Sensors and Green Buildings:

An Analysis of Retrocommissioned Buildings at the University of Illinois

Final Report

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CEE398PBL

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Executive Summary

Buildings account for 70% of the electricity load in the United States, and a large portion of this energy usage comes from the heating and cooling of the building(Knox 2015). The University of Illinois has the goal to reduce their building energy usage by 30% in 20 years (iCAP 2015). One proposed method to do this is the integration of building sensors to help control the heating, ventilation, and air conditioning (HVAC) of the building. This gives control over the heating and cooling of a building from off-site and allows around the clock monitoring of the systems. The objective of this project is to analyze retrocommissioned buildings at the University of Illinois at Urbana-Champaign, use this data to determine the energy, cost, and emissions saved by the process, and to extrapolate the findings to make a general statement on the application of sensor systems to reduce energy usage and increase control.

At the University of Illinois, the Facilities and Services (F&S) Retrocommissioning (RCx) project is the team that is dedicated to upgrading buildings around campus with sensors in the HVAC systems. This gives them total control over the building's systems from off-site and allows for constant monitoring. It was calculated that the buildings have a mean reduction in energy usage of 27%, saving the university over $5 million in annual utility fees. From a cost analysis of six retrocommissioned buildings on campus, it was determined that retrocommissioning reduces the cost of energy by $6.35/sqft over 15 years, leading to a net saving of $4.42/sqft, and yielding a potential savings of $79.6 million. This system also leads to a reduction of greenhouse gas emissions equivalent to taking 13,000 vehicles off the roads a year with the current amount of RCx buildings. Retrocommissioned buildings on campus have a payback period between three and five years, meaning that they are a cost-effective means of reducing greenhouse gas emissions and ultimately saving money for the university.

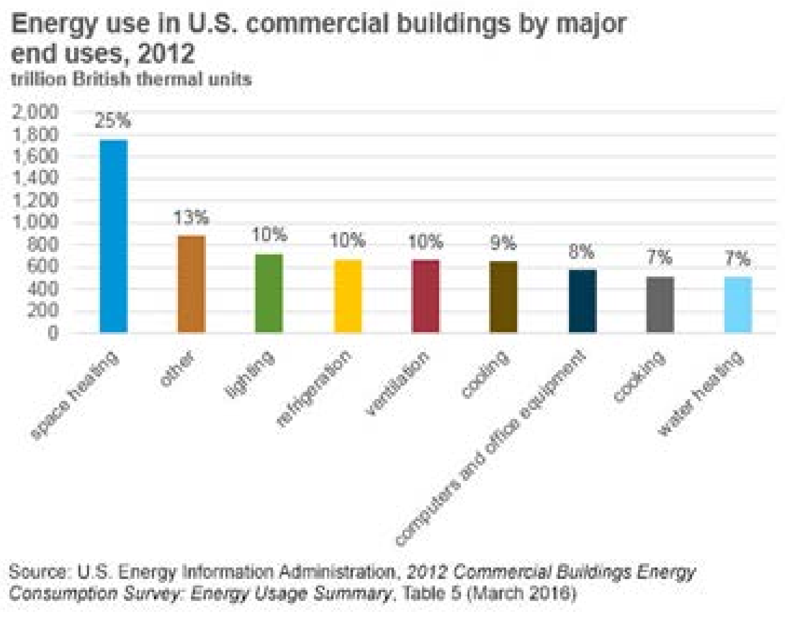
Introduction

Due to the recent revolution in processing power and information sharing, technology is rapidly becoming more powerful and interconnected. An astounding vision of the future; the smart city, seems more feasible now than it ever has. Using extensive sensor networks tied into the systems and inhabitants of a "smart city", daily processes such as commuting and waste disposal could be made more time and energy efficient. While this grand vision is very appealing, there is a great deal of similar innovation making a major impact going unsuspected by most, in buildings people use every day.

According to the US Green Buildings Council, buildings in the US consume 70% of electricity load in the US (Knox 2015). This means that a small change in efficiency of buildings or reduction in emissions can have a large change across the entire energy usage sector. The GBC even estimates that if new buildings used 50% less energy, approximately 6 million tons of CO_2 would be saved annually over the life of the buildings (Knox 2015). This would be equivalent to taking over 1.2 million vehicles off the road each year (U.S. EPA 2017).

Specifically, the University of Illinois is committed to becoming carbon neutral, with the goal to be completely carbon neutral by 2050 (iCAP 2015). The first category in the Illinois Climate Action Plan (iCAP) is energy conservation and building standards. Campus likes to report their energy usage in Energy Usage Intensity (EUI) instead of total energy use. This unit is essentially just the campus's energy usage normalized over the area of used space, making sure to not include construction projects or buildings that are not in use. One of the shortcomings to this method, however, is that as the campus grows, the total amount of energy that the campus uses is likely to increase. If the rate at which energy is used remains the same the EUI metric would illustrate that the campus's footprint is staying the same, but, in reality, the total energy use is increasing. In terms of looking at an individual building's energy usage, the EUI unit can still make a lot of sense. The total square footage of a building does not change, and it only makes sense that large buildings will use more energy overall than smaller buildings. Therefore, in comparing the energy footprint of different buildings in the project, it will make sense to use EUI instead of just overall energy usage. The iCAP goal is to have a 30% reduction in total campus building energy use in 20 years. To accomplish this goal, iCAP has many suggested actions that include expanding the retro-commissioning program, completing energy performance contracts, extending campus lighting projects, and implementing a fume hood efficiency program, amongst others (iCAP 2015).

As previously stated, the focus of this project will be on investigating the integration of sensing systems into buildings and how these systems can help reduce overall energy usage of the building. Therefore, several sensor systems will be investigated and how they can help reduce energy usage. The most basic of these sensors are simple occupancy sensors, which use either passive infrared (PIR) or ultrasonic technology to detect the presence of occupants. Though these systems use different methods, they accomplish the same goal of detecting whether a room is occupied or not. While occupancy sensing can inform almost any building system, we could not encompass the entirety of building operations in this study due to limited time and resources. However, we were able to focus on the building system that is the largest consumer of energy. Heating, ventilation, and air conditioning (HVAC) systems are where most of a building's energy usage comes from. According to Figure 1(U.S. Energy Information 2016), HVAC accounts for 44% of a building's energy usage while lighting only



Source: U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary*, Table 5 (March 2016)

Figure 1: Energy Usage Breakdown in Commercial Buildings (U.S. Energy Information Administration)

accounts for 10%. This means that a small change in HVAC use or efficiency can lead to a large change in overall energy usage. However, a potential downfall of retrofitting a building's HVAC system is that it can be an expensive and something many groups cannot afford.

