Student Energy Audits of Buildings Can Be Done!

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Abstract

Energy conservation and sustainability are at the forefront of engineering today. It is imperative that engineering educators lead in this effort by showing the next generation of engineers that they can have a real impact by saving our energy and resources; this is especially effective when students are led on a journey of discovery, resulting in genuine learning (Adler, 1982). Luckily, it is easy to demonstrate energy conservation in real environments for hands on learning, even right on campus!

In the course Green Facilities Management, student groups performed energy audits of two separate buildings on campus, one constructed in 1948 and the other in 2014. Students first learned about energy sources and then analyzed an actual energy bill; the students then dug into the creation of green buildings, management of renewable energy sources, and life cycle costing. This was supplemented by a key hands-on portion, with building inspection, which included wall and roof material, insulation levels, window and door sizes, leaks, lighting and appliance loads. Occupant interviews were conducted to determine hours of operations and uses, and heating and cooling loads were calculated using real-world sources, like heat given off by people, solar radiation, conduction, and ancillary heat gain. Students then analyzed Energy Management Opportunities (EMOs), Green Energy Opportunities (GEOs) and life cycle costs and stated their prioritized recommendations, including an evaluation of installed and possible future green measures. Finally, during an oral presentation, the buildings, EMOs and GEOs were compared. Results were assessed through both student feedback and project quality. Students appreciated the realistic project and being able to look at energy efficiency and the economics of sustainability. Projects were assessed by the instructor and 78% of the class had a B+ or higher on the project, exceeding expectations. The oral presentation had similarly positive results.

Introduction

In modern engineering design, green engineering and sustainable design have gone from "nice-to-have" to an essential element, taking on an ever-expanding prominence with owners, occupants and regulators. Thankfully, engineering education has been expanding its boundaries rapidly to encompass the emerging disciplines that are the foundational elements of this important focus area [1] Frequently, the focus is on new construction, but much of the best energy savings can be found in renovation of older structures, and, typically, the more complex the systems in those older buildings, the bigger the potential savings as those structures are brought up to modern standards. This means that graduates of modern engineering design programs need to have a solid knowledge base from which to draw, including being capable of performing building energy audits. Fortunately, we have found that students are capable of performing in-depth energy audits of real structures, and that conducting these reality-based audits inspires students towards positive engagement and higher quality work products from those students.

Background

The need for robust methods for educating engineers, particularly civil engineers, in the area of sustainability is great. However, many of our traditional methods are only moderately effective in the face of some of the large, unresolved questions of sustainability, especially those involving value judgements that are only somewhat informed by economics. Further, we must become more efficient at educating civil engineers, since sustainability is now a major component and, in general, nothing has come “off the plate” in terms of more traditional content nor have we added time or credit hours to most curricula. Rajabipour and Radlinska put it well in 2009 when they wrote: “As engineers are greatly responsible for development of infrastructure and technologies necessary for a sustainable world, engineering curricula must address sustainability and prepare students for designing engineering systems with long term social, economic, and environmental benefits” [1]. This need for better educational methods and tools is further reinforced by the fact that sustainability is at the forefront of engineering needs as shown by the National Academy of Engineering, the Civil Engineering Body of Knowledge, and ABET outcomes [2] [3] [4]. It is critical to lead this effort by showing the next generation of engineers how they can affect our resources.

This is best done through offering students real-world, inquiry-based problems which give them transferrable and practical skills and are shown to increase learning [1] [5] [6]. Through energy audits, which are very much hands-on and well within the technical reach of undergraduates, we can teach students about sustainability and ways to reduce energy, an inspiring and fulfilling task when considering our nation’s energy usage and the need to educate these young minds towards becoming stewards of the environment [7]. Energy audits are inquiry-based learning exercises with real-life problems which increase learning. This allows students to see the “real-world application of their engineering education” and to look beyond the classroom [8], thus reaching towards that all-important but oft-elusive pinnacle of teaching; inspiration. Brooks [9] makes a strong argument, backed by cognitive research, for putting energy into connection with students beyond traditional lecture and drill, and hands-on, active learning gives the instructor greatly increased opportunity to connect with students in unexpected and personal ways.

When effective, inspiration can lead to far higher levels of student achievement. “For some time now, we've known that younger students tend to achieve more by working with teachers who expect more of them. For the so-called "Pygmalion effect" to work well in college, however, the students must share the teacher's high expectations of themselves and perceive them as reasonable” [10]. Energy audits of buildings is a clear way to raise those expectations and have students achieve them while at the same time illustrating the instructor’s commitment to sustainability and hopefully inspiring or connecting with students who have or are developing a similar commitment. The project itself calls for students to work in team environments as they will in industry and to present clear arguments, based in facts collected during the exercise, to the owner to ensure their design concepts will be implemented [7]. It is important not to forget that however great an idea, it still must be communicated effectively, often to non-engineers, to ensure funding and application. Building this communication piece into this assignment, coupled with real-world facts the students gathered and a personal commitment to change, works synergistically to build career skills and inspire intrinsic motivation that will carry them past their undergraduate education and into a satisfying and productive career.

