental benefits that can be expected from using green building techniques to renovate Few Quad and other Duke University buildings.

II. Materials and Methods

Background: Sustainability and Green Building at Duke University

In recent years, sustainable design and management have become significant priorities for Duke University students, faculty and administration. The University has adopted a number of policies to address the environmental, economic and social impacts associated with Durham County's largest employer. A few of these policies that are most relevant to this study are described below:

- In 2003, the Office of the University Architect updated the Duke University Design Guidelines to promote green building on campus. These guidelines, which are provided to all consultants engaged in construction or design work with Duke, promote energy conservation best practices and encourage the use of high-efficiency mechanical and electrical systems. All new-construction and renovation projects are also required to be certified by the U.S. Green Building Council (USGBC) according to the LEED Rating System.
- In March 2005, the administration drafted the Duke University Environmental Policy which committed the University to provide leadership in the areas of environmental research and education, environmentally responsible operations, and environmental stewardship in the community.[1]
- In 2007, President Brodhead signed the American College and University Presidents Climate Commitment and thereby pledged to eliminate the campus's greenhouse gas emissions over time. By mid-2009, Duke University must publicly set a target date and action plan for becoming a climate-neutral entity. This significant undertaking also prompted the University

to form the University Sustainability Committee to work with the Environmental Sustainability Coordinator and oversee the management of current and future sustainability initiatives.

Background: Benefits of Green Building

The condition of the built environment is a critical component of the quality of daily life. Beyond providing basic shelter from the elements, buildings provide mankind a place to learn, to work, and to innovate. A building's design and performance influences the physical and mental health of its occupants and contributes to their overall productivity. On a larger scale, buildings facilitate progress in education, trade and commerce, helping to power the global economy. However, traditional buildings also have a direct effect on the natural environment and contribute to environmental degradation. In the U.S., buildings account for: [2]

- 65% of total electricity consumption
- 36% of total primary energy use
- 12% of potable water consumption
- 30% of total greenhouse gas emissions

Green-building practices encourage non-traditional building designs that minimize energy use and natural resource consumption. These techniques reduce long-term operating costs by installing energy-efficient equipment; improve occupant health and productivity by improving ventilation, lighting, and indoor air quality; and minimize negative environmental impacts by conserving water and electricity and reducing greenhouse gas emissions associated with energy use. By renovating existing buildings according to sustainable green building practices, it is possible to design high performance buildings while preserving the original aesthetic characteristics, retaining the valuable embedded energy used to build the original structure and avoiding some of the costs of demolition and new construction.

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ is the nationally accepted tool to guide the design, construction, and operation of high performance green buildings. LEED gives building owners and operators the tools they need to have an immediate and measurable impact on their buildings' performance. LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality.[3] LEED provides a roadmap for measuring and documenting success for every building type and each phase of a building lifecycle. Distinct versions of the LEED Rating System have been created to manage "New Construction (NC)" and "Existing Buildings (EB)" projects. LEED-NC provides guidelines for design and construction, while LEED-EB focuses on ongoing operations and maintenance of green buildings.

Background: Green Building at Duke University

A significant amount of progress towards maintaining Duke's sustainability policies and achieving the Climate Commitment goal can be achieved through effective application of green-building practices for future campus new construction and renovation projects. To date, Duke has completed nineteen building projects that are LEED Certified or registered for certification; two of these projects have been certified at the Silver level and the rest have achieved basic LEED Certification. See Appendix A for a complete list of projects. While, in my opinion, Duke has done an admirable job as an early-adopter of university green-building practices, a majority of these projects have involved new construction rather than renovation. In fact, the entire portfolio of green buildings currently represents just 8% of the 220 buildings on campus. This means that there is enormous potential for improvement of existing buildings through green-building renovation on campus.

The first principle of the 2006 Action Plan, Duke University's planning guide, asks that the historic identity of Duke's architecture be strengthened "by identifying selected buildings…which should be preserved."[4] While many buildings may be deemed inadequate as educational and operational needs evolve over time, it is safe to say that Duke will continue to preserve the historic aesthetic of its existing campus architecture and will not engage in a pattern of replacing existing buildings by demolishing the current structure and rebuilding from scratch. As Duke University nears completion of the current round of construction, it is worthwhile to examine the potential benefits of a new round of green building focused on systematic renovation of the existing building stock on campus in order to improve building efficiency and reduce environmental impact.

The buildings on Duke's campus have varying energy and materials requirements depending on the primary functional needs of its occupants. For our purposes, the existing building stock may be divided into the following sectors based on primary building use:

Duke University Buildings (Excludes maintenance and support facilities)	
Academic and Research	77
Medical Center	56
Athletics and Recreation	13
Residence Halls	29
Central Campus Apartments	45
Total	**220**

Source: http://www.dukenews.duke.edu/resources/quickfacts.html#buildings

These buildings receive utility services from a number of facilities. Electricity is supplied by Duke Power, steam for heating is produced onsite at the Duke coal-fired steam plant, potable water is obtained from the Durham Department of Water Management, and chilled water for air conditioning is produced at either the Duke Central Chiller Plant or by means of individual chiller units per building or set of buildings.

In order to simplify the analysis, this project will focus on the Residence Halls sector, and specifically the “Gothic” residence halls that were the first built on campus. Currently, 68% of the undergraduates on West Campus live in the "gothic" quads.[5] The residence halls provide a number of uses to their occupants, including, but not limited to, sleeping, studying, bathing, and socializing. Accordingly, these buildings are “in-use” twenty-four hours a day and can benefit greatly from renovations that maximize building performance and efficiency.

Background: Potential Drivers of Resource Consumption

The primary objective of this study is to determine the actual impacts of green building renovation on the environmental performance of Kilgo Quad. In addition to analyzing the net changes in resource consumption before and after the renovation, it is also important to consider how this resource consumption may have been influenced by four key drivers: weather, occupancy, infrastructure and demand. This section will describe the background information and assumptions considered for each of these drivers throughout this study.

Effect of Weather

Changes in weather patterns, and specifically changes in temperature, will influence energy and water consumption. A stronger heating season will promote greater steam consumption for space heating, while a stronger cooling season will most likely increase demand for air conditioning, driving consumption of chilled water. Accordingly, increased demand on the HVAC system will increase electricity consumption to power the mechanical system. The key question will be whether there is an observed correlation between changes in outdoor temperature and changes in consumption of electricity and water.

Another especially important weather consideration in this part of the country is the drought condition. Durham is currently experiencing one of the most severe droughts in the region's history, and this comes on the heels of the most recent drought of 1998 – 2002. Tightening or relaxation of local water restrictions, as well as the psychological perception of whether Durham is "in a drought or not", may significantly affect water consumption.

Effect of Occupancy Levels

An important data point to consider is how per capita consumption of energy and water was affected by the Kilgo renovations. Changes to mechanical systems and infrastructure may be accurately reflected in consumption per-square-foot calculations, but the influence of an increase or decrease in building occupancy is another critical piece of information.

Each year, undergraduate students (except for 1st year students) may choose where they will live during the annual "Room Pix" process. These students will live in a specific room for the Fall and Spring semesters of that academic year. Occupancy in the Spring semester will tend to be slightly higher than the Fall Semester because room assignments are reserved for students returning from study-abroad programs. Occupancy data for Kilgo and Few Quads (by semester) from 2000 – 2006 is available in Table 1. The increase in occupancy in Fall 2003 is best explained by an overall increase in the number of 2nd year undergraduates at Duke that year.

Table 1. Occupancy of Kilgo Quad and Few Quad, 2000-2006

Semester	Kilgo	Few
Fall 2000	317	435
Spring 2001	318	436
Fall 2001	308	418
Spring 2002	309	436
Fall 2002	401	400
Spring 2003	393	412
Fall 2003	381	426
Spring 2004	383	435
Fall 2004	378	430
Spring 2005	375	433
Fall 2005	371	428
Spring 2006	374	437
Fall 2006	373	430
Spring 2007	374	437

Effect of Changes in Infrastructure

This driver considers the effects of adding a previously unused technology to the building's main infrastructure. This analysis will specifically consider that central air conditioning was added to Kilgo Quad for the first time ever during the renovation period. This addition to Kilgo's infrastructure will have undoubtedly added to energy requirements for the building regardless of the improved performance or efficiency ratings of any of the new equipment.

Effect of Demand

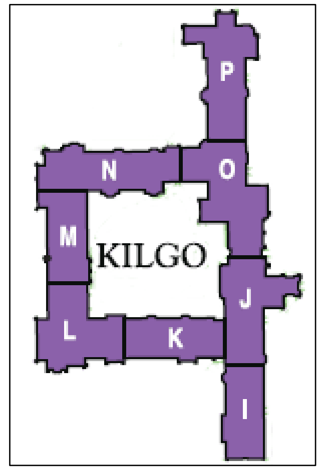
When considering the impact of demand on energy and water consumption in Kilgo, there are two key questions to consider:

1. Has occupant behavior shifted in a way that requires greater or fewer resources?
2. Have building modifications changed the way in which occupants are able to use resources?

Examination of these questions requires that we consider not only the changes to technology implemented during renovation, but also the behavior patterns of the occupants. Human behavior will have a significant impact on whether or not a building performs as the designers and engineers intended.

III. Results

Audit of Kilgo Quad



Kilgo Quad ("Kilgo") was originally built in 1926 as one of the first residence houses for Trinity College undergraduates and students of the professional schools.[6] Kilgo is designed in the Gothic style and was built using structural steel and a combination of native Hillsborough bluestone and Indiana limestone for the solid exterior walls.[7] The structure covers 124,935 external gross square feet and offers 95,992 square feet of total room area for building occupants. Kilgo is adjacent to the West Union building, just across from the Bryan Center Walkway Plaza.

Kilgo is made up of eight individual houses, each labeled respectively from I to P. The number of floors in each house varies from three to five, with each floor containing an average of 10 rooms each. In total, there are 222 bedrooms, 41 bathrooms, one kitchen, one laundry room and twelve large rooms that serve as student common areas, study space, or office space. The maximum capacity during both the Fall semester (August 15 – December 31) and the Spring semester (January 1 – May 15) is 390 full-time occupants. In the summer months of June and July, Kilgo houses students for various camps and summer session classes. However, these records are not kept by Duke University personnel and vary from year-to-year. Therefore, this analysis will focus only on typical occupancy during the academic year. For our purposes, the dorm is at half capacity for the months of May and August, reflecting decreased occupancy as students move in and out of the building at the beginning and end of each school year.

Summary of the Kilgo Quad Renovations, 2002-2004

To provide adequate context for the audit analysis, the features and strategies implemented in the renovation project are described below. Key findings from various planners and consultants are highlighted as well. The Kilgo renovations were originally proposed to improve on three facets of the aging building:

1. Absent, inadequate, or failing mechanical systems
2. Inadequate electrical wiring to meet plug-in load requirements
3. Insufficient structural features to comply with the Americans with Disabilities Act of 1990

In order to fully address each of these areas of improvement while minimizing the effect of construction work on occupants, the University scheduled three renovation phases. Each phase was planned for a 15-week project period during the Summers of 2002, 2003 and 2004. During each separate phase, the renovations were carried out in two to three quad houses and the following tasks were completed:

- HVAC mechanical systems, ductwork and controls were upgraded to employ newer, more efficient equipment. Specifically, fan coil units were installed in every room and outside air handlers with built-in heat recovery systems were installed in each hallway.
- Radiant heating panels were installed in the ceilings of all third floor bathrooms
- A Siemens Direct Digital Control (DDC) system was integrated into the HVAC system so that the FMD Energy Manager would be able to set allowable temperature ranges for each room. Occupants have access to individual room controls and the ability to adjust room temperature between the control setpoints of 66° – 78° Fahrenheit.

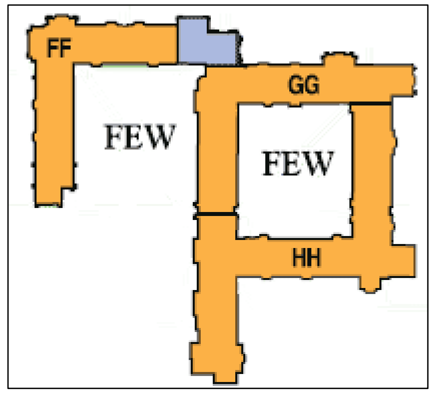
- Electrical wiring was brought up to code by replacing the original wiring and increasing the plug-in load from roughly 6.67 amps per room to 60 amps per room. Circuit breakers were also updated to provide a single breaker per room; prior to the renovations, a single circuit breaker may have controlled a group of rooms and a single room may have been divided by two different circuit breakers.
- Lavatory fixtures were replaced with high-efficiency faucets and showerheads
- Chilled water connections were installed, enabling the use of central air conditioning in each room
- Some interior structural work was completed to widen certain hallways and replace doors and fire suppression systems

Phase I of the renovations was completed in Summer 2002 and focused on Houses K, L, and M. Phase II was completed in Summer 2003 and focused on Houses N, O, and P. This phase also included the elevator installation in House O. Phase III was completed in Summer 2004 and focused on Houses I and J.

<u>LEED Submittals</u>

Throughout the renovation process, the project manager and contractor collaborated with a LEED Accredited Professional (LEED AP) consultant to manage and track the green building upgrades. This LEED AP advised planners on best practices related to energy, water and materials upgrades and prepared the LEED certification submittal paperwork for Phase II and Phase III. Phase II of the project received 30 points on the LEED for New Construction (LEED-NC) rating scale and was awarded the basic level of LEED Certified by the U.S. Green Building Council. The project scorecard is available at http://www.usgbc.org/ShowFile.aspx?DocumentID=535 and is attached as Appendix B. Phase III of the project received 28 points on the LEED-NC rating scale and was also awarded the level of LEED Certified by the USGBC. The project scorecard is available at http://www.usgbc.org/ShowFile.aspx?DocumentID=1080 and is attached as Appendix C. LEED certification was not sought for Phase I of the Kilgo renovations. A full description of the renovation plan as it related to the pursuit of LEED certification is available in Appendix D.

Audit of Few Quad



Few Quad ("Few") was originally built in 1933 to round out the group of Gothic residence halls provided for Trinity College undergraduates and students of the professional schools. Few is identical in architectural style and structural materials to Kilgo, using structural steel, native Hillsborough bluestone and Indiana limestone. The structure covers 138,183 external gross square feet and offers 103,995 square feet of total room area for building occupants. Few is adjacent to Chapel Drive and is located just across from the West Union Building.

Few is made up of three individual residence houses, labeled FF, GG, and HH and also houses the Duke University Women's Center (shown in blue on the floorplan above). The number of floors in each house varies from three to five, with a small six-story tower in House HH. In total, there are 276 bedrooms (including one faculty apartment), 43 bathrooms, seven small kitchens , two laundry rooms and 17 large rooms that serve as student common areas, study space, or office space. The maximum capacity during both the Fall semester (August 15 – December 31) and the Spring semester (January 1 – May 15) is 472 full-time occupants. Again, this analysis will focus solely on the academic year occupancy. For our purposes, the dorm is at half capacity for the months of May and August, reflecting decreased occupancy as students move in and out of the building at the beginning and end of each school year.

Summary of Proposed Few Quad Renovations, 2008-2009

The Few Quad renovations are slated to begin immediately following the conclusion of the 2007-2008 academic year. The renovation period will last from June 2008 – December 2008 and, unlike the Kilgo renovations, will displace building occupants throughout the entire construction project. This project is characterized primarily as an infrastructure modification project and will make comparable modifications to energy and water systems as were completed in the Kilgo renovation.

LEED Submittals

As with all new construction or renovation projects at Duke University, the Few Quad renovation will be completed with the assistance of a LEED AP, who will track accumulated credits and submit the paperwork to register for certification with the USGBC. The project team is seeking a level of Silver certification and is planning to apply under the LEED-NC rating system, although recent changes in USGBC regulations may require that the project application is developed under the LEED for Existing Buildings (LEED-EB) rating system. The current project scorecard may be reviewed in Appendix E, although it is probable that this document will change to some degree before the beginning of the project. The LEED AP has identified 35-41 achievable credits across the entire project. Descriptions of the proposed renovation plan and the targeted LEED credits for energy and water consumption are also included in Appendix D.

Analysis of Kilgo Resource Consumption

To begin my analysis, I reviewed the utility records for electricity, steam and chilled water use for the period of 2000 - 2006. These records were provided by FMD and are available in Appendix F of this report. The numbers provided are not utility-grade data, meaning the measurements inherently have some margin of error, but are still indicative of magnitudes and patterns. While many Duke University buildings share utility meters (in accordance with planning decisions made 50 to 75 years ago), electricity is metered separately for Kilgo Quad and measured in kilowatt-hours (kWh).

Utility records for steam are not available prior to 2003, due to the fact that Kilgo steam condensate was returned to a common header and metered at the West Campus Union, along with a number of other West Campus quads and other buildings. Costs for total condensate for West Campus were allocated to each building on the basis of square footage, so it is impractical to attempt to determine Kilgo's specific usage prior to 2003. The available steam data from 2003 – 2006 is taken from a Kilgo-specific condensate meter and measured in pounds (lbs).

Kilgo Quad did not offer air conditioning to its occupants until the buildings were connected to Duke Central Chiller Plant in Summer of 2003. The available chilled water data from 2003 – 2006 is exported from a Siemens monitoring database integrated into the Kilgo HVAC system and is measured in ton-hours.

Utility data for all potable water meters is reported in cubic feet per month. Kilgo shared one water meter with Few, Craven and Crowell Quads for 2000 –2002, until a building-specific meter was installed in Summer 2003.

Energy Analysis: Electricity Consumption

It is difficult to accurately characterize electricity consumption during the three-year renovation period, due to the fact that the mechanical systems of different quad houses were upgraded at different times during each phase. Therefore, for the purposes of this report, I will consider the renovation completed in Summer 2004 and will focus on the utility records for 2004, 2005 and 2006 in comparison to the pre-renovation baseline of 2001. In order to discuss electricity consumption in a standardized way, I converted the utility data from kWh to Btu,[i] and will refer to both units of measurement throughout the analysis.