At the University of Illinois, a proposed method for decreasing the energy usage of buildings on campus is by "retrocommissioning" them, or integrating sensors into the building's systems, most prominently in the HVAC systems. The retrocommissioning team (RCx), is a division of Facilities and Services, and so far, has retrocommissioned more than 70 buildings on campus. When retrocommissioning a building, the team installs several types of sensors, including, but not limited to, carbon dioxide, humidity, temperature, airflow, and occupancy sensors. These are all connected into a system that links back into F&S's computer network where the status of the system can be monitored from the F&S headquarters. In addition to employees at F&S who monitor and control systems, many major buildings on campus also have their own building manager, allowing for faster access to and more control of individual buildings. This control encompasses many facets, including being able to know the condition of a system, anticipate its failure, and fix it before a major problem occurs. This is a significant improvement over conventional or pneumatic controls that break first and have to be fixed second.

F&S is a large department at UIUC, and is divided into 8 divisions. These include but are not limited to Operations, Maintenance & Alterations (OMA), Utilities & Energy, and Engineering & Construction Services. Its mission is to provide and maintain the physical environment that is conducive to support the development of The University of Illinois in various aspects such as economic, educational and discovery engagement (F&S 2017). From the Everritt Lab renovation, the Illini Union electric service replacement, Scott Hall roof replacement, pavement reconstruction on First and Fourth, and the North Campus parking deck, the F&S has numerous ongoing projects each with its own diverse aspects.

The RCx team falls under the control of the Utilities & Energy Division, as their main goal is improving the energy efficiency of campus buildings. They focus on reviewing and improving the operation and maintenance of the buildings, through implementing strategies that could support greater energy conservation, sustainability, and occupant comfort. "Since August of 2007, RCx teams have updated and upgraded systems in 70+ campus buildings, reducing energy consumption by an average of 27% and avoiding $47M in utility costs for over 10 million gross square feet of facilities." (F&S 2017). Furthermore, the university has made several commitments and contracts related to sustainability with institute for sustainability, energy and environment in U of I (iSEE): Chancellor Barbara Wilson signed Second Nature's Climate Resilience Commitment on Feb. 9, 2016, which combines the Resilience Commitment with the Carbon Commitment the campus signed in 2008, chancellor Phyllis Wise signed LED campus, making LED technology the major source of lightening by 2050, and participating in the Big Ten & Friends Environmental Stewardship Group (iSEE 2017).

Thus, based on the past retrocommissioned projects, and the University's commitment on sustainability, we believe the usage of smart sensors should be continued. This paper would provide examples and research on cost reduction and benefits on these retrocommissioning methods and analyze if the projects are both economically and environmentally beneficial.

Objectives

The objective of this project is to analyze retrocommissioned buildings at the University of Illinois at Urbana-Champaign, determine the energy, cost, and emissions saved by the process, and to use the data acquired to make a general statement on the application of sensor systems to reduce energy usage and increase control. This will be accomplished through a cost-benefit analysis and a life-cycle analysis of multiple retrocommissioned buildings on campus. Information on findings will be presented to both Frank Holcomb from the Construction Engineering Laboratory (CERL) and to Reifsteck Reid, the architecture firm redesigning the Hydrosystems Lab. These findings could be significant in finding a cost-effective way of significantly reducing energy usage in a building, thereby saving money and reducing emissions.

Methodology

This project was broken down into several tasks, each of which has its own subtasks. To generate data that accurately represented the entirety of UIUC campus buildings, a sample group of 6 retrocommissioned buildings was established. The primary tasks involved were to conduct a cost-benefit analysis and life-cycle analysis of the 6 sample buildings on campus. The conclusions and recommendations of the report were then compiled using the findings from these respective calculations.

Task 1: Cost-Benefit Analysis

The first task performed a cost-benefit analysis (CBA) on the retrocommissioning of buildings on campus with sensor systems. These buildings were used because they have sensors integrated into their HVAC systems, in order to reduce energy usage. The data gave the best representation of how much energy and money sensor systems potentially save. The data was gathered from Facilities & Services (F&S) at UIUC, and estimations were made on the costs of retrocommissioning based on detailed evaluations of individual HVAC systems. The whole CBA process was broken into 4 subtasks.

Subtask 1: The first subtask was to gather data from F&S. Much of the data on the retrocommissioned (RCx) buildings is available to the public and easily obtainable, but some specific information required access to F&S's Energy Billing System. Morgan White and Paul Foote provided access to this data, and provided additional insight into the RCx team's operations.

Subtask 2: The second subtask was to use the data from F&S to determine the net costs of retrocommissioned multipurpose buildings. This was the energy usage after retrofitting converted into a monetary value. For the CBA, a group of six buildings was used and the average energy use was obtained. This was done to help eliminate bias towards one building or another, that may be more energy intensive as a result of its use or design. The six sampled buildings represent every kind of multipurpose building on campus, so that the findings can be accurately expanded to apply to the entirety of buildings at UIUC

Subtask 3: The third subtask was to determine the net savings of the buildings through the RCx process, or in essence the amount of money saved. This again was equated as the total energy used converted to a dollar amount.
Subtask 4: The final subtask was to compare these two values to determine if the retrofitting is cheaper over the life of the building. This task also gave a payback period for the integration of a sensor system. This is the time in which the investment of the retrocommissioning is equivalent to the amount of money saved by the system.

Task 2: Life Cycle Analysis

The second task was to conduct a basic life cycle analysis (LCA) of the same sampling of buildings in the CBA. This task was split into three subtasks.

Subtask 1*:* The first was to determine average total emissions a retrocommissioned building reduces per year. These emissions were based on the energy use of the building and converted into emissions. The emissions were based on data for both the local Abbott Power Plant and other local power plants, as this is where the university gets their energy.
Subtask 2*:* The second subtask was to use this information and information from the EPA to present the emissions reductions in values that make sense to a reader.
Subtask 3*:* The final subtask was to extrapolate the findings to other systems, such as the amount of emissions that could be sequestered if this system was used in all commercial buildings.

Task 3: Compile Data and Write Report

The final task was to compile all the data, make conclusions, and report on the outcome. This was divided into 5 subtasks.