Data & Analysis

In the course Green Facilities Management, the intent was to provide a broad understanding of energy and its use within buildings. Specifically, students learned about energy consumption processes and how to perform energy audits of buildings as well as gaining knowledge of the effectiveness of energy management through economic life cycle analysis of structures. Various sources of energy were examined, including an overview of power production methods, energy bills and rate schedules. The course addressed process energy management with emphasis on production, lighting, HVAC, boilers, steam distribution, insulation and control systems. Interaction of these systems as they apply to total heat gains and losses in the building was studied. New technologies and control systems were also discussed. The outline of the semester topics is shown below in Figure 1.

Topic	**Reading Assignment**
Energy Resources & Energy Use	Chapter 1
Electricity	Handout
Coal, Oil & Natural Gas	Handout
Geothermal, Nuclear & Water Energy	Handout
Wind, Solar & Biological Energy	Handout
Understanding Energy Bills	Chapter 3
EXAM #1	
Economic Analysis & Life Cycle Costing	Chapter 4
Energy Audit	Chapter 2
Lighting & HVAC	Chapters 5 & 6
Boilers & Steam Distribution	Chapters 7 & 8
Control Systems & Energy Systems Maintenance	Chapters 9 & 10
EXAM #2	
Creating Green Buildings	Chapter 16
Renewable Energy Sources Management	Chapter 13
PRESENTATION of Semester Project	
FINAL EXAM	

Figure 1: Course Topic Outline. Readings are from Guide to Energy Management 7th Edition by Capehard, Turner, and Kennedy [11].

The first portion of the semester was spent learning about energy sources and then exploring the actual energy bill. Students then dug into the creation of green buildings, management of renewable energy sources, and life cycle costing. The main semester project was performed in four groups of four to five students each, focusing on student-performed energy audits of two campus buildings, one building from 1948 and the other from 2014. This course was offered primarily to seniors.

This initial portion of the project was the facility description. This included the size of the building, construction, layout, map, hours of operation and changes in levels of occupancy throughout the year, taking into account that the campus occupancy varies greatly over the course of a given academic year. The significantly reduced occupancy during the winter and summer directly affects energy usage.

Next, student groups performed an energy bill analysis, investigating electrical and natural gas for usage, demand, and cost looking for base and variable loads. They were to look for any variations or outliers and possible explanations.

The most significant portion of the project were the hands-on building inspections. First, they examined the construction to determine wall and roof materials, as well as insulation levels. Then, they determined window and door sizes and materials and orientation, recording any leaks/holes and relative sizes. Appliances were cataloged and recorded to determine plug loads including computers, copiers, window air conditioners. Lighting observations and tabulation included the number of fixtures, lamps, wattage, hours of operation and controls in place. Occupant interviews were used to determine hours of operations and uses. Cleaning and maintenance were also noted as this affects wear and tear and efficiency of systems.

Heating and cooling loads were calculated using real-world sources, like heat given off by people, solar radiation, conduction, and ancillary heat gain. On a monthly basis, students determined the heating and cooling loads of the facility. Using heating degree days (HDD) and cooling degree days (CDD) students determined the heat given off by people, solar radiation through windows, conduction through walls and roof material as well as heat gain from lighting and equipment. Students then determined what percentage of the total loads were being used for lighting, HVAC, appliances, etc.

The final step in the project was for students to determine the Energy Management Opportunities (EMOs) and associated life cycle costs – a great focal point within the project for students to practice inquiry-based-learning, engage in personal scholarship and generally show creativity and embrace and/or advocate for innovation. Student would then make their recommendations to the client regarding which EMOs would be the best choice to implement and when they should be implemented. They would also look for Green Energy Opportunities (GEOs) including an evaluation of installed and possible future green measures. Finally, during an oral presentation, the buildings, EMOs and GEOs were compared.