Prior to the renovation, Kilgo Quad consumed 1,050,880 kWh of electricity, or 32,992 Btu/ft^2, in 2001. After renovations were finished, electricity consumption in 2004 was reduced to 815,760 kWh, or 25,610 Btu/ft^2. This change represents a decrease of 22% in total electricity consumption for the building since 2001. In 2005, consumption decreased even further to 735,120 kWh, or 23,079 Btu/ft^2, which represents a decrease of 30% from the 2001 baseline. However, utility records indicate that Kilgo consumed 1,006,800 kWh of electricity, or 31,608 Btu/ft^2, in 2006. This data represents a significantly smaller 4.2% annual reduction in electricity consumption compared to 2001. Furthermore, this change represents a 37% increase in total electricity consumption from 2005 to 2006. See Table 2 for detailed information for the entire time period.

[i] One kilowatt-hour (kWh) = 3412 Btu

Table 2. Kilgo Electricity Consumption (annual)

Academic Year	Electricity (kWh)	Total Interior Gross Area (sq. ft.)	Electricity Consumption (Btu/sq.ft)	% change from previous year	% change from 2001
1999	796,320	108,682	25,000	-	-
2000	1,015,680	108,682	31,887	+27.5	-
2001	**1,050,880**	**108,682**	**32,992**	**+3.5**	**-**
2002	755,760	108,682	23,727	-25.6	-25.6
2003	632,880	108,682	19,869	-16.3	-39.8
2004	**815,760**	**108,682**	**25,610**	**+28.9**	**-22.4**
2005	**735,120**	**108,682**	**23,079**	**-9.9**	**-30.0**
2006	**1,006,800**	**108,682**	**31,608**	**+37.0**	**-4.2**

As the renovations were completed, energy-efficient compact fluorescent light (CFL) bulbs were installed in all of the hallways, bedrooms and stairwells. Fan coil terminal units were installed in each room to manage HVAC distribution and air handler units with built-in heat recovery systems were installed in the major hallways. On paper, the CFL bulbs would have improved energy efficiency in the building, while the HVAC modifications, while technically efficient, may have increased demand on the building electrical systems.

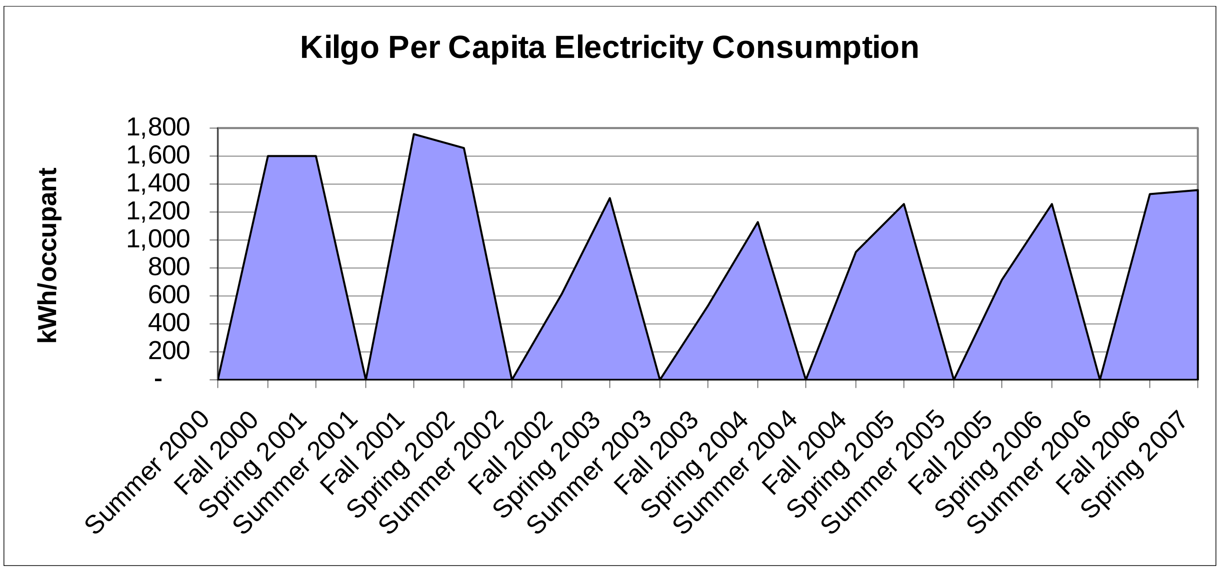
Per Capita Consumption: Electricity

An interesting finding in this analysis is the change in per capita electricity consumption from 2005 to 2006. Compared to the baseline year of 2001, there was a 42% decrease in per capita electricity consumption to 987 kWh per occupant in 2005. However, in 2006, the data indicates a significantly smaller reduction of 20.8% from the baseline. While this still represents a sizeable reduction in per capita electricity use compared to pre-renovation data, it also indicates that, from 2005 to 2006, per capita electricity consumption increased by 36.6% while building occupancy decreased marginally. See Table 3 for details on Kilgo Per Capita Electricity Consumption.

Table 3. Kilgo Per Capita Electricity Consumption

Academic Year	Annual Consumption (kWh)	Occupancy	Per Capita Consumption (kWh/occupant)	% change from previous year	% change from 2001
2000	1,015,680	635	1,599	-	-
2001	**1,050,880**	**617**	**1,703**	**+6.5**	**-**
2002	755,760	794	952	-44.1	-45.8
2003	632,880	764	828	-13.0	-51.4
2004	**815,760**	**753**	**1,083**	**+30.8**	**-36.4**
2005	**735,120**	**747**	**987**	**-8.9**	**-42.0**
2006	**1,006,800**	**745**	**1,348**	**+36.6**	**-20.8**

Figure 1. Kilgo Per Capita Electricity Consumption



<u>Energy Analysis: HVAC Consumption of Steam and Chilled Water</u>

It is challenging to describe the impact of the renovations on steam and chilled water usage, due to the fact that Kilgo was not attached to campus chilled water loop until the renovations began and metering for steam was not detailed enough to accurately measure Kilgo's specific usage until 2003. However, there are two general points that can be illuminated by a broad analysis of steam and chilled water data from 2003 – 2006:

1. Steam and chilled water are generated by processes that burn fossil fuels. Kilgo's carbon footprint will be discussed in a later section, but it is noteworthy to measure how much energy these HVAC inputs add to Kilgo's overall energy signature.
2. Review of the changes in annual consumption may provide general insight into a number of qualitative issues, including occupant usage patterns and perception of the building's overall thermal performance.

Chilled water data was standardized by converting from ton-hours to Btu[ii] and the steam data by converting from pounds to Btu[iii]. In this way, it is possible to examine the impact of the HVAC system in all seasons in a uniform format. Also, this allows a combination of all energy inputs, measured in Btu, to give a total representation of energy use in Kilgo in terms of Btu/ft^2. It is important to note that, when performing calculations related to square footage, I use the Interior Gross Area rather than Total Room Area. This is done in order to account for other non-occupied area that may not be included in Total Room Area, but which may affect thermal conditions in the building. Refer to Figure 2 for a graphical view of Kilgo's total energy consumption over the analysis time period. There are a number of worthwhile results from this analysis:

1. The Btu measurements associated with use of steam and chilled water as thermal inputs for the HVAC system significantly exceed the Btu measurements for electricity consumption. This suggests that heating and cooling systems in Kilgo are more energy-intensive than electrical systems, including lighting and plug-loads.
2. While it is obvious that total energy consumption increases dramatically when steam and chilled water data is added in 2003, it is important to note that there has been a positive

[ii] One ton-hour represents the amount of power required to cool one ton of ice by 1 degree Fahrenheit every 10 minutes. One ton of cooling capacity = 12,000 Btu per hour.
[iii] One pound of steam = 1003 Btu

net change in total energy consumption each year since 2002. This upward trend in total energy consumption has shown consistent growth between 2002 and 2006.

3. It is interesting to note the difference between year-to-year change in chilled water consumption and year-to-year changes in steam consumption. In 2003, 2004, and 2005, there are consistent increases in chilled water usage as the HVAC units come online for each phase of the renovation. Then, in 2006, chilled water use decreases by 7.3%, although it is unclear whether this decrease is due to a shift in demand or a less-intense cooling season. Over the same time period, steam consumption data exhibits the same generally positive trend from year-to-year; again, it is unclear whether this usage pattern is driven by changes in the weather or in occupant behavior.

Figure 2. Kilgo Total Energy Consumption

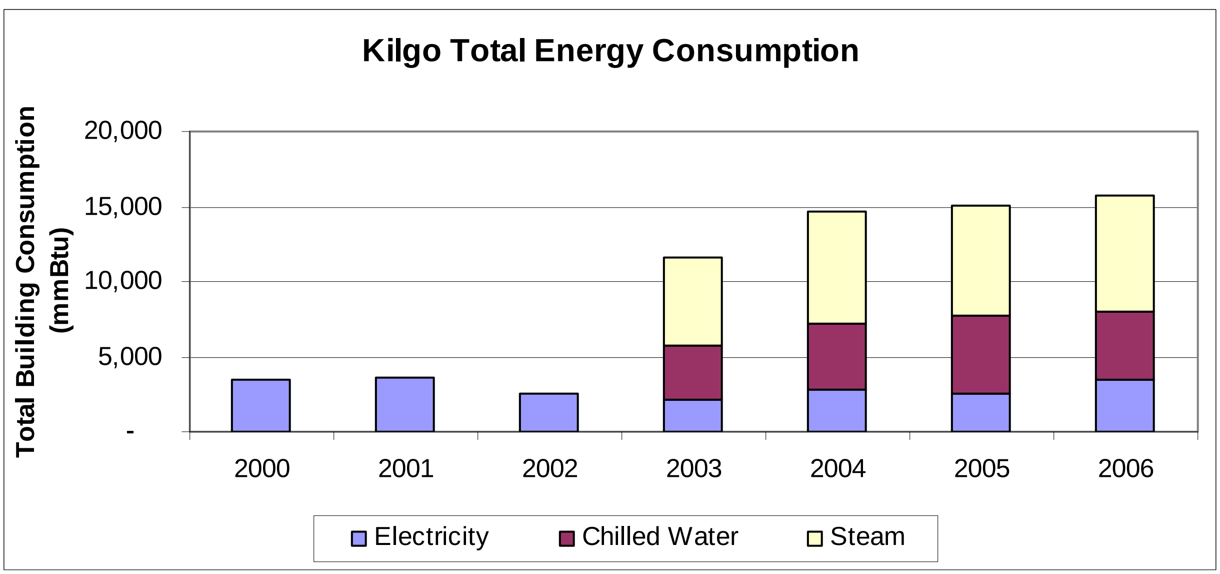


Table 4. Kilgo Total Energy Consumption (Btu)

	Electricity	Chilled Water	Steam	*Total Consumption (Btu/ft^2)	% change from previous year
2000	3,465,500,160	-	-	31,887	-
2001	3,585,602,560	-	-	32,992	+3.4
2002	2,578,653,120	-	-	23,727	-28.1
2003	2,159,386,560	3,591,132,000	5,835,940,659	106,609	+349.3
2004	2,783,373,120	4,357,176,000	7,469,744,676	134,432	+26.1
2005	2,508,229,440	5,208,060,000	7,341,968,776	138,554	+3.1
2006	3,435,201,600	4,543,032,000	7,773,814,736	144,937	+4.6

*This calculation assumes an Interior Gross Area of 108,682 ft^2

Energy Analysis: Building Envelope and Thermal Performance

Because the new mechanical systems were specifically designed to operate efficiently within the existing building envelope, there were no structural changes that would have significantly affected building performance.

However, it worth mentioning the potential effects on thermal performance attributed to the condition of the windows in Kilgo. The original gothic architecture called for as many as seven different custom-sized[8], iron-framed, single-paned windows. These are operable windows that occupants can open and close at will in any season. Over the years, approximately 60% of the windows have been replaced due to regular wear-and-tear.[9] When a window was replaced, the original iron frame was saved and refitted with double-paned glass. At this point in time, low-E or reflective coatings are not employed on any Kilgo windows. According to Wes Foushee, the Kilgo Renovation project manager, the thermal mass of the external walls may be compromised to some unknown extent by the condition of the numerous windows, which essentially act as “holes” in the walls. Anecdotal corroboration by several RLHS engineers and staff has indicated several possible reasons for not upgrading Kilgo windows to more energy-efficient designs:

1. Concerns over capital costs of replacing custom-sized windows
2. Uncertainty over whether high-efficiency windows retain their benefits when they are installed as operable windows
3. Reluctance by the CFE to alter the exterior aesthetic of one of the original Gothic quads

Effect of Weather on Energy Consumption

To examine the effects of weather patterns on Kilgo energy consumption, the most valuable piece of information to evaluate is the relationship of energy consumption to degree days. A degree day is a quantitative index used to reflect demand for energy to heat or cool buildings. A mean daily temperature (average of the daily maximum and minimum temperatures) of 65°F is the base for both heating and cooling degree day calculations. Heating degree days (HDD) are summations of negative differences between the mean daily temperature and the 65°F base; cooling degree days (CDD) are summations of positive differences from the same base. For example, cooling degree days for a monitoring station with daily mean temperatures during a seven-day period of 67, 65, 70, 74, 78, 65 and 68, are 2, 0, 5, 9, 13, 0, and 3, for a total for the week of 32 cooling degree days.[10]

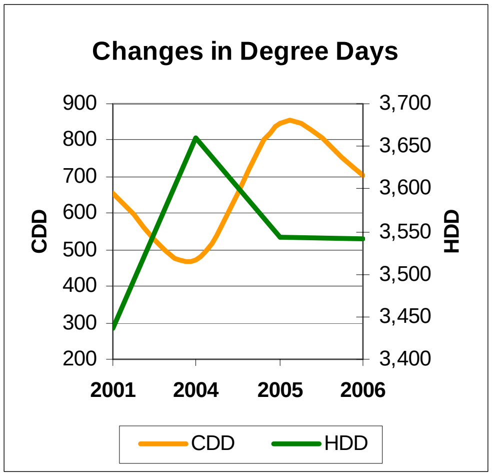
For this report, I've retrieved the data for monthly cooling degree days and heating degree days from the National Climatic Data Center online database[11] for the period from January 2000 through July 2007. These measurements were recorded at the Durham weather station in the NC-03-Northern-Piedmont Climate Division.[iv] Comparisons of total annual degree days before and after the renovation period indicate there were 27% fewer CDD and 6% more HDD in 2004 than in 2001. Data for 2005 indicates that it was a much warmer year, with 30% more CDD and 3.1% more HDD than 2001. Likewise, 2006 showed 7.3% more CDD and 3.1%

[iv] COOP ID# 312515; Elevation: 121.9m (400') above s/l; Lat/Lon: 36°03'N / 78°58'W

more HDD than the baseline; however, in 2006, there was a 17.2% decrease in CDD and no significant change in HDD compared to 2005. Essentially, this means that 2006 had a cooler summer and similar winter when compared to 2005. A summary of the degree days for this period of time may be reviewed in Table 5.

Table 5. Durham Degree Days, 2000 – 2006

	Cooling Degree Days	Heating Degree Days
2000	536	3,961
2001	**654**	**3,437**
2002	674	4,123
2003	777	3,813
2004	**474**	**3,659**
2005	**848**	**3,544**
2006	**702**	**3,542**



When energy consumption is plotted against the fluctuations in degree days, as shown in Figures 3, 4, and 5 below, energy use appears to follow a distinct pattern throughout the year. Steam use for space heating appears to have a direct relationship with number of heating degree days, while chilled water use for air conditioning appears to proportionately track cooling degree days. As data is only available for these energy systems after 2002, we cannot compare steam and chilled water consumption to pre-renovation levels; however, it seems that changes in the consumption of these energy types is directly related to seasonal changes in temperatures. Monthly consumption of steam and chilled water appear to be correlated with changes in HDD and CDD, respectively. However, the relationship of electricity consumption to changes in weather appears to be more complex, with no clear correlation to outdoor temperature. It may be that change in temperature alone is not a significant driver of electricity consumption.