Subtask 1*:* The first was to compile the data from the economic and life cycle evaluations. This was supplemented with overall general energy usage data of all of the retrocommissioned buildings on campus to show trends and overall energy reduction through the use of sensors.
Subtask 2: The second subtask was to write the background, objectives, and methodology of the project. This was done earlier in the process of the project, but was modified and updated as the objectives changed and became more refined.
Subtask 3: The third subtask was to write about the results and conclusions, as well as the other minor sections of the paper. This was the main focus of the paper and is culmination of all of the research and data compiling. It combines the CBA, LCA, and other important research to provide conclusions of how sensor systems can reduce energy usage and cost of a building.
Subtask 4: The fourth subtask was presenting our findings to Frank Holcomb.
Subtask 5: The final subtask was creating the poster for the poster presentation. This was heavily visually and graphically based, allowing for easy interpretation of data.

Results and Discussion

General Analysis of Retrocommissioned Buildings

The analysis of the retrocommissioned buildings started with a general analysis of retrocommissioned buildings around campus. The goal was to obtain a general understanding of how retrocommissioning has impacted energy usage of buildings. There are currently 72 RCx buildings on campus, including buildings such as the Business Instructional Facility, Memorial Stadium, and the Illini Union. Since the project started in 2008, more than $15 million have been spent on retrocommissioning. (Retrocommissioning Report 2017)

A few assumptions were made before analyzing the data from F&S. The first is that the price per million BTU (MBTU) of energy was calculated as the total cost avoided by all the retrocommissioned buildings normalized by the total MBTU avoided by those buildings, shown in Equation 1.

$$Price(MBTU) = \frac{\sum Cost\ Avoided}{\sum Energy\ Avoided} \tag{1}$$

This calculated to a price per MBTU of energy of $8.74. This estimator was used because the F&S data did not include reductions in specific types of energy (chilled water, electricity, and steam), and instead only included an overall energy reduction. In order to determine if this is a good estimator of cost/MBTU, the value was compared to other costs of utilities. According to F&S and through conversions, electricity, chilled water, and steam cost roughly $11.82, $8.97, and $6.22, respectively. If it is assumed that each of these components make up a third of a building's energy usage, the price per MBTU comes out to $9.00/MBTU. Therefore, the estimate of $8.74 is close to the costs of the utilities and will allow for comparisons without knowing the exact breakdown of which energy is being saved. The second assumption was that that each building saves the same amount of energy per year, regardless of weather conditions

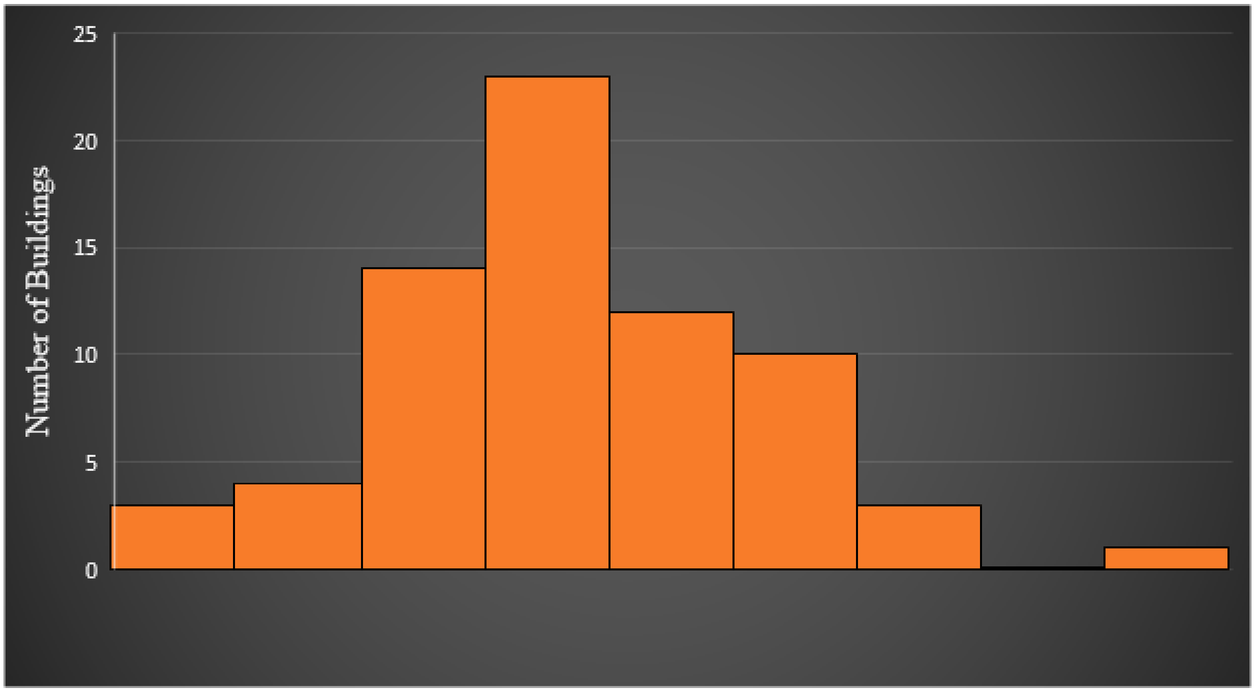


Figure 2: Annual Percent Energy Reduction of Retrocommissioned Buildings at the University of Illinois

that year. This allows for the use of F&S's evaluation period data, even if the evaluation period was a few years ago. This can also reduce bias for recent years as winters have been milder over the past couple years and has led to overall reduced energy usages across campus.

Figure 2 shows the percent of energy that is saved annually from all the retrocommissioned buildings. It shows that generally the addition of sensor networks saves energy. The Henry Administration Building had the maximum energy percent saved per year with 71.2%, significantly higher than the mean value; 27%. It should be noted, however, that there are a couple buildings that had "negative" energy savings, indicating that they are less efficient than they were before retrocommissioning. This could be due to improper installation of the sensor system. The analysis period for each building was conducted starting the month following installation and lasted for a year. There is the potential that the system was incorrectly installed in these buildings, but the engineers were hesitant to go in and change the system, as this would cost extra money. Therefore, for the period of time that the system was not functioning properly, it would appear that it was using more energy. Two of the three buildings analyzed that had a negative reduction in energy usage only had less than 4% change, but the English Building had over 11% change. However, there is overwhelming evidence that in general the RCx process saves an immense amount of energy. These buildings should therefore be considered outliers and should not be the subject of the specific analysis of buildings on campus.

Another interesting item of note is that the largest percent energy reductions did not translate to the largest overall reductions in energy. This is because some buildings had a smaller percent energy reduction, but have such a large footprint that their overall energy reduction was very large. For example, the Library and the Activities & Recreation Center (ARC) had the largest total energy avoidance of 35,649 and 33,372 MBTU, respectively, and had percent energy reductions of 40% and 34%. Although both of these percent energy reductions are above the mean energy reduction, it is still far less than the maximum of 71.2% for the Admissions Building. The Admissions and Records Building, however, only avoided 7,348 MBTU of energy. This comes from its significantly smaller footprint than either the Library or the ARC, but shows that the same process done in different buildings can be drastically different in terms of effectiveness. This also explains, however, why the F&S has retrocommissioned most of the large energy usage, large footprint buildings first. Of the top ten largest buildings on campus, only three have not been retrocommissioned, with The Institute for Genomic Biology being the largest energy user of those. These buildings have the potential to save the University more money on utilities, and it therefore makes sense that they would invest into those buildings first before the smaller and less energy intensive buildings. More graphs and information regarding overall energy usage of buildings on campus can be found in Appendix A.

Cost Benefit Analysis

Sensor System Cost

Through Facilities and Service documents, the total cost for implementing sensors that were used in retrocommissioning, specifically for Air Handling Units (AHUs), was estimated. There are seven different types of sensors that controls the AHUs and the HVAC system: occupancy, humidity, carbon monoxide and nitrogen monoxide, airflow, static pressure, differential pressure, and flammable gas detection sensors. Each sensor would be added into the AHU while retrocommissioning the building.

The documents from F&S provided several examples of the models that were used for each sensor, thus the calculations were based on the average cost of those models. Estimations were made for sensors that did not list the specific name or model. The document stated there were 4 typical manufacturers for occupancy sensors: Hubbell, Watt Stopper, Leviton, and Sensor Switch. Through each document from F&S, the cost of sensors was collected and averaged. Occupancy sensors are used in less densely occupied spaces such as private office, classrooms, open plan offices, and other places where the population variance is small; larger rooms, such as the conference rooms and auditoriums, use CO_2 sensors instead. Using this, the team came up with two results, one using occupancy sensors for the smaller rooms and one using CO_2 sensors for larger rooms. The cost for one AHU can be determined as the cost of all the sensors installed in an AHU, so the cost should be multiplied by the number of AHUs in the building to determine the final cost for a building.

AHUs handle the HVAC through each zone, which is shown in Figure 3 with different color codes on each zone. Each zone consists of multiple areas, such as classrooms and hallways. The total cost for a building per square foot is the number of AHUs multiplied by the cost of each AHUI divided by the total area would result as the total cost for sensors per square foot.

$$\frac{Building\ Cost}{sqft} = \frac{(\#AHU)(cost\ of\ AHU)}{total\ sqft} \tag{2}$$

The example buildings contain an average of 4 to 6 AHUs, with a maximum of two AHU that contain CO_2 sensors. The project summary for retrocommissioned buildings was also provided from the Facilities and Services website. The average costs for total sensor per buildings were made through calculating the costs of each sensor then adding the human labor work, which was 5 people working 8 hours, 5 days per week, with a wage of $40 per hour. Each project took approximately 4 months, therefore

$$\frac{wage * \#\ of\ workers * time(hours) + cost\ of\ sensor\ (occupancy\ and\ CO_2)}{Total\ Area\ (sqft)} \tag{3}$$

is the total cost of sensor installation per square foot. This calculation came out to be approximately $4.59/sqft when averaged across the five buildings that were analyzed.

The actual numbers as to how much money F&S has spent on RCx, obtained from Morgan White, give that the cost per square foot is around $2.30/sqft (Morgan White Email 2017). This was obtained by taking the cost that was spent on RCx in a specific year and dividing it by the total square feet that were retrocommissioned that year. The average was taken over the nine years of available data resulting in the value of $2.30/sqft. The differences in the calculated value and the value from F&S can come from a couple of different reasons. The first, and most predominate, is how labor is factored into each value. In the estimation, labor was taken at an hourly rate and assumed a certain number of workers. Labor made up most of the estimation, and even a slight change in number of workers or amount of time spent on a project can vastly change the total amount calculated. Also, according to Morgan White, the figures from F&S do include labor, but she did not elaborate on what the breakdown of labor and materials was. Because many of the people at F&S are salaried in, it is unlikely to assume that their entire pay is taken into account in the F&S data, as RCx is only part of one of their jobs they are tasked with doing. In the analysis of specific buildings, the cost of the sensors is assumed to be much closer to the F&S value, but on a per building basis instead of averaged.