Figure 3. Kilgo Steam Consumption against Heating Degree Days

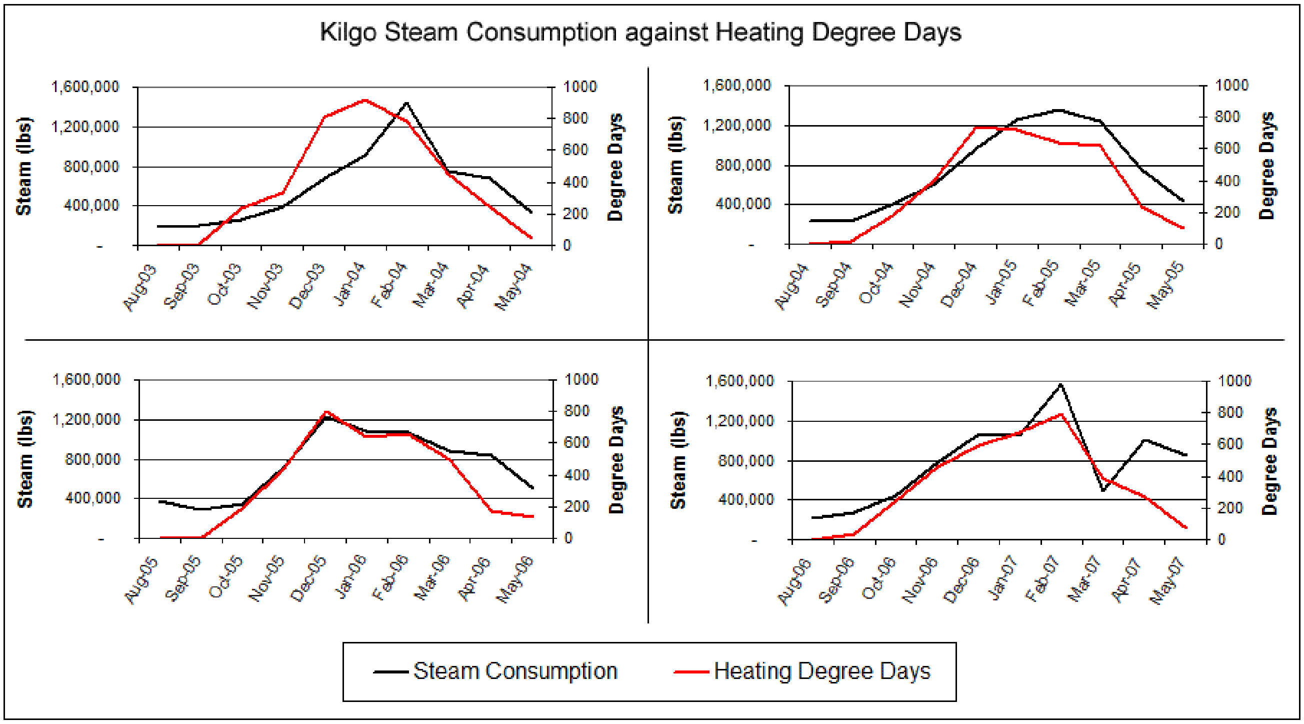


Figure 4. Kilgo Chilled Water Consumption against Cooling Degree Days

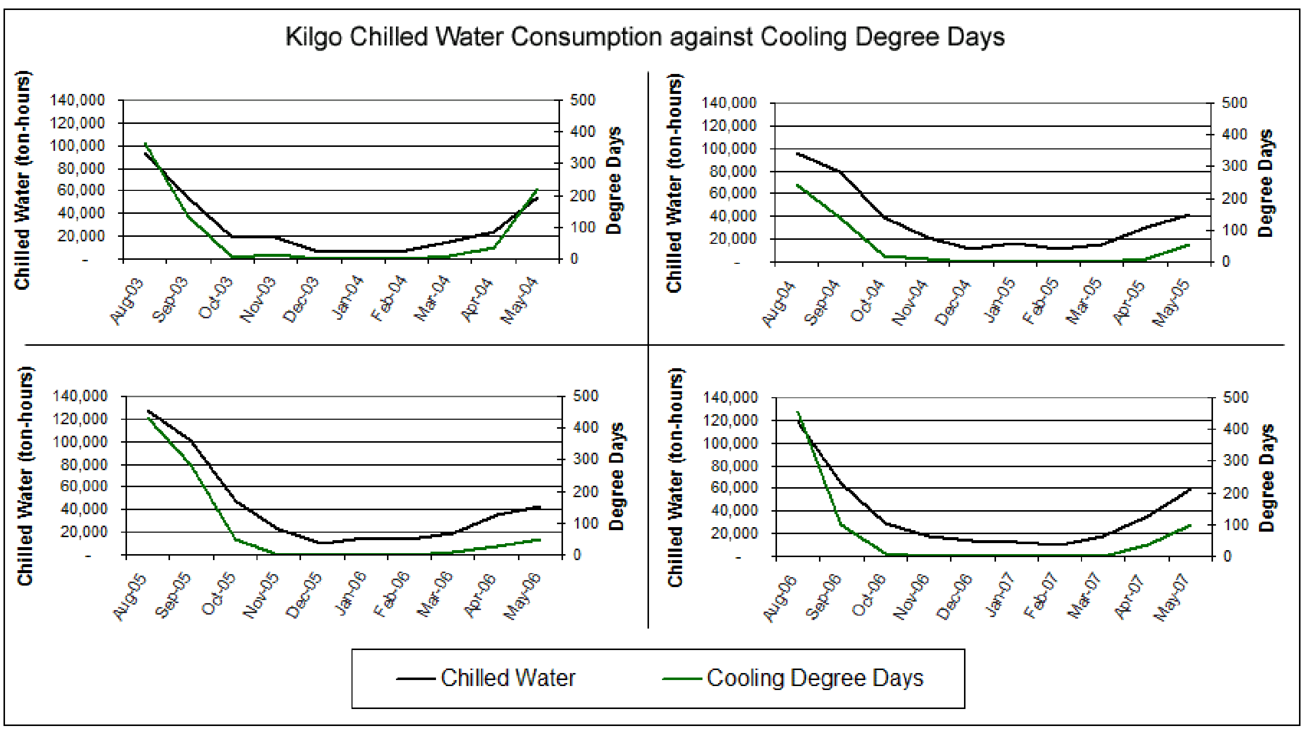
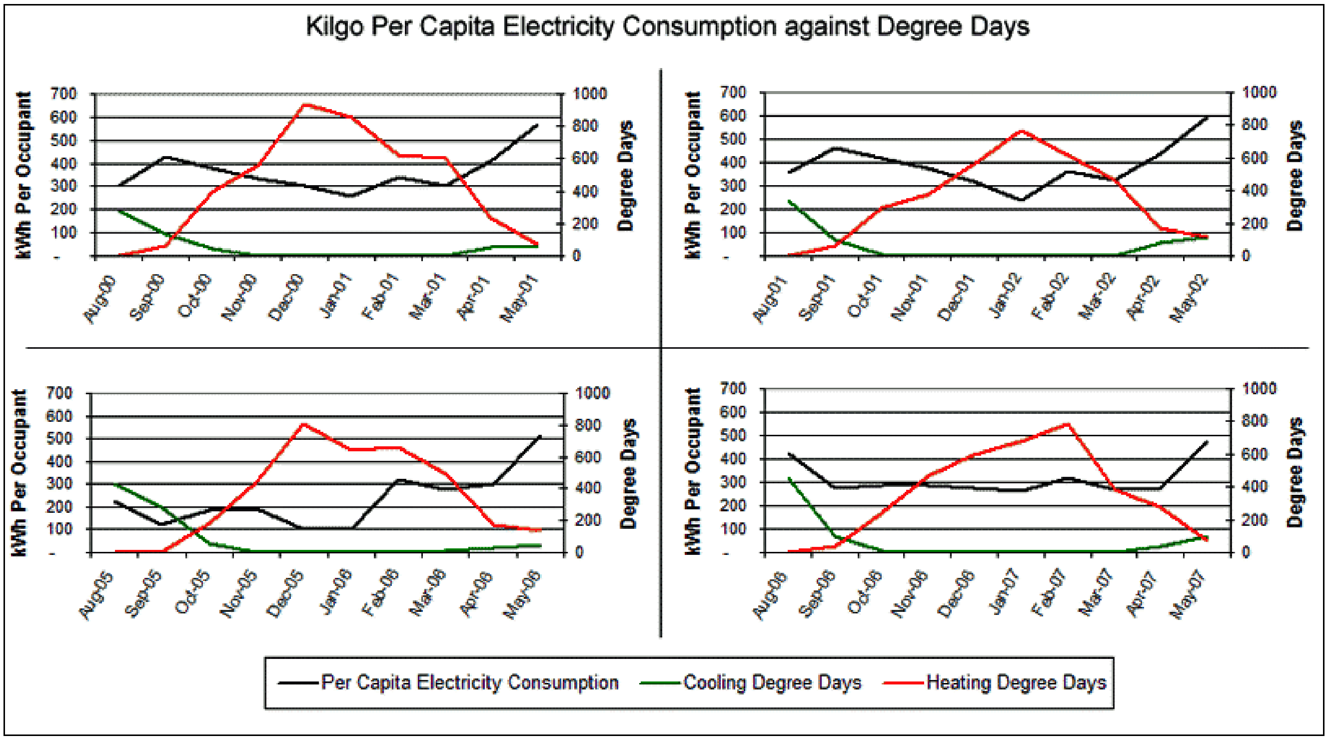


Figure 5. Kilgo Per Capita Electricity Consumption against Degree Days



Effect of Infrastructure Changes on Energy Consumption

Due to the fact that the electrical systems at Kilgo are not sub-metered, it is impossible to quantify the exact amount of electricity consumption attributable to the addition of air conditioning. Obviously, there is a large addition to the building's overall energy consumption due to the fact that chilled water is now being used. Beginning in 2004, the use of chilled water added approximately 40,000 Btu/ft^2 to the energy signature of Kilgo Quad each year. However, it is difficult to partition out the change in electricity consumption attributable to the use of central air conditioning without having precise data available through detailed sub-metering records.

Effect of Demand on Energy Consumption

The 21st century has ushered in a new golden age of personal electronics and it can be reasonably stated that college students are representative of both the cutting-edge and the early adopters. A 2006 study by the National Retail Federation identified the biggest driver in college student spending, going into 2006, as electronics. College students were expected to spend 27.5% more ($10.46 billion) than the previous year on electronics purchases including flat screen TVs, XBoxes, iPods, and notebook computers.[12]

Based on this information and anecdotal evidence, it is reasonable to speculate that a majority of Duke undergraduates use all or most of the following electronic devices in their rooms:

- Television
- Stereo
- Computer
- Mini-refrigerator
- Cell phone
- MP3 player

Admittedly, the same types of items were most likely found in dorm rooms in 2001 as were found in 2005. However, it is my opinion that the prevalence of these devices has increased during that time period. Flat-screen and plasma televisions have become more affordable and supplanted the traditional television. In a double-occupancy room, it is very likely that *both* occupants charge their own cell phone and MP3 player on a regular basis. Likewise, it is also probable that both occupants own and charge their own personal computer. More and more of these devices are used now than they ever were.

On its face, this may not seem like a good explanation for reported increases in electricity demand. However, it is vital to realize that the Kilgo renovation enabled occupants to use electricity differently. Most importantly, the renovation increased the plug-load for each bedroom by nearly a factor of ten. In 2001, the building still operated with the original wiring from the 1920s. Each bedroom was wired to share a 20-amp circuit with two other rooms, effectively restricting the plug-load to 6.67 amps per room. Students were informed when they moved in that the use of a hair dryer in a dorm room meant that you would blow the fuse for not only your room, but your neighbors as well. After the renovations were completed, the building was re-wired to exceed the NC building Code[v]. Consequently, each bedroom was re-wired to accommodate three 20-amp circuits per room[13], effectively raising the plug-load to 60 amps per room and allowing occupants to safely use a greater amount of electricity. The increased capacity allows greater use of electronics, which increases the number of plugs and chargers used in each room. Without collecting occupant survey data on personal behavior, it is difficult to know whether occupants unplug appliances and electronics when not in use. However, it is also reasonable to assume that, given the demographics, many occupants do not unplug chargers and power cords, adding a phantom load that draws electricity even when the device is not turned on. The U.S. Department of Energy has found that, in the average home, 25% of the electricity used to power home electronics is consumed while the products are turned off; it is reasonable to assume that some significant amount of electricity consumption in Kilgo and Few is part of this phantom load.

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[v] NFPA 70 - National Electrical Code requires a guest room (hotel or dormitory) to have a 1.5 amp outlet available every 12 feet. The code would therefore require that a typical double bedroom have 6 outlets with a total plug-in load of 9 amps.

Furthermore, while it's true that many new electronic devices are more energy-efficient than they were 5-10 years ago, the efficiency of these devices is diminished when barriers are reduced or removed that allow people to use the devices more frequently. This "rebound effect"[vi] may actually be reducing the initial efficiency gains of the renovation that were realized with the installation of more efficient lighting and mechanical systems. This theory echoes the findings of a 2005 Duke University study on greenhouse gas reductions which suggested that "some of the growth [in electricity-related CO2-eq emissions] may also be due to the proliferation of plug-in electronic devices."[14] The author acknowledged that further analysis would be needed to verify whether the growth in the number of electronic devices had resulted in a net increase in electricity usage and called for further study on the impacts of increased plug-in load capacity. RLHS may want to consider conducting annual occupant surveys to try to gauge how students are using energy and whether the current system is adequate or over-delivers in terms of providing capacity.

Changes in demand due to increased use of plug-in appliances are most likely limited to individual rooms of the occupants and not the common spaces in the building. The appliances provided by Duke University, including but not limited to, a microwave, stove, and refrigerator in the quad kitchen and high-efficiency, front-loader washing machines and dryers are all relatively new, Energy Star-rated equipment. There is a University policy that encourages occupants to purchase Energy Star products, but no official requirements are enforced. Likewise, there are no university-sponsored purchasing programs that provide Energy Star products directly to occupants.

[vi] The rebound effect, or Jevons Paradox, is typically used to describe the economic scenario whereby improving the efficiency lowers the cost of using a resource, which then increases demand. Most recently, the rebound effect concept has been applied to the perceived value of increasing automobile fuel efficiency – critics contend that we will see neither fuel savings or environmental benefits because the lower cost of driving will increase the total amount that consumers drive, thus reducing the original efficiency gains.

Analysis of Kilgo Water Consumption

For the purposes of this analysis, I used available data on quad occupancy and potable water consumption to estimate the approximate water consumption for Kilgo Quad from 2000 – 2002. The challenging aspect of analyzing Kilgo water consumption data is that, prior to 2003, the utility data summarizes the combined consumption of all occupants of Kilgo, Few, Craven, and Crowell Quads. In order to estimate Kilgo-specific consumption for 2000 – 2002, I perform the following calculations:

1. Convert the utility data from cubic feet to gallons of water[vii]
2. Summarize the combined annual water consumption for Kilgo, Few, Craven and Crowell using utility data for water meters M47 and M57.
3. Summarize the combined annual occupancy for Kilgo, Few, Craven and Crowell using data provided by RLHS.
4. Calculate the Per Capita Water Consumption for an occupant of any of the four quads by dividing Combined Water Consumption by Combined Occupancy
5. It is then possible to back out the estimated Kilgo Water Consumption for 2000 – 2002 by multiplying the Per Capita Water Consumption by the reported occupancy of Kilgo during those years.

This process allows us to get a better idea of the water consumption in Kilgo before and after the renovation period. It is important to note that only the data for 2000 – 2002 is estimated; the Kilgo Water Consumption for 2003 – 2006 is reported in utility records for water meter M146. This data is provided in Table 6 below.

[vii] One cubic foot of water = 7.48 gallons

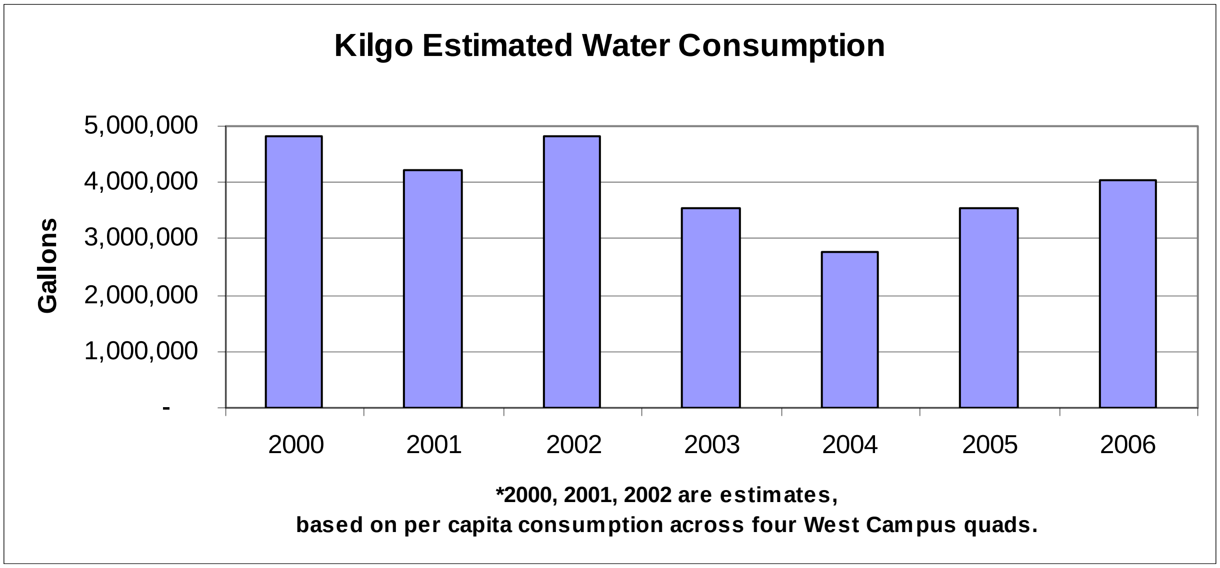
Analysis of this data indicates that, prior to the renovation, Kilgo Quad consumed 4,230,378 gallons of water in 2001. Following completion of the entire renovation, water consumption in 2004 decreased by 35% compared to the pre-renovation baseline. Although water consumption decreased in 2005 by 16.1% compared to pre-renovation levels, consumption levels increased by 29% from the previous year. Likewise, water consumption in 2006 showed a much smaller overall reduction of 4.5% compared to the 2001 baseline, and indicated a 13.8% increase from the previous year. Figure 6 illustrates the year-to-year trend in Kilgo water consumption and clearly indicates the increase in water consumption throughout the post-renovation period.

Table 6. Kilgo Estimated Water Consumption

	Combined Data for Four West Campus Quads			Kilgo Estimated Data			
	Combined Water Consumption (gal)	Combined Occupancy	Per Capita Consumption (gal/occupant)	Kilgo Occupancy	Kilgo Water Consumption (gal)	% change from previous year	% change from 2001
*2000	19,428,776	2,554	7,607	635	4,830,569	-	-
*2001	17,031,212	2,484	6,856	617	4,230,378	-12.4	-
*2002	19,758,420	3,264	6,053	794	4,806,429	+13.6	+13.6
2003	3,529,812	764	4,620	764	3,529,812	-26.6	-16.6
2004	2,751,144	753	3,654	753	2,751,144	-22.1	-35.0
2005	3,550,756	745	4,766	745	3,550,756	+29.1	-16.1
2006	4,041,444	747	5,410	747	4,041,444	+13.8	-4.5

*The Kilgo Water Consumption data for these years is estimated using the calculations described above.

Figure 6. Kilgo Estimated Water Consumption



Per Capita Consumption: Potable Water

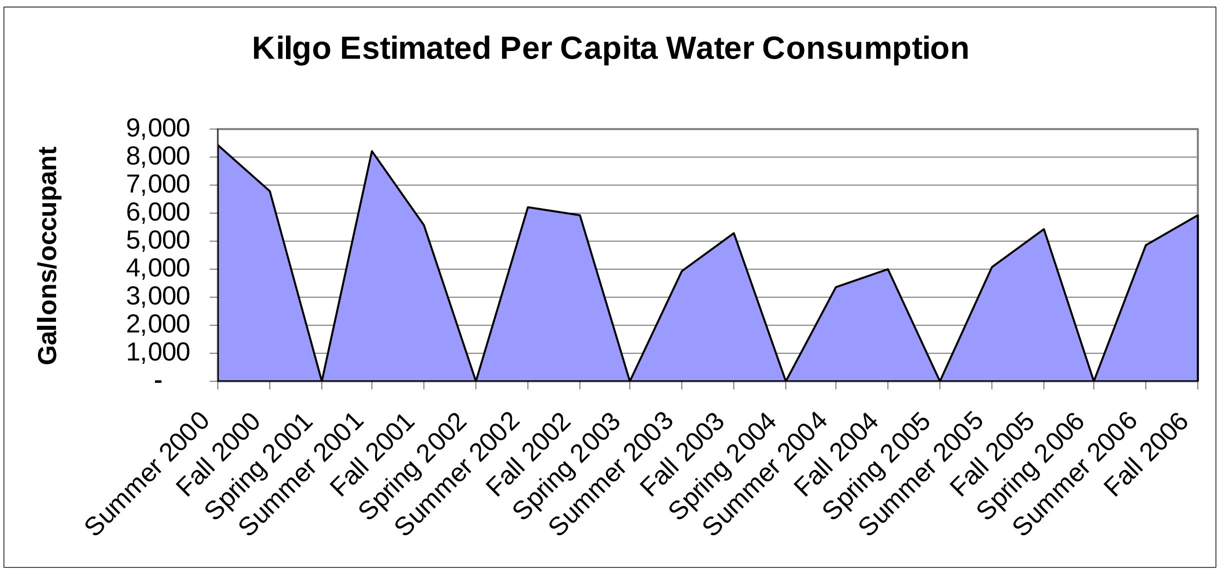
The data for per capita water consumption exhibits a similar pattern to the per capita electricity consumption data. Compared to the baseline year of 2001, there was a 46.7% decrease in per capita water consumption to 3,654 gallons/occupant in 2004. However, in 2005, there is a smaller decrease of 30.5% relative to the 2001 baseline and a 21.1% relative decrease in 2006. This still represents a sizeable reduction in per capita water consumption compared to pre-renovation data, but also indicates that, from 2004 to 2006, per capita water consumption increased by 48% while building occupancy decreased marginally. See Table 7 for details on Kilgo Per Capita Water Consumption.

Table 7. Kilgo Per Capita Water Consumption

	Annual Consumption (gal)	Occupancy	Per Capita Consumption (gal/occupant)	% change from previous year	% change from 2001
*2000	4,830,569	635	7,607	-	-
*2001	4,230,378	617	6,856	-9.9	-
*2002	4,806,429	794	6,053	-11.7	-11.7
2003	3,529,812	764	4,620	-23.7	-32.6
2004	2,751,144	753	3,654	-20.9	-46.7
2005	3,550,756	745	4,766	+30.4	-30.5
2006	4,041,444	747	5,410	+13.5	-21.1

*The Kilgo Water Consumption data for these years is estimated using the calculations described above.

Figure 7. Kilgo Per Capita Water Consumption



Weather Effects on Water Consumption

Part of the water efficiency renovation strategy was to reduce potable water use for irrigation purposes. The primary means to achieve reductions in landscape irrigation was by installation of weather-based irrigation controls that would interrupt the watering schedule if a "qualifying" (proximity, duration, total rainfall, etc.) rain event occurred. A detailed examination of the effects of the 1998-2002 North Carolina drought is beyond the scope of this particular study. However, it is reasonable to assume that local water restrictions and community/university advocacy campaigns would have some impact on the level of water consumption during and immediately following the drought. It may also be reasonable to assume that water consumption may have tended to increase upon relaxation of water conservation programs when that drought ended.

Effect of Infrastructure Changes on Water Consumption

There were no changes to plumbing infrastructure or pumping systems that would have significantly altered water consumption during the renovation.

Effect of Demand on Water Consumption

The effects of individual demand are most likely linked to the effects of weather over this time period, but it is extremely difficult to directly correlate the effects of the 1998-2002 drought with changes in individual demand for potable water. Traditionally, average occupant demand for potable water is fairly consistent over time, but any conservation measures taken to address the 1998-2002 drought would have more than likely affected occupant demand patterns. The replacement of bathroom fixtures during the renovation period would have improved operational efficiency, but most likely not have affected occupant behavior and usage patterns. However, it may be conceivable that a "rebound effect" was felt in water consumption as well. It is possible, although not entirely probable, that newer, more-efficient fixtures motivated occupants to take longer showers, run the lavatory faucets more, etc.

VI. Analysis of Few Resource Consumption, 2000 – 2006

There are two primary reasons to analyze Few resource consumption:

1. A similar analysis of an existing Duke residence hall will provide a baseline with which to compare Kilgo building performance over the period from 2000 – 2006
2. The results from the evaluation of Kilgo can be used to predict energy and water impacts of the Few renovation project

In order to produce a comparable analysis to the Kilgo analysis, I will evaluate resource consumption at Few Quad while considering the same four drivers of demand for energy and water in Duke Residence halls.

The Few utility records for electricity, steam and chilled water use for 2000 – 2006 were provided by FMD and are available in Appendix G of this report. Few Quad has two electricity meters: one that measures Few lighting directly and another that combines HVAC data with Keohane Quad. Few also shares a steam condensate meter with Keohane Quad and shares water meters with Craven and Crowell as previously mentioned. As with Kilgo, the available chilled water data from 2003 – 2006 is exported from a Siemens monitoring database integrated into the Few HVAC system.

In order to adjust for the shared meters, I have employed the same technique used to estimate Kilgo's potable water consumption; electricity and steam consumption at Few is estimated by breaking down the total amount of the resource consumption according to the proportions of the Interior Gross Area. It is important to note that Few has a slightly larger footprint than Kilgo, with an Interior Gross Area of 115,711 ft^2; the Interior Gross Area of Keohane Quad is 147,291 ft^2.

Energy Analysis: Electricity Consumption

The electricity consumption data for Few Quad should provide a representation of typical consumption patterns for a “gothic” Duke residence hall over the period of 2000 – 2006. Minor renovations in Summer 2001 upgraded the air handlers to improve efficiency, but no other renovations have been made to the building during that time period. In order to discuss electricity consumption in a standardized way, I converted the utility data from kWh to Btu, and will refer to both units of measurement throughout the analysis.

In the baseline year of 2001, Few Quad consumed 2,382,448 kWh of electricity, or 50,849 Btu/ft^2. Electricity consumption decreases year-to-year until in 2004, the building consumed 1,135,390 kWh, or 33,480 Btu/ft^2; this represents a decrease of 34% in total electricity consumption relative to the 2001 baseline. In 2005, the building consumed less electricity and exhibited a decrease of 42% in total electricity consumption for the building since 2001. Data indicates that Kilgo consumed 1,197,970 kWh of electricity, or 35,325 Btu/ft^2, in 2006, representing a smaller 30.5% annual reduction in electricity consumption compared to 2001. Furthermore, this change represents a 19.5% increase in total electricity consumption from 2005 to 2006. See Table 8 for detailed information for the entire time period.

Table 8. Few Electricity Consumption (annual)

	Electricity (kWh)	Total Interior Gross Area (sq. ft.)	Electricity Consumption (Btu/sq.ft)	% change from previous year	% change from 2001
1999	2,382,448	115,711	70,251	-	-
2000	2,039,991	115,711	60,154	-14.4	-
2001	**1,724,447**	**115,711**	**50,849**	**-15.5**	**-**
2002	1,189,676	115,711	35,080	-31.0	-31.0
2003	1,252,838	115,711	36,943	+5.3	-27.3
2004	**1,135,390**	**115,711**	**33,480**	**-9.4**	**-34.2**
2005	**1,002,388**	**115,711**	**29,558**	**-11.7**	**-41.9**
2006	**1,197,970**	**115,711**	**35,325**	**+19.5**	**-30.5**

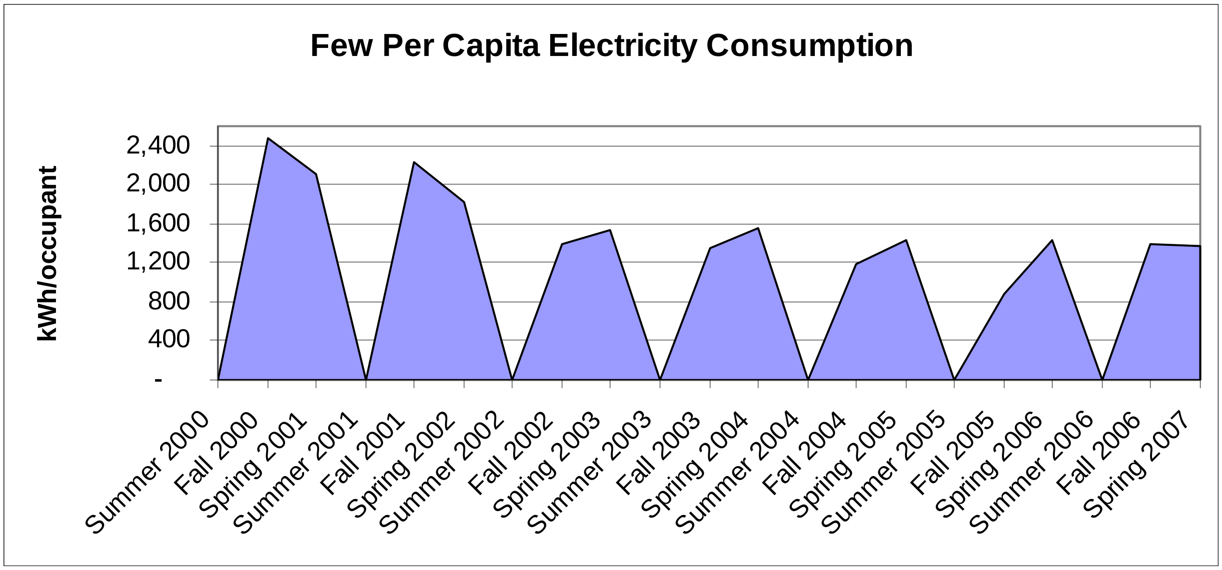
Per Capita Consumption: Electricity

Analysis of Few electricity data indicates that, compared to the baseline year of 2001, there was a 35.3% decrease in per capita electricity consumption to 1,307 kWh per occupant in 2004. In 2005, per capita consumption decreases even further to reflect a 42.6% decrease from the 2001 baseline. However, in 2006, the data indicates a smaller reduction of 31.6% from the baseline. While this still represents a sizeable reduction in per capita electricity use compared to pre-renovation data, it also indicates that, from 2005 to 2006, per capita electricity consumption increased by 19.2% while building occupancy increased only marginally. See Table 9. for details on Few Per Capita Electricity Consumption.

Table 9. Few Per Capita Electricity Consumption

	Annual Consumption (kWh)	Occupancy	Per Capita Consumption (kWh/occupant)	% change from previous year	% change from 2001
2000	2,039,991	892	2,287	-	-
2001	**1,724,447**	**854**	**2,019**	**-11.7**	**-**
2002	1,189,676	812	1,465	-27.4	-27.4
2003	1,252,838	861	1,455	-0.7	-27.9
2004	**1,135,390**	**869**	**1,307**	**-10.2**	**-35.3**
2005	**1,002,388**	**865**	**1,159**	**-11.3**	**-42.6**
2006	**1,197,970**	**867**	**1,382**	**+19.2**	**-31.6**

Figure 8. Few Per Capita Electricity Consumption



Energy Analysis: HVAC Consumption of Steam and Chilled Water

Like Kilgo, Few Quad was not attached to the campus chilled water loop until early 2003 and detailed metering for steam also became available in 2003. Analysis of the trends in consumption patterns, even over a portion of the time frame that we used to examine the Kilgo renovations, help to track the changing carbon footprint of the typical gothic quad.

Using standardized data in units of Btu for chilled water and steam, it is possible to examine the impact of the HVAC system in terms of a square footage calculation. Again, the square footage variable for Few is the amount for Interior Gross Area rather than Total Room Area, in order to account for all conditioned spaces in the building. Refer to Figure 10 for a graphical view of Few's total energy consumption over the analysis time period. This analysis indicates that, while the magnitude of energy consumption obviously increases dramatically upon introduction of HVAC system energy data, there has been an overall declining trend in total energy consumption each year since 2000. There is a slight increase in total energy consumption in 2006, but the other year-to-year comparisons indicate a decrease.

Figure 9. Few Total Energy Consumption

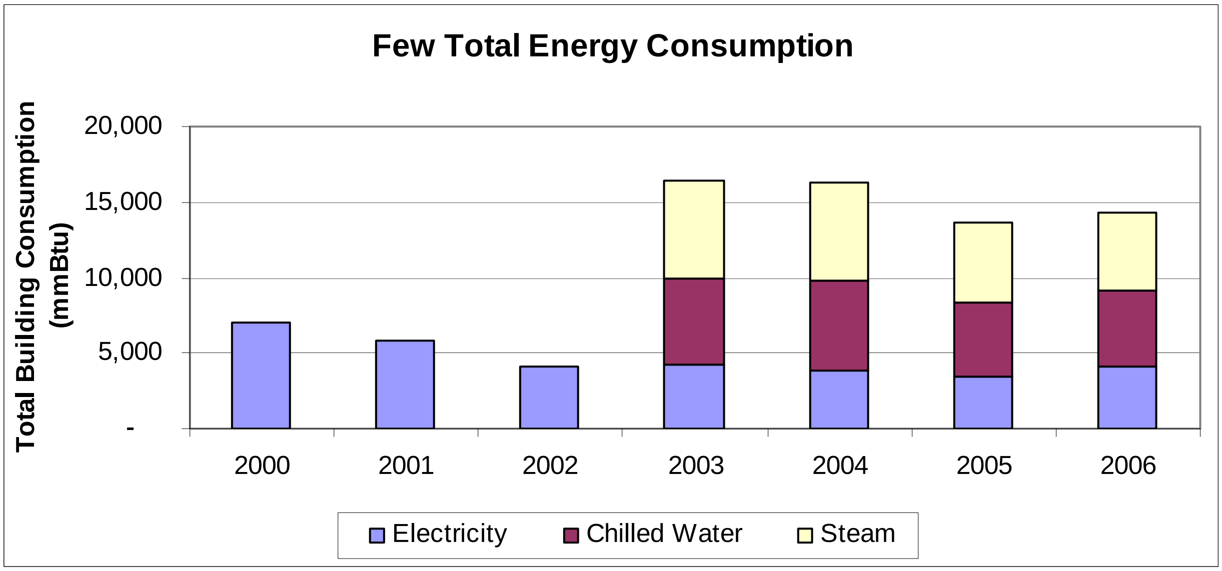


Table 10. Few Total Energy Consumption (Btu)

	Electricity	Chilled Water	Steam	*Total Consumption (Btu/ft^2)	% change from previous year
2000	6,960,449,505	-	-	60,154	-
2001	5,883,813,216	-	-	50,849	-15.5
2002	4,059,174,052	-	-	35,080	-31.0
2003	4,274,683,709	5,683,056,000	6,498,775,496	142,221	+305.4
2004	3,873,950,551	5,939,196,000	6,530,757,980	141,248	-0.7
2005	3,420,149,462	4,887,852,000	5,337,476,248	117,927	-16.5
2006	4,087,473,212	5,004,768,000	5,263,011,418	124,061	+5.2

*This calculation assumes an Interior Gross Area of 115,711 ft^2

Energy Analysis: Building Envelope and Thermal Performance

Few Quad and Kilgo have comparable building envelopes and may be assumed to have similar thermal performance characteristics. No renovations are planned that would modify the building envelope and HVAC systems will be designed around the current structure.

Analysis of Few Water Consumption

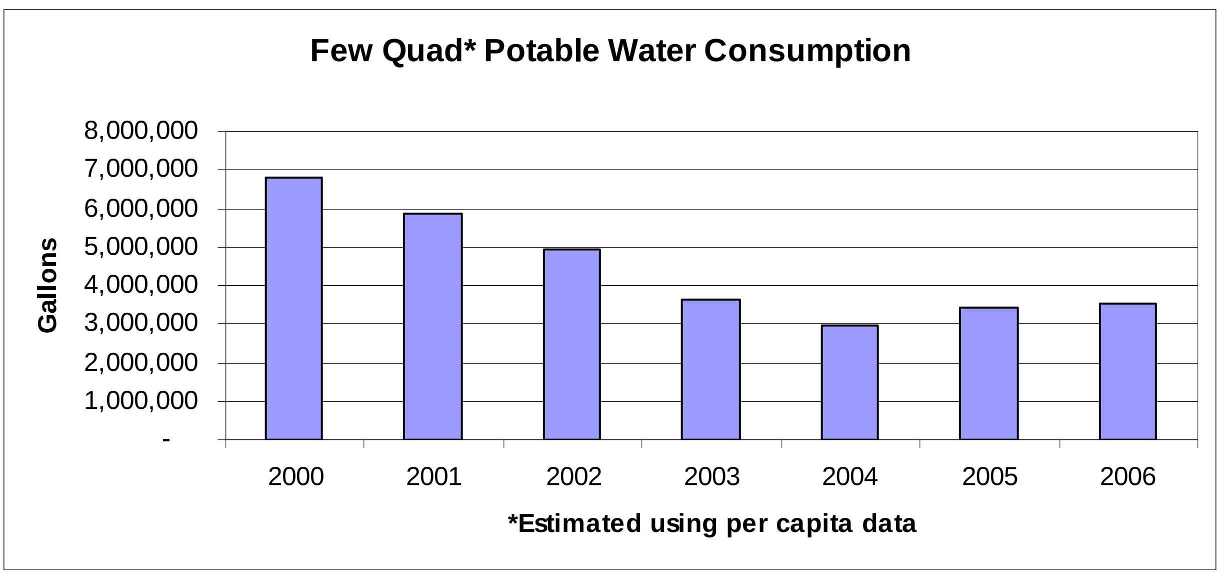
The same procedure described in the Kilgo analysis was used to estimate the total water consumption specifically for Few Quad for 2000 – 2006 from the shared data for water meters M47, M57 and M145. Water data is combined for Few, Craven and Crowell Quads and, prior to 2003, included Kilgo Quad as well. All water data for Few is estimated based on occupancy of these four residence halls from 2000 – 2006; this data is provided in Table 11 below.

Analysis of this data indicates that Few Quad consumed 5,855,336 gallons of water in 2001. The total water consumption declines each year until 2005, when consumption rises by nearly 16% to 3,432,190 gallons. In 2006, water consumption increases slightly by 3.4%, however, this still represents a nearly 40% decrease from the total consumption in 2001. Figure 10 illustrates the year-to-year trend in Few water consumption.