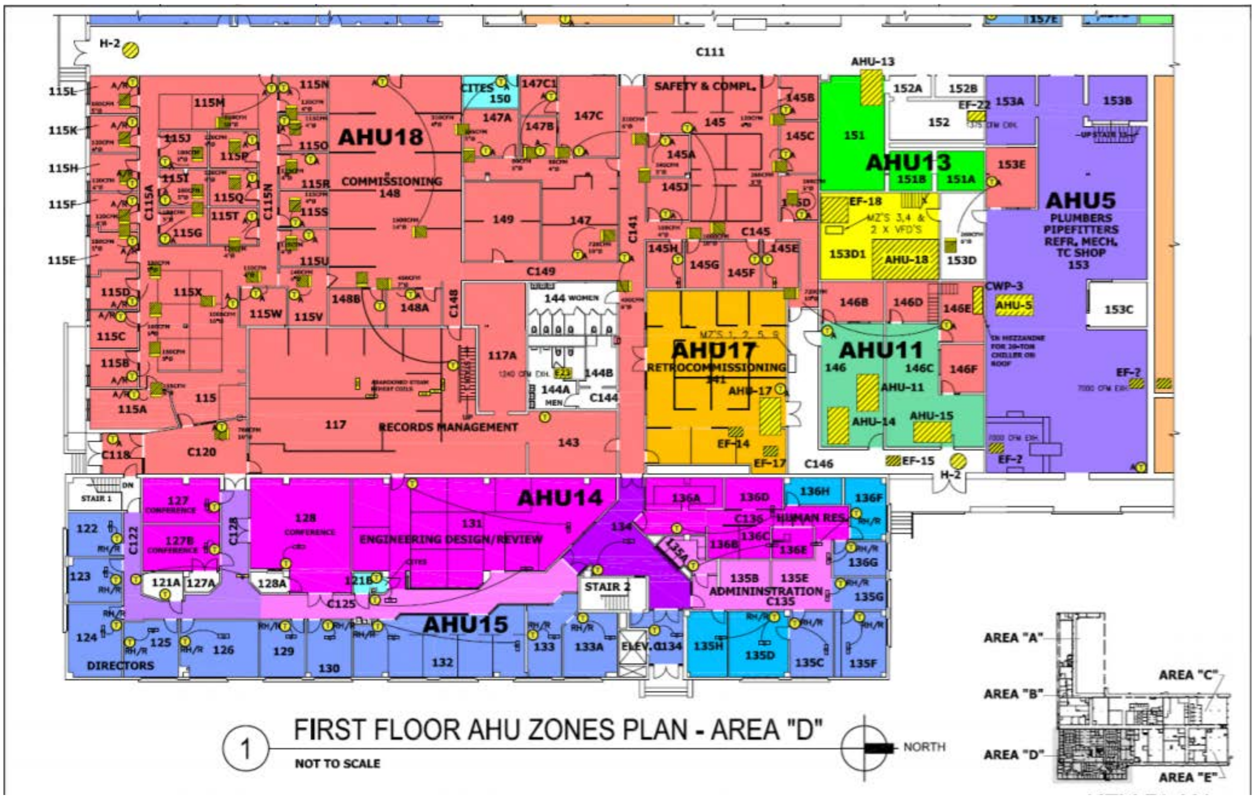


Figure 3:Air Handling Unit Zones Plan, showing how different AHUs control different parts of a building. Each color on the figure represents an area controlled by a separate AHU.

Comparison of Specific Buildings on Campus

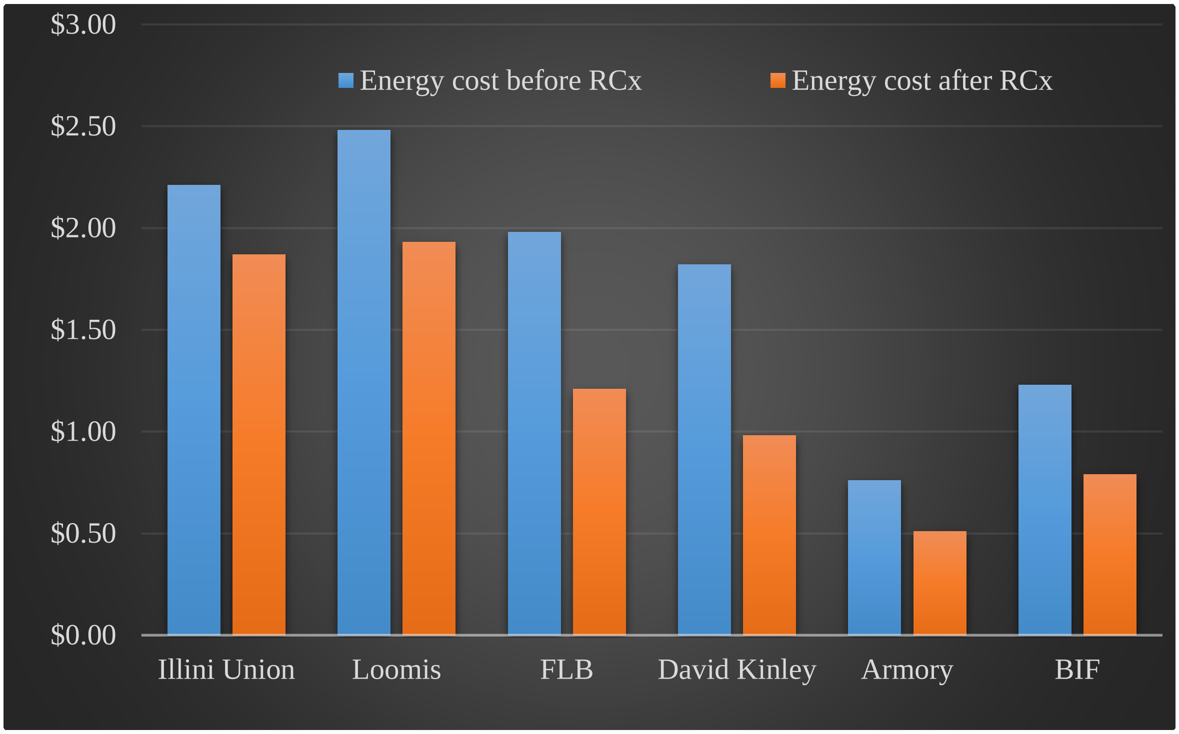


Figure 4: Cost of Energy Before and After Retrocommissioning per Year per Square Foot. The height of the bars is an indicator to the energy intensity of the building, ex. Loomis uses a significant amount more energy per square foot than the BIF.

The energy usage of the Illini Union, Loomis Laboratory, Foreign Language Building (FLB), David Kinley, Armory, and Business Instructional Facility (BIF) were analyzed before and after their retrocommissioning, and the result can be seen in Figure 4. From Figure 4, it is clear that there is more to how much energy a building uses than purely the installation of sensors. For example, a building like Loomis Laboratory contains many labs that draw an immense amount of power, and this causes it to have a higher energy cost/use per square foot. The BIF, on the other hand, uses almost half the amount of energy per square foot as Loomis, and this can most likely be accredited to its LEED Platinum certification. However, the integration of sensors actually saves more money per square foot in Loomis than in the BIF, indicated by the larger difference in before and after costs. According to F&S, RCx projects have a payback period of 3-5 years. (Foote Personal Interview 2017) This can be calculated as the price to retrofit the building divided by the cost avoided. Using the data, payback periods for the analyzed buildings are between 2.7 years and 4.2 years, for the Union and Armory, respectively. This corresponds well with what F&S states as their payback periods.

In order to see how retrocommissioning saves money over many years, a 15-year cost analysis for the six buildings was performed. 15 years is the approximate lifespan of a sensor system that F&S installs due to degradation of the sensors and the need to update the system. It was determined that over 15 years with a discount rate of 3% the average energy savings is

$6.35/sqft, not including the cost of the sensors. If the one-time cost of the sensor installation is applied at year 0 for this cost analysis, the total present value of the net savings of the system becomes **$4.42/sqft**.

For all of the current RCx buildings on campus this translates to a net potential savings of $43.2 million, with an additional $36.3 million savings if the remaining buildings are retrocommissioned. This leads to a total campus-wide savings of **$79.6 million**. These figures were obtained by the equations below.

$$\frac{\$4.42}{sqft} * 8.24 million\ sqft_{nonRCx} = \$43.2\ million \tag{4}$$

$$\frac{\$4.42}{sqft} * 9.76 million\ sqft_{RCx} = \$36.3\ million \tag{5}$$

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Life Cycle Analysis

The goal of this life cycle analysis (LCA) is to determine how the greenhouse gas emissions that the university produces are changed via retrocommissioning buildings with sensors. First, it was necessary to determine how the University gets their power. Abbott Power Plant supplies approximately 88% of the University energy demand, meaning that approximately 12% is bought from outside sources. For the purpose of this analysis, the solar farm was not included as it only supplies 2% of the energy used and, as of recently, has been inoperable due to a failed transformer (Erickson 2017). According to the EPA, the Champaign area receives 82.4% of electricity from coal, 12.2% from nuclear plants, and the remaining 5.4% from hydro, gas, and other non-hydro renewables (How Clean Is the Electricity I Use 2017). According to F&S, the Abbott Power Plant reduces CO_2 emissions by 101,000 tons per year, NO_X emissions by 560 tons per year, and removes 90% of the SO_2 from coal (F&S 2017). Emissions data for Champaign and the University is presented in Table I

Table I: Emission Information for Ameren and Estimations for the University of Illinois

Emission Type	Ameren Emissions (lb/MWh)	Abbott Reductions (lb/MWh)	Equivalent UIUC Emissions (lb/MWh)	CO_2 Equivalents (lb CO_2e/MWh)	Total Emissions (lb CO_2e/MWh)	Total Emissions (lb CO_2/MBTU)
CO_2	1772	165	1607	1607	1721	505
NO_X	1.3	0.915	.385	114		
SO_2	2.9	2.61	.29	N/A		

The emissions in Table I for Ameren were gathered from the EPA. The reductions by Abbott Power Plant were calculated by Equation 6

$$\frac{tons\ reduced}{year} * \frac{2000\ lb}{ton} * \frac{1\ year}{1076722\ MWh} * .88 \tag{6}$$

Where 1,076,722 was the total MWh used by the university in 2014 according to iCAP (iCap 2015). This equation accounts for the improved reduction of emissions from Abbott and also accounts for it only being a part of the University's energy use. The UIUC emissions were found by subtracting the Abbott reductions from the Ameren emissions. It is known that NO_X emissions are much worse greenhouse gasses than CO_2, and has a conversion factor of 298 lb CO_2/lb NO_X ("CO2 equivalents | Climate Change Connection" 2017). Although SO_2 is a known pollutant, it does not have a CO_2 equivalent, and therefore cannot be added to the total emissions equivalent category. However, because Abbott has such a high reduction of SO_2 emissions, this can mostly be disregarded. SO_2 is one of the main contributors to acid rain and is a powerful pollutant, so having Abbott reduce most of its emissions is very beneficial.

Using this method to determine emissions from the university, it was calculated that the university produces 1.85 billion lbs CO_2 per year. Recently acquired data from F&S indicates that the university actually emits only 1.07 billion lbs CO_2 per year, yielding a percent error of 73%. There are many things that could have caused this error to occur. The first is that the Abbott reductions were reductions on what Ameren produces, and Abbott power plant is probably cleaner and more efficient than them to start. This on top of Abbott's ongoing efforts to be a cleaner power plant and implementing top of the line scrubbing methods most likely led to this extreme error. The university report also indicates that they generate 198 lbs CO_2/MBTU, far less than the 505 that was calculated. This error is because in the university report they added more energy to campus than what the report from iCAP reported in 2014. The university report includes several extra categories including student and faculty commuting and air transportation. This 198 lbs CO_2/MBTU will be used for on campus calculation, however the larger 505 lbs CO_2 will be used for extrapolating past the university, as these emissions are closer to what large scale power plants would generate.

The value for the total emissions generated per MBTU of energy was then applied to the energy that is saved by retrocommissioned buildings on campus. When this was done, it was determined that retrocommissioned buildings reduce emissions by an average of 14 lbs CO_2/sqft,/year corresponding to over 137 million lbs CO_2/year. According to the EPA's greenhouse gas equivalency calculator, that is equivalent to taking 13,000 vehicles off of the road each year (U.S. EPA 2017).

Using this same estimation, it is possible to extrapolate the possible emissions savings to the rest of campus as well. So far, F&S has retrocommissioned approximately 9.76 million square feet of buildings at UIUC, leaving approximately 8.2 million square feet left. This means that there could be an additional reduction in greenhouse gas emissions of about 116 million lbs CO_2/year, or the equivalent of 12,000 vehicles.

In the United States, there were approximately 260 million vehicles on the road in 2015 ("Number of cars in U.S. | Statista" 2017). The population of the United States is roughly 323 million people, so therefore there is about 0.81 vehicles for each person in the United States ("Population Clock" 2017). Also, according to the Census Bureau, the population of Champaign is approximately 87,000 people. Therefore, if all buildings were retrocommissioned on campus and we approximate that there are 0.81 vehicles for each person in Champaign, there would be a reduction in CO_2 emissions equivalent to taking 35% of all vehicles off of the roads.

This idea could also be extrapolated into all commercial buildings in the U.S., an area of over 87 billion square feet ("CBECS 2012: Building Stock Results" 2017). For this calculation, it will be assumed that emissions are closer to that of Ameren, so the 505 lbs CO_2/MBTU value will be used to calculate savings. If it is assumed that all of these buildings could be retrocommissioned and that none of them currently are, the total emissions reductions would amount to over 305 million vehicles, or taking 116% of all vehicles off of the road.

Funding Analysis

Since its inception in 2007, more than $13 million have been spent on RCx, and over $47 million has been avoided in utility costs (F&S 2017). Based on that aggregate return on investment, as well as the conclusion this paper draws about RCx's return on investment, it's clear that more funding should be provided for the program.

However, based on recent developments at the end of FY2017, that will be an uphill battle. The University of Illinois received more than $1.5M in energy conservation grant funding from the Illinois Department of Commerce and Economic Opportunity (DCEO) in August 2016 for various conservation work, including Retrocommissioning and Recommissioning (Energy Conservation 2016). However, this grant money was not renewed for FY2017, and the University must now look to other sources to compensate for this unexpected loss in funding in order to implement critical projects key to energy conservation, and the Illinois Climate Action Plan.

To date, the RCx team has accrued over $48 million since FY08, and are averaging approximately 27% energy reduction in buildings that have been retrocommissioned. Energy consumption at the University of Illinois is down ~33% since FY07, and it is essential that this trend continues for the iCAP goal of 40% reduction in total campus building energy use by 2030 to be achieved (iCAP 2015). Although the significant gains in energy reduction to date have been steps in the right direction, it could all go to waste if further funding is not found for the RCx program.