Table 11. Few Estimated Water Consumption

	Combined Data for West Campus Quads			Few Estimated Data			
	Combined Water Consumption(gal)	Combined Occupancy	Per Capita Consumption (gal/occupant)	Few Occupancy	Few Water Consumption (gal)	% change from previous year	% change from 2001
2000	19,428,776	2,554	7,607	892	6,785,618	-	-
2001	17,031,212	2,484	6,856	854	5,855,336	-13.7	-
2002	19,758,420	3,264	6,053	812	4,915,391	-16.1	-16.1
2003	11,958,725	2,815	4,248	861	3,657,713	-25.6	-37.5
2004	9,726,476	2,854	3,408	869	2,961,565	-19.0	-49.4
2005	11,122,610	2,804	3,967	865	3,431,190	+15.9	-41.4
2006	11,506,746	2,811	4,093	867	3,549,039	+3.4	-39.4

Figure 10. Few Estimated Water Consumption



<u>Per Capita Consumption: Potable Water</u>

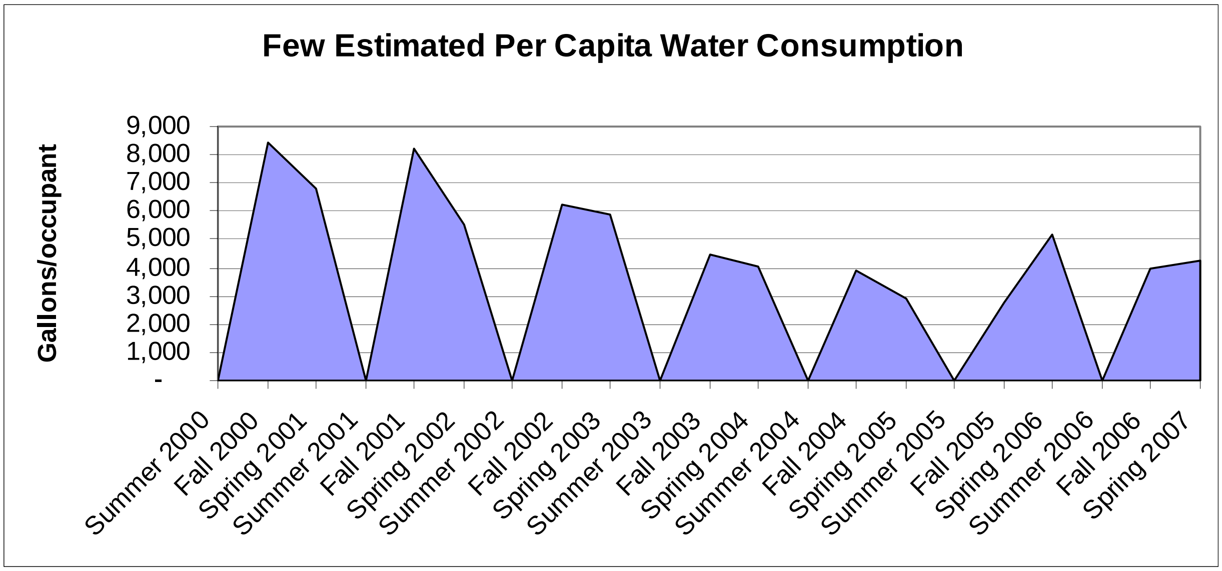
The data for per capita water consumption exhibits a similar pattern to the per capita water consumption data for Kilgo. Compared to the baseline year of 2001, there was a 50% decrease in per capita water consumption to 3,408 gallons per occupant in 2004. However, in 2005 and 2006, the data shows that the magnitude of the annual reductions gets smaller over time. Data for 2006 indicates a marginally smaller reduction of 40%, relative to the 2001 baseline. Like Kilgo, this still represents a sizeable reduction in per capita water consumption compared to pre-renovation data, but also indicates that, from 2004 to 2006, per capita water consumption increased by 20% while building occupancy decreased slightly. See Table 12 for details on Few Per Capita Water Consumption.

Table 12. Few Estimated Per Capita Water Consumption

	Annual Consumption (gal)	Occupancy	Per Capita Consumption (gal/occupant)	% change from previous year	% change from 2001
2000	6,785,618	892	7,607	-	-
2001	5,855,336	854	6,856	-9.9	-
2002	4,915,391	812	6,053	-11.7	-11.7
2003	3,657,713	861	4,248	-29.8	-38.0
2004	2,961,565	869	3,408	-19.8	-50.3
2005	3,431,190	865	3,967	+16.4	-42.1
2006	3,549,039	867	4,093	+3.2	-40.3

*The Few Water Consumption data for these years is estimated using the calculations described above.

Figure 11. Few Per Capita Water Consumption



VII. Carbon Footprints at Kilgo Quad and Few Quad

The greenhouse gas (GHG) emissions associated with Kilgo and Few can be measured by calculating the CO2-equivalent (CO_2-eq) emissions released by each utility provider at the source power plant. For our purposes, we will consider the carbon footprint of each building as the CO_2-eq of the combined GHG emissions released by each utility plant to provide energy to that building. For more information on the methodology used to determine these emissions at Duke University, please refer to Appendix H.

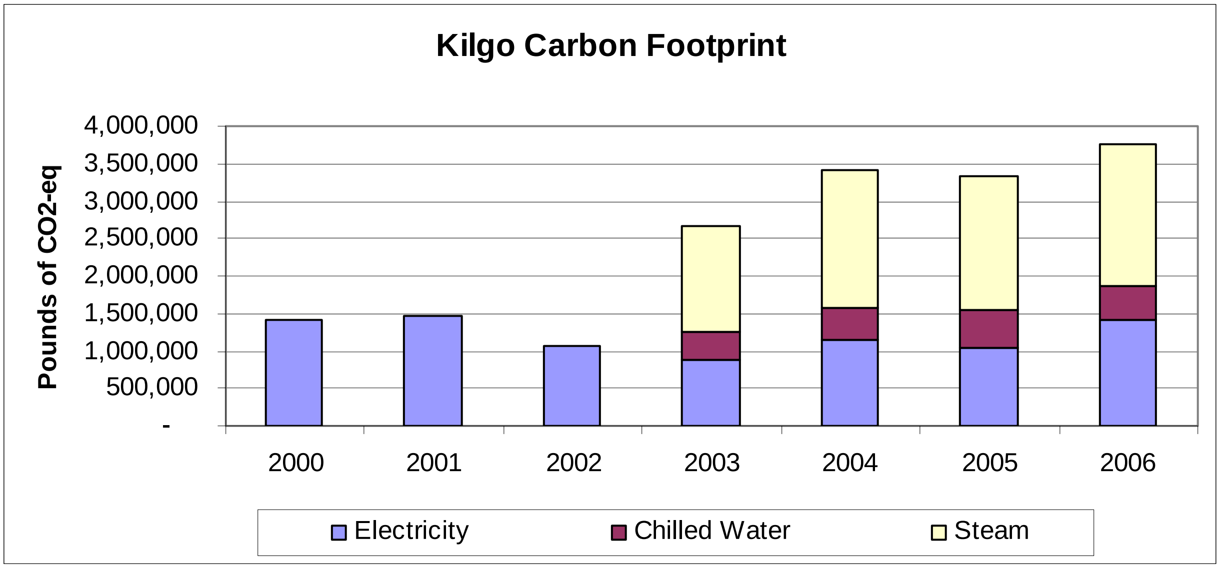
Kilgo Quad CO_2-eq emissions

After applying the appropriate emissions factors to the available utility data, I calculated the annual CO_2-eq emissions, attributable to energy consumption, for Kilgo Quad. All data in this section is displayed in units of pounds of CO_2-eq. In 2006, 37% of CO_2-eq emissions are associated with electricity consumption, 51% with the use of steam, and 12% with chilled water consumption. Emissions associated with chilled water decreased from 2005 to 2006, while emissions associated with steam usage increased.

Table 13. Kilgo Quad Annual CO_2-eq emissions (pounds of CO_2-eq)

	Electricity	Chilled Water	Steam	Total
2000	1,421,952	-	-	1,421,952
2001	1,471,232	-	-	1,471,232
2002	1,058,064	-	-	1,058,064
2003	886,032	364,500	1,419,282	2,669,814
2004	1,142,064	442,253	1,816,618	3,400,935
2005	1,029,168	528,618	1,785,543	3,343,329
2006	1,409,520	461,118	1,890,567	3,761,205

Figure 12. Kilgo Quad Annual CO2-eq emissions



There are two distinct ways to consider this data as we attempt to determine the impact of the renovations on Kilgo's carbon footprint.

The first is to consider only emissions that are attributable to electricity consumption and examine the net change in CO_2-eq emissions from 2001 to each of the post-renovation years. In 2001, Kilgo electricity consumption accounted for 1,471,232 pounds of CO_2-eq emissions. Immediately following completion of the renovation project, CO_2-eq attributed to electricity consumption decreased by 22% and in 2005, emissions associated with electricity use were 30% lower than they were in 2001. However, in 2006, the net decrease in CO_2-eq emissions attributed to electricity since 2001 was only 4%.

Table 14. Kilgo CO_2-eq Emissions attributable to Electricity Consumption

	Electricity (lbs of CO_2-eq)	% change from previous year	% change from 2001
2000	1,421,952	-	-
2001	1,471,232	+3.5	-
2002	1,058,064	-28.1	-28.1
2003	886,032	-16.3	-40.0
2004	1,142,064	+28.9	-22.4
2005	1,029,168	-9.9	-30.0
2006	1,409,520	+37.0	-4.2

The second way to address this emissions data is to consider the year-to-year changes in net CO_2-eq emissions, attributable to all energy uses.

Prior to 2002, Kilgo's observed CO_2-eq emissions would have been attributable to electricity and steam consumption. When air conditioning began to come online in 2003, the emissions attributable to chilled water use are included. However, due to the fact that accurate data for steam consumption prior to 2003 is unavailable, the summary of CO_2-eq emissions from 2000 through 2002 is a conservative estimate. There is a clear pattern that the CO_2-eq emissions for Kilgo have grown significantly or remained relatively stable each year since 2002. No two-year period indicates any significant decline in total CO_2-eq emissions.

Table 15. Kilgo Total CO_2-eq Emissions

	Total CO_2-eq Emissions (lbs)	% change from previous year	% change from 2001
2000	1,421,952	-	-
2001	1,471,232	+3.5	-
2002	1,058,064	-28.1	-28.1
2003	2,669,814	+152	+81
2004	3,400,935	+27.4	+131
2005	3,343,329	-1.7	+127
2006	3,761,205	+12.5	+155

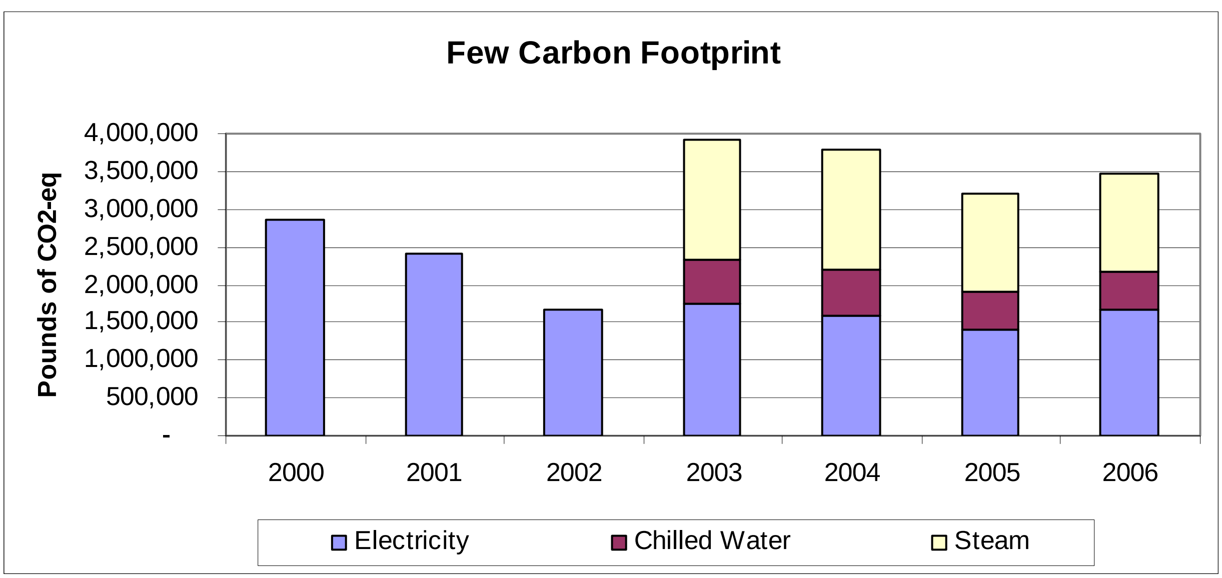
Few Quad CO_2-eq emissions

For comparison, I have also calculated the CO_2-eq emissions from Few Quad for the same time period. In 2006, 48% of the CO_2-eq emissions were associated with electricity consumption, 37% with the use of steam, and 15% with the use of chilled water. It is interesting to note that Few exhibited an opposing change in chilled water and steam emissions in 2006, with chilled water emissions increasing and steam emissions decreasing.

Table 16. Few Quad Annual CO_2-eq emissions (pounds of CO_2-eq)

	Electricity	Chilled Water	Steam	Total
2000	2,855,987	-	-	2,855,987
2001	2,414,226	-	-	2,414,226
2002	1,665,546	-	-	1,665,546
2003	1,753,973	576,830	1,580,481	3,911,285
2004	1,589,546	602,828	1,588,259	3,780,634
2005	1,403,344	496,117	1,298,057	3,197,518
2006	1,677,158	507,984	1,279,948	3,465,089

Figure 13. Few Quad Annual CO2-eq emissions



In 2001, Few electricity consumption accounted for 2,855,987 pounds of CO_2-eq emissions. In 2004 and 2005, CO2-eq emissions attributed to electricity consumption decreased by 34% and 42%, respectively. In 2006, the net decrease since 2001 was 30.5%.

Table 17. Few CO_2-eq Emissions attributable to Electricity Consumption

	Electricity (lbs of CO_2-eq)	% change from previous year	% change from 2001
2000	2,855,987	-	-
2001	2,414,226	-15.5	-
2002	1,665,546	-31.0	-31.0
2003	1,753,973	+5.3	-27.3
2004	1,589,546	-9.4	-34.2
2005	1,403,344	-11.7	-41.9
2006	1,677,158	+19.5	-30.5

From 2001 on, emissions from Few Quad appear to decrease on a year-to-year basis (excluding 2003 when steam and chilled water data are added to the calculations). The only real year-to-year growth in CO2-eq emissions is from 2005 to 2006 when emissions increased by 8.4%.

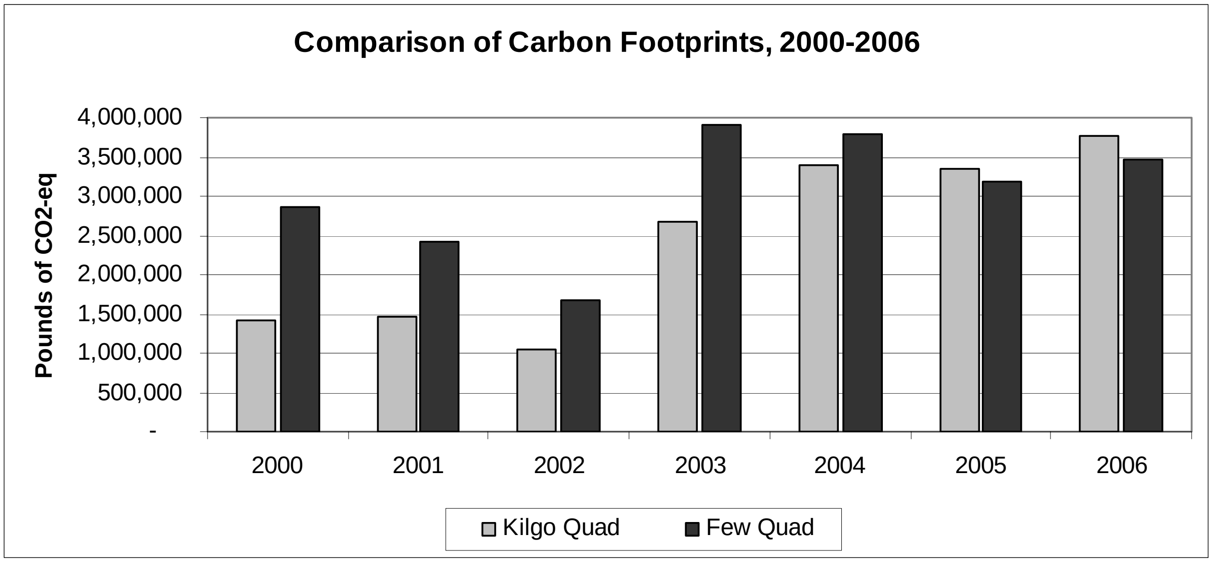
Table 18. Few Total CO_2-eq Emissions

	Total CO_2-eq Emissions (lbs)	% change from previous year	% change from 2001
2000	2,855,987	-	-
2001	2,414,226	-15.5	-
2002	1,665,546	-31.0	-31.0
2003	3,911,285	+134.8	+62.0
2004	3,780,634	-3.3	+56.6
2005	3,197,518	-15.4	+32.4
2006	3,465,089	+8.4	+43.5

Comparison of Carbon Footprints

When the carbon footprints for both buildings are compared side-by-side, it is evident that Few Quad emissions have exhibited a generally decreasing trend over time, while the emissions at Kilgo Quad have exhibited a generally increasing trend. See Figure 14. for the graphical representation of this comparison.

Figure 14. Comparison of Carbon Footprints, 2000-2006



While Few Quad accounted for nearly two-thirds more emissions than Kilgo in 2001, the annual growth rate in emissions has been much greater at Kilgo since the renovation project began.

Table 19. Comparative growth rates in CO_2-eq emissions, relative to 2001

	Few CO_2-eq Emissions (lbs)	% change from 2001	Kilgo CO_2-eq Emissions (lbs)	% change from 2001
2001	**2,414,226**	-	**1,471,232**	-
2002	1,665,546	-31.0	1,058,064	-28.1
2003	3,911,285	+62.0	2,669,814	+81
2004	3,780,634	+56.6	3,400,935	+131
2005	3,197,518	+32.4	3,343,329	+127
2006	**3,465,089**	**+43.5**	**3,761,205**	**+155**

Ultimately, this data indicates that even though Kilgo Quad:

- occupies 6% less Interior Gross Area than Few Quad,

- shares the same climate and endures the same weather patterns as Few Quad,
- houses 14% fewer occupants than Few Quad during the academic year, and
- underwent a renovation designed to improve energy and water efficiency,

emissions of CO_2-eq from Kilgo grew at a rate nearly three times faster between 2001 and 2006 than they did in Few. Most notably, in 2006, Kilgo surpassed Few's total emissions level, despite the fact that Kilgo is a smaller building with fewer occupants.

It is true that both buildings experienced an increase in energy consumption and CO_2-eq emissions in 2006. However, the magnitude of the increase at Kilgo, relative to the baseline emissions of 2001, indicates that there are factors at work in that building, other than occupancy and weather, which drove energy consumption at such a rapid rate after the renovations began. One important factor to remember is the introduction of air conditioning to Kilgo Quad in 2002. The addition of new air handler equipment would account for substantial increases in electricity consumption and consequently CO2-eq emissions. However, Kilgo renovations were completed before the start of 2004. If the growth in electricity consumption were entirely due to air conditioning demands, one must ask why electricity consumption and CO2-eq emissions increased significantly from 2005 to 2006 when there were no increases in occupancy levels and a significant decrease in cooling degree days.

IV. Discussion

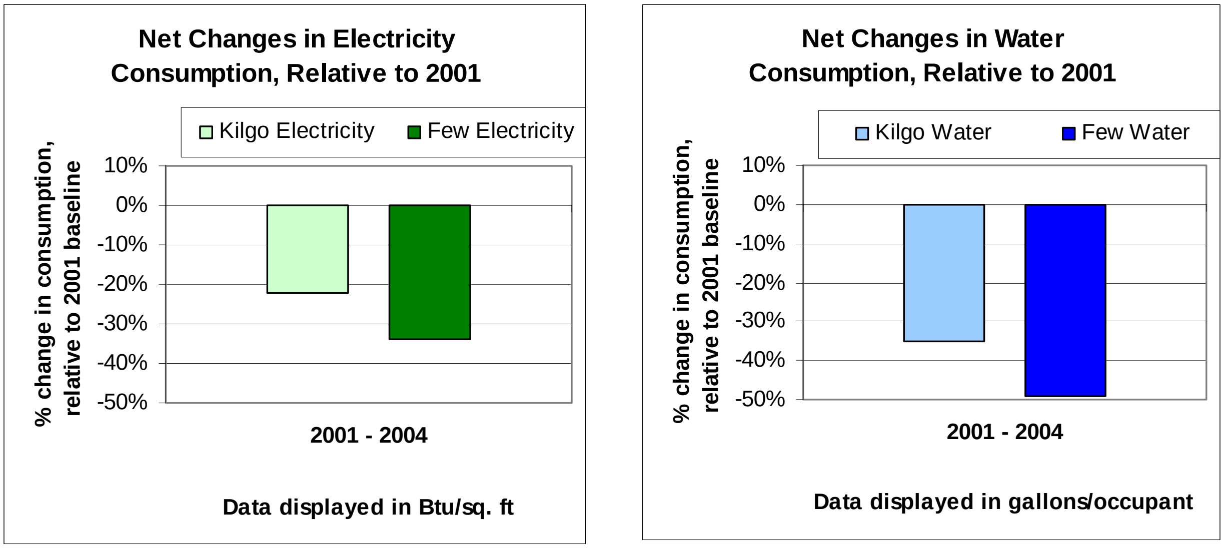
Summary of Analysis of Kilgo and Few

Before beginning this analysis, I expected to find that Kilgo Quad utility data would indicate significant reductions in resource consumption and GHG emissions following the renovation. At the very least, if occupancy levels remained stable and unusual weather patterns did not adversely affect energy demand, I expected that the data would not show any increases once the renovation was completed.

While it is evident that there were net reductions in Kilgo's total electricity and water consumption from 2001 to 2006, when the data is compared to the building performance at Few Quad, there are several data points that question the effectiveness of the renovation to improve the building's environmental impact:

- Relative to 2001, consumption of electricity and water decreased in both buildings in 2004. Figure 15 below shows the net percentage change in consumption levels in each building, relative to the 2001 baseline, after the Kilgo renovation project was completed. However, whereas Kilgo indicated a 20% reduction in electricity consumption, Few indicated a greater reduction of nearly 35% in electricity consumption. Likewise, whereas Kilgo experienced a substantial 35% reduction in water consumption after the renovation was completed, Few experienced an even greater reduction of nearly 50% in water consumption. Essentially, Few Quad exhibited significantly larger reductions in resource consumption in 2004, despite the renovations intended to improve efficiency at Kilgo.

Figure 15. Net Changes in Resource Consumption in 2004, relative to 2001 baseline



- When post-renovation consumption levels are examined in more detail, it is plain to see that Kilgo exhibited significant decreases in electricity and water consumption after the renovation was completed in 2004. However, between 2004 and 2006, consumption levels increased steadily until they were nearly back to pre-renovation levels in 2006. Few Quad exhibited similar patterns over the same time period, with significant decreases in 2004 and increases in consumption after that. However, there were much larger overall increases in consumption at Kilgo and a much more dramatic trend over the post-renovation period. Per capita water consumption at Kilgo rose especially quickly, rising nearly 50% from 2004 to 2006.

Table 20. Comparison of changes in per capita resource consumption, from 2004 to 2006

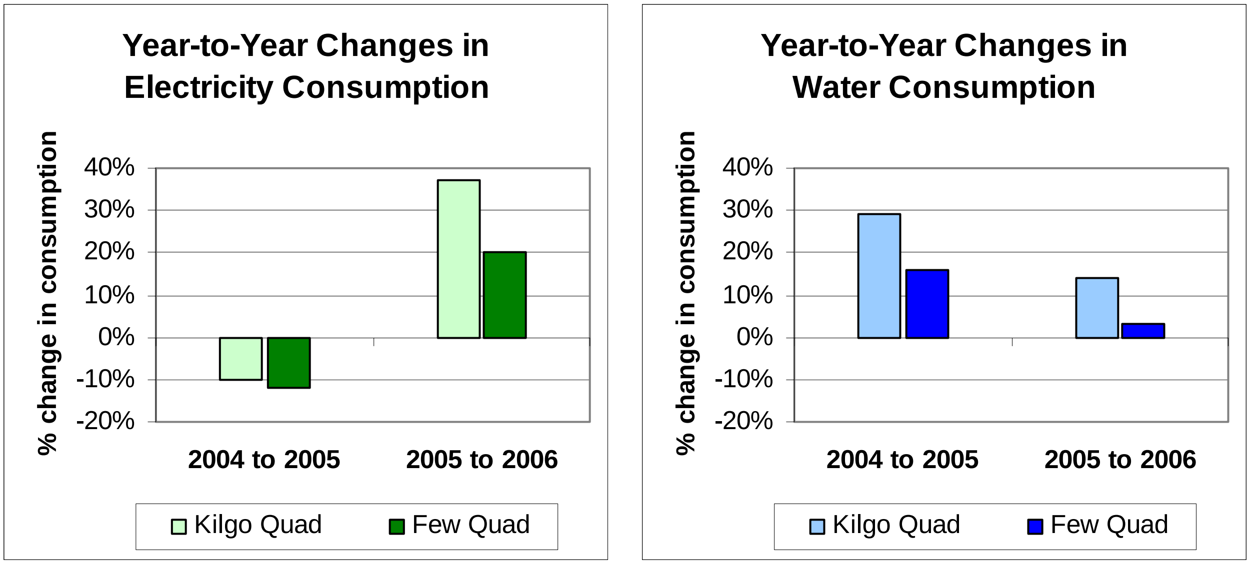
	Kilgo Electricity (per capita)	Few Electricity (per capita)	Kilgo Water (per capita)	Few Water (per capita)
2004 → 2006	+25%	+6%	+50%	+20%

- From 2005 to 2006, the increases in consumption of electricity and potable water at Kilgo were two to three times larger than the increases at Few. This is when both buildings were operating at full capacity and experienced the same external influences of weather and temperature. If the introduction of air conditioning into Kilgo is suggested to explain the increase in electricity consumption after the renovation, it is then reasonable to question why there was not a similar increase, but in fact a decrease of 10%, in electricity consumption in 2005, when air conditioning was operating at full capacity and weather data indicates the warmest year of the three-year period from 2004-2006.

Table 21. Comparison of year-to-year changes in resource consumption (percentages)

	Kilgo Electricity	Few Electricity	Kilgo Water	Few Water	Kilgo Total Energy	Few Total Energy
2000	-	-	-	-	-	-
2001	+3.5	-15.5	-12.4	-13.7	+3.4	-15.5
2002	-25.6	-31.0	+13.6	-16.1	-28.1	-31.0
2003	-16.3	+5.3	-26.6	-25.6	+349.3	+305.4
2004	+28.9	-9.4	-22.1	-19.0	+26.1	-0.7
2005	**-9.9**	**-11.7**	**+29.1**	**+15.9**	**+3.1**	**-16.5**
2006	**+37.0**	**+19.5**	**+13.8**	**+3.4**	**+4.6**	**+5.2**

Figure 16. Post-renovation year-to-year net changes in resource consumption



- In 2006, Kilgo Quad consumed 17% more Btu per square foot and 32% more water per person than Few Quad. It is important to keep in mind that Kilgo had 6% less area and 14% fewer occupants than Few Quad during that academic year.

Each of these points suggests that there is some factor or combination of factors unique to Kilgo Quad that may be responsible for these unexpected changes in resource consumption. It is critical to remember that the impact of outside temperature affected both buildings equally and can thus be ignored, and that there were no appreciable changes in occupancy levels in either building from 2005 to 2006. With this in mind, I believe that individual demand is the key driver of resource consumption in Kilgo Quad. It is possible that changes in the efficiency and capacity of building equipment and the quantity and complexity of occupant possessions (namely personal electronic devices) contributed to unanticipated levels of consumption following the renovation.

<u>Opportunities for Increased Benefits from Green Building Renovations</u>

As Duke University planners and architects develop future green renovation projects for existing campus buildings, there are several opportunities to increase the overall energy and environmental benefits

<u>Occupant Education Programs</u>

A green building achieves energy and water efficiencies through the use of advanced mechanical equipment. In most cases, the new systems will have different performance characteristics than the equipment replaced during the renovation. In order for the building to perform according to the designed specifications, the occupants must "use" the building properly.

Occupant education, conducted each semester during orientation week, would teach the students about the connections between personal energy and water consumption and the negative effects of climate change. FMD staff should develop these education programs in collaboration with building managers and resident assistants, who should then facilitate the educational sessions with the students. By explaining the impacts of unplugging device chargers, turning off the lights when leaving a room, and using less water in lavatories and showers, staff will empower students to make small changes in their daily lives that will aggregate to provide substantial savings at the end of each semester.   In order to gather constructive information to design these sessions, RLHS could distribute a brief energy survey to incoming students to gauge the average types and quantities of electronic devices that will be in an average room.

There would most likely need to be some incentives provided to reduce consumption as well, as recent studies have indicated that knowledge alone does not prompt behavior change.

Modification of personal behavior may be a challenge to promote, but when those habits are shifted towards greater conservation of resources, the building will receive those benefits for as long as the occupant is a member of the Duke community and the occupants will gain valuable knowledge for their personal lives beyond Duke University.

Benefits of Improved Campus Metering

There are a number of challenges to determining a given building's utility consumption and efficiency at Duke University. Specific data is not always available for a building or its subsystems (lighting, irrigation, etc.) and in many cases, several buildings share one or more meters for energy or water. As in the case of this analysis, these deficiencies require an analyst to estimate data based on available square footage or occupancy data. FMD is well aware of the limitations of the nearly century-old metering strategy still operating at Duke University and they are replacing meters and installing sub-metering when and where they can. However, a significant investment in redesigning the metering capabilities of the existing buildings at Duke would enable more accurate measurement of a building's inputs, and thus, more effective management of a building's operations. There is also an opportunity to further enhance occupant education through the installation of real-time monitoring software utilizing improved metering technology.

Lucid Design Group, a California-based company, has developed the Building Dashboard™ for Schools, an interactive, web-based monitoring interface that displays real-time building performance data on touch-screen monitors in the hallways of the building itself. Oberlin College has successfully implemented Lucid's technology in its Campus Resource Monitoring System, a campus-wide monitoring and display system that tracks floor-by-floor electricity consumption in 26 dormitories on the campus in real time. Lucid's Dashboard™ will also be implemented in upcoming construction and renovation projects at UNC-Chapel Hill, Ohio University, and Sierra Nevada College. If occupants can casually use the touch-screen display at the end of their hallway to see how much electricity each person is using that week and the amount of GHG emissions that will result from that consumption, the education session from orientation will resonate in a much stronger way.

Customized Duke University "LEED-plus" Standards

The Kilgo renovation projects received LEED certification from the USGBC, but it may be disputed that the top priority in the design process was occupant comfort rather than energy efficiency and GHG reductions. Duke University should re-evaluate their primary objective in undertaking a new green-building renovation project in any of the 200 existing buildings on campus that are not LEED-certified. There are two possible perspectives:

1. To approach green-building as an "add-on" to a project and make the minimum investment in order to achieve basic certification and add to the impressive list of LEED-certified campus buildings, or
2. To view green-building as an integral component of a project and make the specific investment necessary for each project in order to renovate the building to reduce its long-term impacts on energy services and the environment.

Especially in the light of the obligations to become carbon-neutral under the President's Climate Commitment, Duke may wish to consider developing customized green-building standards that include energy and water efficiency policies which require design specifications beyond the basic or Silver levels of certification in the LEED Rating System. Several major universities, including Stanford, Harvard, and Cornell, are adopting such policies.

The Harvard Green Campus Initiative has created Green Building Guidelines that require Life Cycle Analysis (including costing) to be performed at each step and encourage project managers to strive for Gold LEED certification. Of eighteen new construction or renovation projects that have been completed or are in progress, twelve have received Gold certification or higher.[15]

Stanford University planners have recently adopted their own Guidelines for Sustainable Buildings that are based on the LEED Rating System, but emphasize minimization of energy and water resources. Stanford has decided to forego the LEED certification process and instead use the money that would go towards the USGBC certification fee to invest in the building instead. "What is important is achieving sustainability goals, not so much getting a particular rating," according to David Orenstein, spokesman for the Stanford School of Engineering. "It is in a sense akin to studying to learn rather to do well on a test."[16]

By enhancing the current Duke Design Guidelines to promote continued and long-term energy and water efficiency as key priorities, Duke will be able to reduce its carbon footprint and make progress towards becoming carbon-neutral, regardless of the level of recognition from the USGBC.

<u>Benefits of High-Efficiency Windows</u>

As stated earlier, the most effective way to reduce a building's carbon footprint is to reduce the building energy demand. Heat transfer through the traditional single-paned windows in Kilgo may account for up to 34% of the cooling load and 23% of the heating load in the building. Replacing these with high-efficiency windows may be costly, but will help to improve the building envelope and regulate the interior temperature. Manufacturers such as Hope's Windows, Inc. provide custom solutions that could replicate the historic aesthetic character of the original windows, thus balancing the University's desire to preserve the historic integrity of the West Campus gothic buildings with its future plans to position itself as a leader in sustainable design. University planners and architects will be able to design the most effective solution for such renovation projects by taking advantage of recent developments in Building Information Modeling (BIM). Modeling software such as Energy Plus or eQuest allows designers to calculate the impacts of various building materials within the specific North Caroline climate to optimize the renovation project.

LEED-EB Certification

Moving forward, most renovation projects at Duke University will most likely be required to apply for certification under LEED for Existing Buildings rather than LEED for New Construction. The LEED-EB system was not in place during the Kilgo renovation project, but is now fully developed. This rating system provides a better measure of a building's ongoing performance and operational efficiency because it requires that certified projects apply for recertification after a performance period of no more than five years in order to maintain their LEED standing with the USGBC. A critical requirement for a LEED-EB certified building is the availability of accurate and effective metering and monitoring technology to provide the proof for each recertification submission that the building continues to operate as the designers intended.

Adopting a requirement to apply for LEED-EB certification for all green renovation projects would be an effective driver to ensure that Duke renovation projects are continually monitored after construction work is finished. It is equally important that a building is operating within energy and water efficiency parameters at milestone dates of six months, one year, and five years following project completion.

Conclusion

This study indicates that, despite the best design intentions, significant variability is possible in energy and water consumption in a Duke Residence Hall on a year-to-year basis. Although Kilgo Quad experienced substantial reductions initially, in the span of two short years consumption had nearly increased back to pre-renovation levels. By 2006, despite having less square footage, fewer people and the benefit of the recently-completed renovations, Kilgo Quad used more energy per square foot and more water per person than Few Quad. Kilgo Quad's overall CO_2-eq emissions actually surpassed Few Quad's emissions in 2006 as well. There are many possible reasons for the unexpected performance levels at Kilgo Quad. The addition of central air conditioning was an essential piece of the renovation in order to improve occupant comfort. However, the introduction of this new mechanical system increases the requirements for chilled water on campus and has a complex effect on electricity demand at Kilgo Quad. Without having sub-metered data available, it is difficult to determine exactly how much energy use increased at Kilgo when air conditioning began to be used on a regular basis. It is also unclear whether the new high-efficiency mechanical systems installed in Kilgo are being used by the occupants and maintained by building managers per the design expectations. The relatively poor performance with regards to water efficiency is also perplexing because the efficiency improvements that were implemented during the Kilgo renovation would have been expected to reduce water consumption and cause Kilgo to use substantially less water than Few Quad. Further study is needed to determine why Kilgo Quad is not performing as well as Few Quad following the renovation. Building managers may also want to assess whether Kilgo Quad is still performing at the design standards that enabled it to receive its LEED certification in the first place.