The danger with the sudden lack of funding lies in the iterative process of Retrocommissioning. Although we have been referring to the team as RCx this entire time, and measuring the energy usage of buildings before and after they are retrofitted, this is by no means a permanent change in the building's energy consumption. The Recommissioning (REx) and Preventative Maintenance (PM) teams are both essential to the campus's continued energy saving operations, just as much as the RCx team is. Recommissioning is a process in which building operating and maintenance systems are examined for damages or malfunctions, and then either fixed or replaced to ensure the building operates at peak efficiency, as it would directly follow an RCx team retrofit. F&S states that for optimal performance, REx will usually evaluate a building 5 years after the initial RCx renovation, and subsequently every 5 years after. To summarize, while the RCx team is what initially provides the largest cut in building energy consumption, the REx team is essential to ensure the continued efficient operations of these buildings (White 2017). Both the REx and RCx teams received funding from the ~$1.5M DCEO grants, and as such are in the greatest jeopardy in the upcoming fiscal year due to the lack of these funds.

One of the inherent challenges with funding for the RCx program is publicity. Other than campus administrators, leadership in F&S, and activists on the Student Sustainability committee, not many on campus are aware of the Retrocommissioning process or its benefits. Due to its huge potential energy saving ability, and incredible return on investment rates, it's clear that the RCx program is a great investment. It would be impossible to achieve iCAP commitments on campus energy consumption reduction without the RCx program.

Attention must be brought to the iCAP program, and the RCx program's importance to those commitments. The student sustainability committee has the power of both funding and student outreach to make this happen. While it may not be feasible to allocate all their sustainability project funding to RCx, they can at least reach out to students, making them aware of the iCAP Program and RCx's importance to that. The RCx program was initially funded by the Academic Facilities Maintenance Fund (AFMFA), when it began in 2007. Grant money has since replaced that, but initially this fund was a small chunk of student's tuition (Energy Conservation 2016). A similar method could be instituted by the university, either on a required or donation-based system. If more students were aware of the RCx team and the iCAP goals, they would convince their parents or alumni to donate to the program. The issue is pressing, there's $1.5M in funding that needs to be replaced in some form, without which the whole RCx operation will slowly deteriorate without.

Conclusions

Based on our study and Cost-Benefit Analysis of the data from six buildings on campus, it is clear that retrocommissioning is a good option for the university's Facilities & Services Department to improve building efficiency and stay on track with the University Climate Action Plan. According to the CBA, the average cost of energy saved is $4.42/sqft. in 15 years. This translates to a savings of approximately $1.1 million per building. Further expanding this average savings and applying it to the total square footage of non-retrocommissioned buildings on campus, we found an additional $36.3 million could be saved if the remaining buildings were retrocommissioned.

From the emissions analysis of the RCx process, it was found that the RCx buildings reduce emissions by 14 lbs CO_2/sqft/year, the equivalent of taking over 13,000 vehicles off of the road each year. This total was extrapolated to include all the university buildings and it was found that the equivalent of 25,000 vehicles emissions could be taken out of the atmosphere through continuing the retrocommissioning process. In addition, the emissions analysis of campus buildings showed that if retrocommissioning was adopted in all commercial buildings in the US (>87 billion sqft), the equivalent emissions of 116% of all vehicles in the US would be taken out of the atmosphere.

Building sensors are essential to the retrocommissioning process, and F&S's continual job of building maintenance and repair. Using live data from sensors in HVAC systems, F&S is able to rapidly dispatch technicians where and when they're needed to fix specific problems. This streamlined process is essential to maintaining such a large campus like the University of Illinois. Additionally, compiled data from these various system sensors allows F&S's retrocommissioning teams to fine-tune the HVAC systems so that they minimize wasted energy and increase the efficiency of the buildings. With a payback period of 3 to 5 years, retrocommissioning is a cost effective means to minimize building energy usage.

Acknowledgements

This paper is based on the research conducted on retrocommissioned buildings in University of Illinois at Urbana-Champaign. We would like to thank CERL for supporting on our topic, professors from the CEE and ENVS departments who helped us through the class and providing us great feedback. Also, we would like to thank the F&S team, especially Morgan White and Paul Foote for their great help in obtaining our data. Finally, we would like to thank all the great TAs who has given feedback and support through the semester.

Group Reflections

Our group overall thought that this project went well. There were definitely setbacks along the way, but in the end, we managed to analyze retrocommissioned buildings on campus and discovered that incorporating sensors into a building to make it more "smart" really does have a great impact on its energy usage and total cost. This project evolved many times as we started by dreaming big, and then eventually settled into a project that was feasible and impacts most people at UIUC. This project focused on something that we think most people have never thought of in buildings, and we never knew that this system was being implemented on campus until starting this project.

If we could go back and change anything from this project, it would definitely be our organization in the first few weeks of working. In these first few weeks we spent more time dreaming and thinking of ideas than getting hard data analyzed and research done. Then, after we realized that many of our ideas were too far reaching for the amount of time that we had left, we ended up always rushing to finish deadlines and find times to get everybody together. We think that this could have been mitigated from having a better plan at the beginning of the semester as to what everybody's role was and how we all could work together to meet those goals. Often, we had a difficult time all meeting up due to outside projects and other classes. This could have been mitigated by better planning and communication on our part, figuring out everybody's class schedule in full and really setting aside time every week to work instead of scrambling close to deadlines to finish everything.

We think the main turning point for the project was when we decided that it was not feasible to pursue our initial goal of separating sensors installed for lighting and HVAC and analyzing them separately. Prior to this, we had only slightly talked about the retrocommissioning process for buildings, and more thought it was going to be a supplement to our data. However, after we had our meeting with Paul Foote about the RCx process, we knew that that was the direction that our project was going to have to turn in order to get any good, quantifiable data. Although we did not analyze as many outside projects as we would have liked, we believe that we got a good amount of data and were able to qualitatively and quantitatively show that sensors improve a building's energy usage.

We think that there are many more places that projects similar to this could go. We think that a group could analyze F&S's information collection system and see if it is the most efficient way to go about collecting and using the data acquired from sensors. This would probably require some Computer Science knowledge, however, so it may be outside the scope of this class. Another group could research how sensors can help out buildings that have as much infrastructure as the University or are not as connected. One of the reasons that the UIUC system works so well is that it contains over 70 buildings, and all of these lead back to one location for all of that information. Projects could focus on sensors if incorporated into a single commercial building owned by one company or something similar would have the same savings as at the University.