Most importantly, it is imperative to understand that, although green building renovation offers numerous benefits, achieving LEED certification does not necessarily guarantee long-term reductions in energy and water consumption. Renovations aiming to improve the energy efficiency of buildings do not by themselves guarantee the reduction in energy consumption in the long run; if occupants want to improve their indoor comfort, the building's net energy consumption may still increase.[17] University planners must consider whether a renovation will change a building's capacity for consuming resources and then seek a good balance between optimal comfort and effective resource management. Occupant education and improved metering strategies are critical keys to successful renovations at Duke University. The refurbished building will never perform as well as possible if the occupants do not understand how to use the building's systems properly. Likewise, the old adage still rings true – if you can measure it, you can manage it. Once FMD and building managers are equipped with building-specific data and sub-metering capabilities, it will be much easier to diagnose a problem area of a building and adjust management strategies to help improve overall building performance. With careful planning and continuous monitoring, Duke University will be able to renovate existing buildings in a way that provides comfortable spaces to live and work, while contributing to the goal of becoming a carbon-neutral campus in the future.

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Appendix A. LEED Buildings at Duke University

Total projects = 19 (as of May 2008)

Certified

Project	Rating System	Level
Fitzpatrick Center for Interdisciplinary Engineering, Medicine and Applied Sciences (FCIEMAS)	LEED-NC	Silver
French Family Science Center	LEED-NC	Silver
Kilgo Dormitory Phase II - Houses N, O, & P	LEED-NC	Certified
Kilgo Dormitory Phase III - Houses I & J	LEED-NC	Certified
School of Law Addition	LEED-NC	Certified
Smith Warehouse	LEED-EB 1.0 pilot	Certified

Registered

Project	Rating System	Target
Bell Tower Dormitory	LEED-NC	Silver
Duke Center for Integrated Medicine (DCIM)	LEED-NC	Certified
Few Quad Renovations	LEED-EB	Silver
Fuqua School of Business Addition	LEED-NC	Certified
Home Depot Smart Home	LEED-NC	Platinum
Medical Sciences Research Building (MSRB) II	LEED-NC 2.2	Certified
Ocean Science Teaching Center (Duke Marine Lab)	LEED-NC	Gold
Old Art Museum	LEED-NC	Silver
Perkins Library Addition (Bostock)	LEED-NC	Silver
Sanford Institute (Rubenstein Hall)	LEED-NC	Certified
Smith Warehouse Renovation	LEED-CS	Silver
School of Law Commons	LEED-NC	Certified
School of Nursing	LEED-NC	Certified

Appendix B

Kilgo Quad Renovations Phase 2
LEED® Project # 2054
LEED Version 2 Certification Level: CERTIFIED
June 21, 2004

30 Points Achieved — Possible Points: **69**

Certified 26 to 32 points   Silver 33 to 38 points   Gold 39 to 51 points   Platinum 52 or more points

4 Sustainable Sites — Possible Points: 14

Y			
Y	Prereq 1	**Erosion & Sedimentation Control**	
1	Credit 1	**Site Selection**	1
	Credit 2	**Urban Redevelopment**	1
	Credit 3	**Brownfield Redevelopment**	1
1	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
	Credit 4.3	**Alternative Transportation**, Alternative Fuel Refueling Stations	1
	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
1	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
	Credit 6.2	**Stormwater Management**, Treatment	1
	Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
	Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
	Credit 8	**Light Pollution Reduction**	1

3 Water Efficiency — Possible Points: 5

Y			
1	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
	Credit 2	**Innovative Wastewater Technologies**	1
1	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
1	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

7 Energy & Atmosphere — Possible Points: 17

Y			
Y	Prereq 1	**Fundamental Building Systems Commissioning**	
Y	Prereq 2	**Minimum Energy Performance**	
Y	Prereq 3	**CFC Reduction in HVAC&R Equipment**	
2	Credit 1.1	**Optimize Energy Performance**, 20% New / 10% Existing	2
2	Credit 1.2	**Optimize Energy Performance**, 30% New / 20% Existing	2
2	Credit 1.3	**Optimize Energy Performance**, 40% New / 30% Existing	2
	Credit 1.4	**Optimize Energy Performance**, 50% New / 40% Existing	2
	Credit 1.5	**Optimize Energy Performance**, 60% New / 50% Existing	2
	Credit 2.1	**Renewable Energy**, 5%	1
	Credit 2.2	**Renewable Energy**, 10%	1
	Credit 2.3	**Renewable Energy**, 20%	1
	Credit 3	**Additional Commissioning**	1
	Credit 4	**Ozone Depletion**	1
1	Credit 5	**Measurement & Verification**	1
	Credit 6	**Green Power**	1

9 Materials & Resources — Possible Points: 13

Y			
Y	Prereq 1	**Storage & Collection of Recyclables**	
1	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
1	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Shell	1
	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
1	Credit 2.1	**Construction Waste Management**, Divert 50%	1
1	Credit 2.2	**Construction Waste Management**, Divert 75%	1
	Credit 3.1	**Resource Reuse**, Specify 5%	1
	Credit 3.2	**Resource Reuse**, Specify 10%	1
1	Credit 4.1	**Recycled Content**	1
1	Credit 4.2	**Recycled Content**	1
1	Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
1	Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
	Credit 6	**Rapidly Renewable Materials**	1
1	Credit 7	**Certified Wood**	1

6 Indoor Environmental Quality — Possible Points: 15

Y			
Y	Prereq 1	**Minimum IAQ Performance**	
Y	Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	
	Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	1
	Credit 2	**Increase Ventilation Effectiveness**	1
	Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
	Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
1	Credit 4.2	**Low-Emitting Materials**, Paints	1
1	Credit 4.3	**Low-Emitting Materials**, Carpet	1
	Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
1	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
1	Credit 6.1	**Controllability of Systems**, Perimeter	1
1	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

1 Innovation & Design Process — Possible Points: 5

Y			
	Credit 1.1	**Innovation in Design**:	1
	Credit 1.2	**Innovation in Design**:	1
	Credit 1.3	**Innovation in Design**:	1
	Credit 1.4	**Innovation in Design**:	1
1	Credit 2	**LEED® Accredited Professional**	1

Appendix C

Kilgo Dormitory Renovation III

LEED® Project # 3160

LEED Version 2 Certification Level: CERTIFIED

29 August 2005

LEED-NC

28 Points Achieved — Possible Points: **69**

Certified 26 to 32 points **Silver** 33 to 38 points **Gold** 39 to 51 points **Platinum** 52 or more points

4 Sustainable Sites — Possible Points: 14

Y			
Y	Prereq 1	**Erosion & Sedimentation Control**	
1	Credit 1	**Site Selection**	1
	Credit 2	**Urban Redevelopment**	1
	Credit 3	**Brownfield Redevelopment**	1
1	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
	Credit 4.3	**Alternative Transportation**, Alternative Fuel Refueling Stations	1
	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
1	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
	Credit 6.2	**Stormwater Management**, Treatment	1
	Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
	Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
	Credit 8	**Light Pollution Reduction**	1

2 Water Efficiency — Possible Points: 5

Y			
1	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
	Credit 2	**Innovative Wastewater Technologies**	1
1	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

7 Energy & Atmosphere — Possible Points: 17

Y			
Y	Prereq 1	**Fundamental Building Systems Commissioning**	
Y	Prereq 2	**Minimum Energy Performance**	
Y	Prereq 3	**CFC Reduction in HVAC&R Equipment**	
2	Credit 1.1	**Optimize Energy Performance**, 20% New / 10% Existing	2
2	Credit 1.2	**Optimize Energy Performance**, 30% New / 20% Existing	2
2	Credit 1.3	**Optimize Energy Performance**, 40% New / 30% Existing	2
	Credit 1.4	**Optimize Energy Performance**, 50% New / 40% Existing	2
	Credit 1.5	**Optimize Energy Performance**, 60% New / 50% Existing	2
	Credit 2.1	**Renewable Energy**, 5%	1
	Credit 2.2	**Renewable Energy**, 10%	1
	Credit 2.3	**Renewable Energy**, 20%	1
	Credit 3	**Additional Commissioning**	1
	Credit 4	**Ozone Depletion**	1
1	Credit 5	**Measurement & Verification**	1
	Credit 6	**Green Power**	1

8 Materials & Resources — Possible Points: 13

Y			
Y	Prereq 1	**Storage & Collection of Recyclables**	
1	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
1	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Shell	1
	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
1	Credit 2.1	**Construction Waste Management**, Divert 50%	1
	Credit 2.2	**Construction Waste Management**, Divert 75%	1
	Credit 3.1	**Resource Reuse**, Specify 5%	1
	Credit 3.2	**Resource Reuse**, Specify 10%	1
1	Credit 4.1	**Recycled Content**	1
1	Credit 4.2	**Recycled Content**	1
1	Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
1	Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
	Credit 6	**Rapidly Renewable Materials**	1
1	Credit 7	**Certified Wood**	1

6 Indoor Environmental Quality — Possible Points: 15

Y			
Y	Prereq 1	**Minimum IAQ Performance**	
Y	Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	
	Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	1
	Credit 2	**Increase Ventilation Effectiveness**	1
	Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
1	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
	Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
1	Credit 4.2	**Low-Emitting Materials**, Paints	1
1	Credit 4.3	**Low-Emitting Materials**, Carpet	1
	Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
1	Credit 6.1	**Controllability of Systems**, Perimeter	1
1	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

1 Innovation & Design Process — Possible Points: 5

Y			
	Credit 1.1	**Innovation in Design**:	1
	Credit 1.2	**Innovation in Design**:	1
	Credit 1.3	**Innovation in Design**:	1
	Credit 1.4	**Innovation in Design**:	1
1	Credit 2	**LEED® Accredited Professional**	1

Appendix D

Summary of the Kilgo Quad Renovation Plan

Energy

In the LEED category of Energy & Atmosphere, after meeting the prerequisite for Fundamental Building Systems Commissioning, the Kilgo renovation plan received six credits in both Phase II and Phase III for optimizing energy performance and one credit in each phase for meeting energy measurement and verification requirements. This awarded each phase of the project with four points out of a possible total of seventeen points for the Energy & Atmosphere Category. According to documents submitted to the USGBC, the intent of the Kilgo renovations, with respect to energy, was to "achieve increasing levels of energy performance above the prerequisite standard to reduce environmental impacts associated with excessive energy use."[i] To achieve this goal, the LEED AP determined that the design energy cost for the project "exceeds the ASHRAE/IESNA Standard 90.1-1999[1] for regulated energy systems by 32%."[ii] Essentially, this meant that, in the areas of lighting and HVAC systems, the renovated building was expected to perform 32% more efficiently than required by industry. Energy savings were claimed in four categories: lighting, space cooling, pumps and ventilation fans. The LEED AP completed an Energy Cost Budget Compliance Report to detail the design specifications and calculate the expected net energy savings relative to the "budget building" specified by ASHRAE/IESNA standards.

[1] ASHRAE/IESNA Standard 90.1-1999, Energy Standard for Buildings Except Low-Rise Residential Buildings. ASHRAE is the American Society for Heating, Refrigeration and Air Conditioning Engineers and IESNA is the Illuminating Engineering Society of North America. This

The majority of the expected energy savings were claimed in the lighting category, which was projected to directly reduce energy usage while indirectly influencing energy usage for heating and cooling. While high-efficiency lighting systems could be predicted to decrease Kilgo's Energy Cost Budget, the reduction of lighting levels by 60%[iii] could also be expected to produce less radiant heat. The reduction in radiant heat could be expected to increase energy usage for space heating during the heating season and decrease energy usage for cooling in the cooling season. In fact, the projected reduction in cooling load would result in a 23% cost savings in chilled water purchased from the Central Chiller Plant.

Significant energy savings were also claimed in the category of pump energy usage to control chilled and hot water distribution. The savings were realized through the implementation of variable frequency drives (VFDs) to replace the industry standard constant volume pumping system with a more efficient variable speed pumping system. The projected energy savings by the VFDs was approximately 37% relative to the budget building.[iv]

While improvements were made to Kilgo in the category of ventilation fans, the expected energy savings were minimal. The primary modification to the ventilation system was the installation of a VFD in the outside air handler unit that manages the constant air exchanges in the building throughout the day. Although the energy usage is approximately the same as it was prior to renovation, the VFDs keep the design building from becoming overly pressurized, or from becoming negatively pressurized which would result in the infiltration of unconditioned and unfiltered outside air.[v]

Building Envelope and Thermal Performance

While the LEED Rating System does not explicitly require building envelope management, many principles of building envelope best practices are implicitly addressed in several of the LEED category requirements. The Kilgo renovation plan did not set out to modify the building envelope, but the LEED AP did comment on the energy-efficient features already present in the Kilgo envelope.

All of the externally-facing features of a building – walls, roof, windows, doors, and ventilation units – combine to form the building envelope. In addition to basic protection from the elements, the condition of the building envelope will also directly affect the pressure differential and thermal transfer between the interior and exterior environments.

Pressurization of specific rooms or floors will influence the amount of conditioned air that is leaked to the outdoors and the amount of ambient, unconditioned air that enters the building. Room pressure is managed by controlling the air exchange through the HVAC system.

Insulation of conditioned spaces will have a direct effect on the amount of thermal transfer between the interior spaces and the outdoor environment. Insulating materials are measured by their R-value, which is the measure of a material's resistance to heat flow. A higher R-value indicates better insulating properties. Materials are combined in the exterior walls and roofing spaces throughout the construction or renovation process in order to assemble an adequate net R-value for a building that is specific to its particular climate. Certain materials may also function as a thermal mass because of their capacity to store heat from solar energy. A thermal mass will help to regulate interior temperatures more efficiently than the surrounding air and keep the building warmer in heating season and cooler in cooling season.

Finally, the thermal performance of the building's windows will influence the overall building envelope and affect heating and cooling loads. Windows are the least insulating part of the thermal envelope with a heat-loss coefficient that is typically 4-10 times higher than the external wall.[vi] It is estimated that window heat transfer produces, on average, 34% of the cooling load and 23% of the heating load in U.S. residential buildings.[vii] Overall window performance is a function of the glazing properties of the glass: solar energy transmittance through the glazing, reflectance of the glazing, the width of the air space (if applicable) and the configuration of the spacer around the perimeter of the window.[viii] Thermal performance of glazing is expressed in terms of U-value, which is a measure of air-to-air heat transmission due to thermal conductance and the difference between indoor and outdoor temperature. A lower U-value indicates reduced heat transfer through the glass. Single-pane glass has poor thermal performance and is not recommended for applications where the designer wants to control heat transfer through the building envelope. Low-emissivity (low-E) and reflective coatings will reduce interior heat gain by reflecting heat energy and solar energy, respectively. According to the EPA Energy Star program, double-paned windows, which consist of two glass panels separated by a small space filled with air or non-toxic gas like argon, will insulate much better than a single pane of glass.[ix]

The LEED AP described the energy-efficient features of Kilgo's building envelope as follows:

- Massive wall construction with good thermal performance characteristics

- Low window to wall area ratio
- Moderate floor to wall/roof area ratio

In summary, the report indicated that the 16-inch exterior walls, consisting of single layers of stone, air space, terra cotta, and plaster, provided good insulation and created an effective thermal mass. The architectural design minimized the window to wall area ratio, minimizing the amount of thermal transfer through the thinner windows. The design also provided adequate floor space for occupants relative to the overall surface area of walls and roof that would facilitate the majority of the thermal loss or gain. Essentially, the contractors and LEED AP decided to use the features of the existing building envelope as assumptions in their calculations while designing and installing the new energy and HVAC systems.

<u>Water</u>

In the LEED category of Water Efficiency, the Kilgo renovation plan was awarded two credits for Phase II (30% reduction) and one credit in Phase III (20% reduction) for water use reduction. Both project phases also received one credit for water-efficient landscaping, reducing estimated irrigation requirements by 50% by installing weather-based irrigation control overrides. This awarded Phase II with three points and Phase III with two points, out of a possible total of five points for the Water Efficiency Category. According to documents submitted to the USGBC, the intent of the Kilgo renovations, with respect to energy, was to "maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems."[x]

To achieve this goal, the LEED AP recommended strategies that, in aggregate, use 20% (or 30%) less water than the water use baseline calculated for the building (not including irrigation) after meeting Energy Policy Act of 1992[2] fixture performance requirements.[xi] In practice, this was accomplished by installing water consuming fixtures and valves that exceeded the federal performance requirements and by providing a water budget calculation demonstrating that occupancy-based potable water consumption would be reduced by an estimated 20% (or 30%) over baseline standards. The new plumbing fixtures included 1.6 gallon per flush (gpf) water closets, 0.5 gallon per minute (gpm) lavatory fixture aerators, and 2.0 gpm shower heads.

Additionally, prior to the renovation, water use at Kilgo Quad was measured in aggregate with other West Campus buildings, including Few Quad, Craven Quad, and Crowell Quad. Up until 2003, the potable water for all four of these quads was supplied by water meters M47 and M57. In June 2003, water meter M146 was installed to supply Kilgo Quad, providing building-specific meter readings.

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[2] The Federal Energy Policy Act of 1992 requires that all faucet fixtures manufactured in the United States restrict maximum water flow at or below 2.5 gallons per minute (gpm) at 80 pounds per square inch (psi) of water pressure or 2.2 gpm at 60 psi. This ensures that most faucet products available will offer at least minimal water efficiency benefits.

Summary of Few Quad Proposed Renovation Plan

Energy

In the LEED category of Energy & Atmosphere, the Few project scorecard includes two points for optimizing energy performance, one point for enhanced commissioning and one point for enhanced refrigerant management. This would give the project four points out of a possible total of seventeen points for the Energy & Atmosphere Category. According to scorecard notes, the intent of the Few renovations, with respect to energy, will be to "provide energy cost savings of 7% from [the] AHSRAE 90.1 baseline with VFDs, energy-efficient lighting, and DDC VAV box controls." Essentially, this means that the project will:

- replace aging HVAC equipment with newer VFD air handlers
- install DDC variable air volume (VAV) box controls that will allow the FMD Energy Manager to set an allowable range of use for individual room HVAC controls
- upgrade lighting systems in hallways, stairwells and common rooms to use more energy-efficient light bulbs

These modifications are anticipated to set the design energy cost for the project so that it exceeds the ASHRAE/IESNA Standard 90.1 budget building energy performance by 7%. Like the Kilgo renovations, the majority of the expected energy savings will most likely be claimed in the lighting category, which will also result in indirect effects on energy usage for heating and cooling. The thermal mass of external walls and thermal performance of existing windows is comparable to Kilgo. The Few building envelope is not going to be altered in any way, therefore these current thermal performance characteristics will be used as assumptions in the design of the new HVAC system.