We also think that this project could expand into different areas, though our paper focuses specifically on retrocommissioned buildings in the campus, the concept itself could be applied on a city scale. Especially when implementing smart technologies that could control smart sensors in a creative and secure way, cost would act critically on decision making.

In conclusion, although our group hit rough patches throughout the semester, in the end we produced a good product that we were proud to put our name behind.

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Appendix A: Additional Graphs of Energy Usage of Buildings on Campus

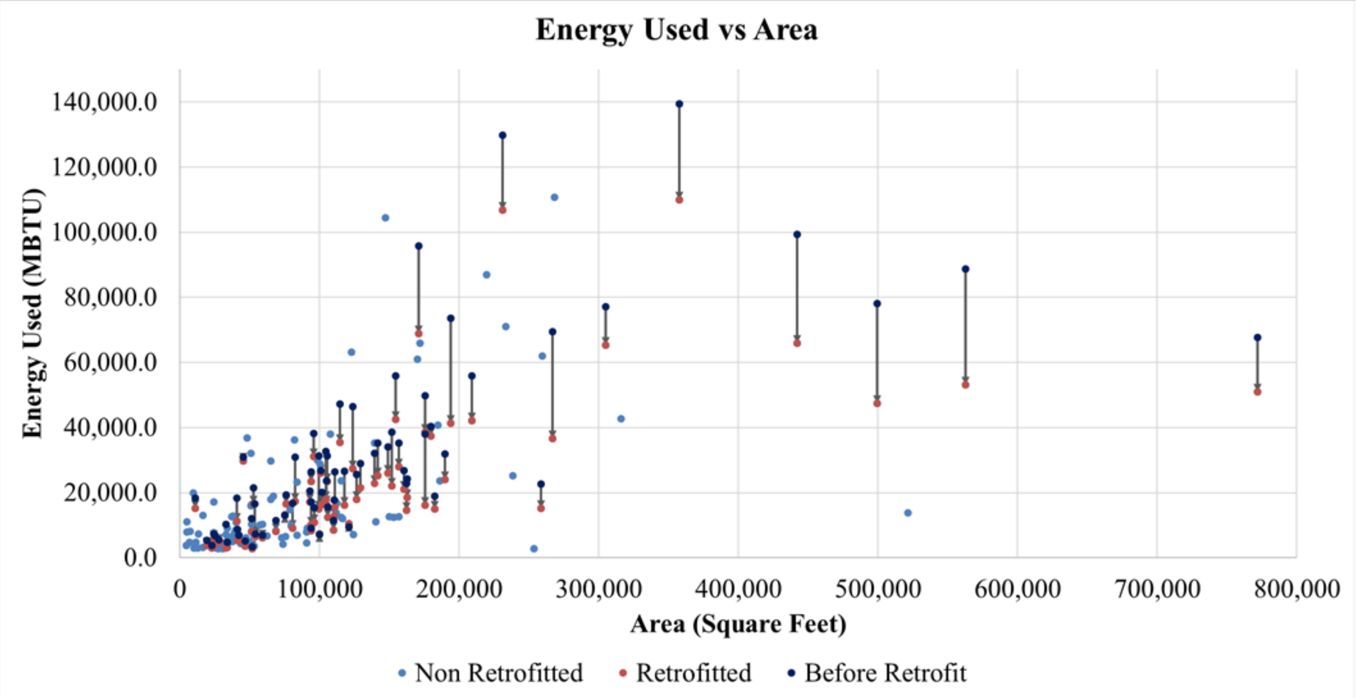

Figure A- 1: Graph of Energy Use vs Area for all buildings on campus. This figure shows energy usage of buildings before and after retrofit and shows that most of the large footprint buildings have been the focus of RCx projects, while many of the small buildings have not been retrocommissioned. There are still two of the four largest energy users that have not been retrocommissioned. These are the Institute for Genomic Biology and the Campus Recreation Center East.

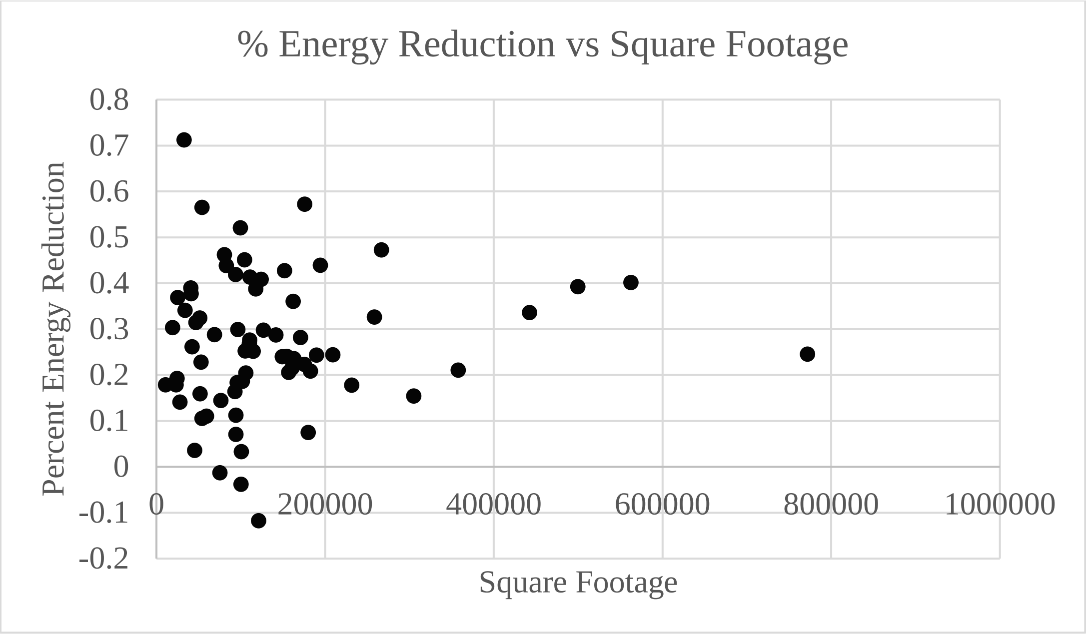

Figure A- 2: Scatter Plot of % Energy Reduction vs Square Footage of RCx Buildings. Below 300,000 square feet, there is no correlation between percent energy reduction and the square footage of a building. However, between 300,000 and 600,000 square feet, there is a near linear relationship. This chart helps emphasize that there is no trend, generally, based on the footprint of a building, and that no matter what the size of the building is, the percent energy reduction generally falls between 20 and 50%. Future groups could compare different types of buildings and see how their energy reduction compares. For example, comparing old versus new building and see if there is a trend.