Water

In the LEED category of Water Efficiency, the Few project scorecard includes two points for water use reduction and two points for water-efficient landscaping, eliminating estimated irrigation requirements entirely. This would give the project four points out of a possible total of five points for the Water Efficiency Category. The project plan calls for the installation of new, high-efficiency plumbing fixtures, including lavatory fixtures, shower heads and water closets. These new fixtures are expected to use 30% less water than the water use baseline calculated for the building (not including irrigation) after meeting Energy Policy Act of 1992 fixture performance requirements. Water use at Few Quad is currently measured in aggregate with Craven Quad and Crowell Quad. As stated earlier, the potable water for Few, Kilgo, Craven and Crowell was supplied by water meters M47 and M57 up until June 2003. At that time, water meter M145 was installed to supplement the water supply to Few, Craven and Crowell. Following the renovation, the metering scheme will be modified to allow building-specific metering at Few Quad.

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[i] Thompson, Samuel T., P.E. "EA Credit 1.3: Optimize Energy Performance." January 2005.
[ii] Ibid.
[iii] Ibid.
[iv] Ibid.
[v] Ibid.
[vi] United Nations Environment Programme (UNEP). "Buildings and Climate Change: Status, Challenges and Opportunities." 2007.
[vii] Winkelmann, Frederick C. "Modeling Windows in Energy Plus." Environmental Energy Technologies Division, Lawrence Berkley National Laboratory. *Building Simulation 2001*. September 2001.

[viii] Vigener, Nik and Mark A. Brown. “Building Envelope Design Guide – Glazing.” Whole Building Design Guide web site. Last updated in March 2006. Viewed in February 2007 at < http://www.wbdg.org/design/env_fenestration_glz.php>
[ix] EPA Energy Star website. “Anatomy of an Energy Efficient Window.” Viewed February 2008. < http://www.energystar.gov/index.cfm?c=windows_doors.pr_anat_window>
[x] Thompson, Samuel T., P.E. “WA Credit 3.1: Water Use Reduction.” January 2005
[xi] Ibid.

Appendix E

LEED-NC

LEED-NC Version 2.2 Registered Project Checklist - October 2005

DUKE UNIVERSITY - FEW QUAD RENOVATIONS
Durham, NC

Yes	Maybe	No		
4	2	8	**Sustainable Sites**	
Y			Prereq 1	**Construction Activity Pollution Prevention** Approved Erosion and Sedimentation Plan
1			Credit 1	**Site Selection** Site is not farmland, flood plain, endangered habitat, wetlands, 50' of stream, or public parkland.
	1		Credit 2	**Development Density & Community Connectivity** Previous developed site w/ residential desnsity of 10 units per acre and 10 basic services within 1/2 mile raidus
1			Credit 3	**Brownfield Redevelopment** Asbestos abatment per ASTM E1903-97
1			Credit 4.1	**Alternative Transportation**, Public Transportation Access Site is within 1/4 mile of 2 campus bus lines.
		1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms
		1	Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles
1			Credit 4.4	**Alternative Transportation**, Parking Capacity Provide no new parking
		1	Credit 5.1	**Site Development,** Protect of Restore Habitat
		1	Credit 5.2	**Site Development,** Maximize Open Space
		1	Credit 6.1	**Stormwater Design,** Quantity Control
		1	Credit 6.2	**Stormwater Design,** Quality Control
	1		Credit 7.1	**Heat Island Effect,** Non-Roof Shade 50% of hardscape within 5 years.
		1	Credit 7.2	**Heat Island Effect,** Roof
		1	Credit 8	**Light Pollution Reduction**

Yes	Maybe	No		
4		1	**Water Efficiency**	
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%
1			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation No irrigation for landscaping
		1	Credit 2	**Innovative Wastewater Technologies**
1			Credit 3.1	**Water Use Reduction**, 20% Reduction
1			Credit 3.2	**Water Use Reduction**, 30% Reduction Provide low flow faucets, showers and flush valves with automatic shut-off.

Yes	Maybe			
4	1	2	**Energy & Atmosphere**	
Y			Prereq 1	**Fundamental Commissioning of the Building Energy Systems** University will hire Commissioning Agent
Y			Prereq 2	**Minimum Energy Performance** Design shall meet ASHAE 90.1-2004
Y			Prereq 3	**Fundamental Refrigerant Management** No CFC-based refrigerants in HVAC systems
2			Credit 1	**Optimize Energy Performance** Provide energy cost savings of 7% from AHSRAE 90.1 baseline with VFD, energy efficient lighting, and DDC VAV box controls.

		1	Credit 2	**On-Site Renewable Energy**
1			Credit 3	**Enhanced Commissioning**
				Cx Agent can provide 3rd party reviews
1			Credit 4	**Enhanced Refrigerant Management**
				Meet refrigereant formula and minimize ozone depletion
		1	Credit 5	**Measurement & Verification**
	1		Credit 6	**Green Power**
				University may purchase green power in the future, with 35% for this project
Yes	Maybe			
10		**3**		**Materials & Resources**
Y			Prereq 1	**Storage & Collection of Recyclables**
1			Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof
1			Credit 1.2	**Building Reuse**, Maintain 95% of Existing Walls, Floors & Roof
				Maintain 95% of surface area of structure and envelope
		1	Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements
1			Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal
1			Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal
				Divert 75% of demolition and construction waste (by weight) from landfill
		1	Credit 3.1	**Materials Reuse**, 5%
		1	Credit 3.2	**Materials Reuse**,10%
1			Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)
1			Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)
				Specify materials with recycled content for 20% of material cost of the project
1			Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regionally
1			Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regionally
				Specify materials from within 500 miles for 20% of material cost of the project
1			Credit 6	**Rapidly Renewable Materials**
				Specify rapidly renewable materials for 2.5% of material cost of the project
1			Credit 7	**Certified Wood**
				Use 50% of wood from FSC certified source
Yes	Maybe			
11	**2**	**2**		**Indoor Environmental Quality**
Y			Prereq 1	**Minimum IAQ Performance**
				Design to meet ASHRAE 62.1-2204, Paragraph 5.1, with natural ventilation
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**
				Prohibit smoking in the bldg and provide designated smoking areas 25' away from bldg.
		1	Credit 1	**Outdoor Air Delivery Monitoring**
		1	Credit 2	**Increased Ventilation**
1			Credit 3.1	**Construction IAQ Management Plan**, During Construction
				CM shall meet SMACNA IAQ Guidelines and use MERV 8 filters
1			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy
				Cx Agent provides air testing
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants
				Specify low VOC materials
1			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings
				Specify low VOC products that meet Green Seal
1			Credit 4.3	**Low-Emitting Materials**, Carpet Systems
				Specify carpet that meets CRI Green Label
1			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products
				Specify wood products with no added urea-formaldehyde resins.
	1		Credit 5	**Indoor Chemical & Pollutant Source Control**
				Provide permanent entry-way systems 6' long that allow cleaning.
1			Credit 6.1	**Controllability of Systems**, Lighting
				Provide individual lighting controls for 90% of the occupants and light-controls in Commons

Yes	Maybe	No	Credit	Description
1			Credit 6.2	**Controllability of Systems**, Thermal Comfort Provide separate thermostats for 50% of occupants, or operable windows
1			Credit 7.1	**Thermal Comfort**, Design Design HVAC system to meet ASHRAE 55-2004
	1		Credit 7.2	**Thermal Comfort**, Verification Implement a thermal comfort survey within 6-18 months of occupancy.
1			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces Design glazing factor of 2% for 75% of regularly occupied spaces.
1			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces Design direct line of sight to outdoors from 90% of regularly occupied spaces

Yes	Maybe	No		
2	**1**	**2**	**Innovation & Design Process**	
1			Credit 1.1	**Innovation in Design**: Education and Training Develop program for education and training of residents for operation of bldg
	1		Credit 1.2	**Innovation in Design**: Green Housekeeping University will have program for green products and methods for housekeeping
		1	Credit 1.3	**Innovation in Design**: Provide Specific Title
		1	Credit 1.4	**Innovation in Design**: Provide Specific Title
1			Credit 2	**LEED® Accredited Professional** CN Design team will have LEED AP in all disciplines

Yes	Maybe		
35	**6**	**18**	**Project Totals** **(pre-certification estimates)**

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

Appendix F - Kilgo Quad Utility Data

Kilgo							
Electricity							
Month	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Jul	60,080	61,360	7,840	52,880	77,280	42,560	78,240
Aug	48,080	54,480	13,120	21,440	67,200	41,280	78,480
Sep	135,520	143,120	35,040	38,960	56,000	46,320	101,760
Oct	120,480	128,800	65,600	32,560	60,000	68,160	107,280
Nov	106,240	115,920	67,360	67,360	88,000	70,320	106,320
Dec	96,400	97,680	64,480	42,800	72,000	38,640	103,200
Jan	82,960	73,840	66,960	100,800	89,840	38,160	97,680
Feb	108,080	111,200	108,080	138,080	109,360	120,240	119,520
Mar	97,120	99,840	104,560	118,320	97,040	103,680	100,080
Apr	130,960	134,240	111,760	36,080	89,840	112,560	103,920
May	89,840	91,760	118,800	36,480	86,480	95,760	88,560
Jun	37,360	79,440	68,080	93,680	43,600	68,880	74,640
Steam							
Month	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Jul	-	-	-	129,405	158,065	115,366	232,783
Aug	-	-	-	188,925	232,796	379,668	214,694
Sep	-	-	-	197,950	228,345	283,760	268,624
Oct	-	-	-	258,571	403,545	346,176	448,380
Nov	-	-	-	392,168	601,709	725,437	780,480
Dec	-	-	-	672,172	958,604	1,226,779	1,063,290
Jan	-	-	-	914,099	1,252,636	1,084,100	1,051,826
Feb	-	-	-	1,441,881	1,348,681	1,060,105	1,575,961
Mar	-	-	-	744,783	1,233,129	879,340	487,375
Apr	-	-	-	683,181	756,446	832,232	1,002,760
May	-	-	-	324,754	431,513	502,412	857,172
Jun	-	-	-	141,942	362,210	277,990	286,485
Water							
Month	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Jul	236,180	40,000	177,000	2,500	2,900	26,400	25,000
Aug	249,600	205,000	250,000	9,000	2,300	22,900	29,500
Sep	269,580	242,000	246,340	28,300	22,000	16,000	24,600
Oct	315,240	270,000	224,110	56,900	57,200	53,200	79,200
Nov	334,950	305,000	309,720	59,000	40,100	64,300	54,300
Dec	260,540	315,000	233,920	47,100	47,300	45,900	55,900
Jan	19,075	225,000	213,560	109,600	16,600	30,300	41,300
Feb	204,075	200,000	271,030	52,900	40,600	42,200	52,100
Mar	276,370	220,000	305,040	30,000	48,000	63,700	69,600
Apr	305,000	220,000	271,050	19,300	43,000	63,700	44,500
May	363,000	74,900	316,730	59,800	50,700	72,500	89,300
Jun	250,000	260,010	119,500	5,100	11,300	17,300	15,600

Appendix G - Few Quad Utility Data

Few & Kilgo Utilities							
Few							
Electricity Meter 103 - Lighting							
Month	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Jul	45,600	56,300	32,300	2,000	21,100	25,000	27,480
Aug	43,200	40,500	31,100	20,800	21,700	30,000	30,240
Sep	70,000	78,200	78,500	59,100	37,200	45,000	55,680
Oct	98,000	89,700	61,300	55,100	40,000	40,000	60,240
Nov	86,100	89,500	90,700	90,700	90,000	58,200	58,680
Dec	100,100	90,000	74,900	90,000	87,000	43,800	54,240
Jan	97,700	79,300	71,400	89,300	88,000	63,000	41,760
Feb	117,100	98,600	84,700	98,000	80,000	60,120	69,600
Mar	93,800	99,000	90,600	100,000	75,000	59,640	57,480
Apr	103,900	108,500	74,600	100,000	87,000	75,240	60,000
May	61,200	68,900	67,100	65,000	89,000	60,360	46,200
Jun	22,400	36,300	32,700	50,000	44,000	22,320	21,600
Electricity Meter 101 - HVAC							
Month	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Jul	545,760	159,840	68,640	135,360	55,600	40,000	163,600
Aug	390,240	236,160	93,120	128,880	41,120	20,800	168,080
Sep	338,400	228,960	112,720	164,880	127,280	24,800	159,120
Oct	339,840	211,680	83,760	94,240	122,000	95,200	157,920
Nov	221,760	264,960	105,600	105,600	118,000	81,200	145,680
Dec	257,760	288,000	106,640	104,000	116,000	142,640	150,240
Jan	306,720	285,120	120,640	96,400	88,000	151,120	158,640
Feb	200,160	181,440	124,000	93,600	84,000	136,080	150,960
Mar	181,440	161,280	109,200	94,400	76,800	126,160	135,120
Apr	194,400	8,000	78,960	88,000	122,000	138,720	139,360
May	226,080	139,680	121,760	132,000	106,000	144,800	143,760
Jun	180,000	216,000	113,920	236,000	68,000	150,320	149,840
Steam							
Month	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Jul	-	-	-	864,706	1,004,478	871,427	713,999
Aug	-	-	-	702,156	976,074	714,187	514,665
Sep	-	-	-	570,383	903,046	430,250	722,473
Oct	-	-	-	567,666	864,013	962,738	804,561
Nov	-	-	-	1,222,699	1,104,312	1,575,262	1,415,889
Dec	-	-	-	609,622	1,663,784	1,860,599	582,093
Jan	-	-	-	3,478,960	2,460,535	1,365,090	1,274,234
Feb	-	-	2,600,000	2,702,906	2,202,151	1,856,187	3,115,786
Mar	-	-	2,785,227	1,686,189	2,054,555	1,348,387	1,278,872
Apr	-	-	1,354,399	2,120,523	1,750,000	1,287,343	1,137,372
May	-	-	1,207,684	1,065,935	821,046	695,347	1,080,698
Jun	-	-	1,086,227	381,468	873,329	292,621	669,439
Water							
Month	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Jul	236,180	40,000	177,000	175,000	82,200	125,000	83,400
Aug	249,600	205,000	250,000	112,900	142,240	85,900	65,500
Sep	269,580	242,000	246,340	200,800	104,701	90,700	63,500
Oct	315,240	270,000	224,110	91,670	161,510	95,500	163,230
Nov	334,950	305,000	309,720	236,180	140,110	93,000	278,660
Dec	260,540	315,000	233,920	192,800	191,740	144,210	165,490
Jan	19,075	225,000	213,560	65,880	135,730	159,660	137,620
Feb	204,075	200,000	271,030	263,040	91,900	176,500	168,870
Mar	276,370	220,000	305,040	150,700	102,400	197,840	153,700
Apr	305,000	220,000	271,050	128,050	115,500	197,840	131,500
May	363,000	74,900	316,730	156,740	114,500	245,830	210,265
Jun	250,000	260,010	74,560	86,700	68,800	49,250	39,350

Appendix H. Calculating CO_2-eq emissions

The Fourth Annual Report (FAR) by the Intergovernmental Panel on Climate Change (IPCC) categorizes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) as the most important anthropogenic greenhouse gases considered to be drivers of climate change. According to the IPCC FAR, the "CO_2-eq emission is the amount of CO_2 emission that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs. The equivalent CO_2 emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP)[1] for the given time horizon." After summarizing the annual changes in energy consumption, it is a straightforward calculation to convert energy usage data to approximate total CO_2-eq emissions.

For our purposes, we will consider the carbon footprint of each building as the CO_2-eq of the mixture of GHG emissions released by each utility plant to provide energy to that building. Duke utility providers generate energy according to the following specifications:

Energy Type	Electricity	Chilled Water	Steam
Provider	Duke Energy Corp (DUK)	Duke Central Chiller Plant	Duke Central Steam Plant
Fuel Mix	North Carolina Fuel Mix, by generation[i], • 51% coal, oil and gas • 48% nuclear • 1% hydro	Electricity provided by Duke Energy	Fuel Mix, by generation[ii], • 92% coal, with energy content of 13,000 Btu/lb • 6% natural gas • 2% recycled blended oil

[1] The Global warming potential (GWP) of all greenhouse gases is calculated relative to CO_2. Methane and nitrous oxide emissions are adjusted by their GWP factors of 23 and 296, respectively

Because varying fuels are being used to generate energy across each of these utilities, I have used a number of emissions factors to calculate the total CO_2-eq associated with each energy type.

According to Duke Energy Corporation's 2006 response to the Carbon Disclosure Project[iii], the North Carolina fuel mix generates 1,260 pounds of CO_2-eq per net megawatt-hour generated. Emissions attributed to each electricity consumption for each Duke residence hall were calculated by multiplying the total consumption (in megawatt-hours) by this emissions factor and dividing by .90 to account for an assumed 10% efficiency loss during transmission.

The Duke Central Chiller Plant uses a closed loop system to produce chilled water for portions of the campus. This process is energy-intensive and powered by electricity purchased from Duke Energy Corp. Production of one ton of chilled water uses approximately 0.87 kWh of electricity; once the equivalent amount of kWh is calculated, the same calculation used for electricity can be used to calculate CO_2-eq for chilled water. Transmission losses for the campus chilled water loop are assumed to be negligible.

The Duke Central Steam Plant uses a number of different fuels to generate steam for campus use. Using CO_2-eq emission factors for each fuel type, I have calculated the weighted CO_2-eq emissions, according to the Steam Plant fuel mix, to be 243.2 pounds of CO_2-eq per pound of steam generated. The data used to calculate the CO_2-eq emissions are shown in Table 22 below. Again, transmission losses on the campus closed loop are assumed to be negligible.

Table 22. CO_2-eq Emission Factors for Steam Generation

Fuel Type	CO_2-eq (lbs)	% of utility mix	weighted emissions (lbs. of CO_2-eq)
Natural Gas	139.21	0.06	8.35
Recycled Oil	212.77	0.02	4.26
Coal	250.64	0.92	230.59
		Total	243.20

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[i] Research Triangle Region North Carolina web site. "RTRP: Electricity." Viewed February 2008. <http://www.researchtriangle.org/pages.php?page1=52&page2=91&page3=93&page_id=93>

[ii] Kennedy, Dennis. Personal Communication, Duke Central Steam Plant. February 2008.

[iii] Carbon Disclosure Project web site. Responding Corporation: Duke Energy Corporation. Viewed February 2008. <http://www.cdproject.net/online_response.asp?cid=1015&id=5&exp=61&desc=Electric+Utility&letter=D&year=2>