Another piece that was added onto this was the ranking of group members after the project and presentation were completed. Team members had a chance to reward members that participated heavily in the project, report or presentation. These ranks and comments were anonymous as they were to self-rank as well. Some comments from students included "Honestly, it was the best team I have ever worked with. We all participated equally. Even though we have different schedules, we managed to communicate efficiently using conference calls and Google Drive." Another student commented, "Great experience working in this group. Despite busy schedules, all group members were able to make the time to complete the project." A third student commented, "This was an ideal team setup. We all agreed to take sections of the project and supported each other to be successful. Considering we all work and have varying school schedules, inspection were performed in groups, we worked using a shared Google Drive, and employed a few conference calls to shape direction and deliverable outcomes." Whether the realistic nature of the project contributed to the team commitment and thus performance is not directly measured in this case, but student feedback and instructor observation does indicate that the teams were more motivated, active and cooperative than is typical and we believe the inspiration derived from taking on a real-world project played a significant role in creating that positive, high-performing team environment.

Energy management opportunities (EMOs) was an area where students could get creative, and the first step toward identifying potential EMOs was the most hands-on portion of the exercise, where two teams examined each building. At 67,400 SF and 5 stories, the 2014 building was rated LEED Gold at the time of initial commissioning and had the following features: green roof, enhanced commissioning, high efficiency lighting design, occupancy-based lighting and HVAC, demand-based ventilation, high efficiency condensing boilers and low flow bathroom fixtures. The building includes eating areas, fitness areas, offices, meeting rooms and ballrooms. After a careful examination, the students identified some genuine opportunities. For instance, students noticed the existing temperature of the facility during spring and summer months was lower than standards required, and many thermostats had a 'change filter' notification. Based on this, students recommended retro-commissioning the building. Based on their observations, the students recommended other EMOs for the 2014 building:

- The building had been designed with shades that would respond to the sun in order to conserve energy. However, some were broken and others were overridden by users and did not reset until the evening; they recommended limiting the override controls and fixing the broken shades to decrease energy consumption.
- After students' interviews with building management and staff, they discovered that the hours of operations of the shared serices within the building were longer than necessary. The fitness center as well as the Starbucks were not utilized from 6-7am and 10-11pm, and these hours could be curtailed.
- Lighting reduction recommendations were that some offices and mechanical rooms lights were left on during the inspection; an occupancy sensor could eliminate this problem. Also, outdoor lights were deployed in an all or nothing approach during dusk and dawn times. Students recommended cycling the lights. Students calculated that reducing these loads and therefore reducing the peak demand in February could result in a savings of up to $6,000 per year.
- Students found during their inspections that the fitness center had thirty treadmills with 15" display screens that were left on 24 hours a day. Installing a power switch for staff to control the power supply to the machines would reduce consumption during nights and holidays. Students calculated a savings of $2,500 per year.

The second building, also inspected by two student teams, was a 143,000 SF academic building, converted in 1964 from a factory originally built in 1948. The building is three stories with a full basement as well. The building includes classrooms, laboratory's, computer labs, offices, and common areas. During the inspection, students noted leaks in the building where doors were not fully closing or were gaps under the doors, and various windows were left open do to the uneven heating within the building. All of these opening were allowing heat to escape, biasing already-inadequate HVAC controls and therefore running the HVAC system inefficiently. For this more vintage building, the students came up with the following:

- Some immediate improvements that students recommended were to set the computers to have an automatic shutoff at the end of the day, specifically those in the computer labs that are not accessible once the building is closed for the evening. The same scheme could be applied to the vending machines with the use of a timer, as they could be off when the building is closed overnight and on Sundays.
- Students found that the heating and cooling was a major issue in the building. The imbalanced heating systems caused faculty, staff and students to leave windows open, as well as run space heaters and fans. Improved HVAC controls would also aid in this problem, as would insulating duct work. Additionally, maintenance of the building could be improved by cleaning filters, lowering energy costs for moving air.
- Students also found several water leaks that came through the ceiling tiles. Complete and functional ceiling tiles are important to keeping conditioned air within the occupied space.
- Upgrading the window shades in the building would also help reduce solar heat gains as many were damaged or inoperable.
- Although some classrooms had occupancy sensors not all rooms had been converted. This implementation would save on lighting demand which could save approximately $1200 per year.

More broadly, retro-commissioning and tightening of the building openings was recommended. Students recommended using the large flat roof as an area that would adequately work for solar panels as a smaller nearby building rooftop was already being sued for a solar hot water heater.

Grades in the course were as follows for the 18 students as shown in Figure 2. Exam #1 had an average score of 89% which is a B+. The second exam has an average of 83% which is a B. AS shown in Figure 1, the first exam included fossil and renewable fuels while the second exam covered energy auditing, boilers, and controls. These questioned posed more difficult for the students. The project yielded the best scores and many groups went well above expectations with an average of 93% which is an A-. Therefore 77% of the class performed with a B+ or higher on the project and 44% earned an A on the project. As a whole, student performance on the group project exceeded performance on exams. As this was a newly developed course offered for the first time, student performance proved a positive reflection on the course development.

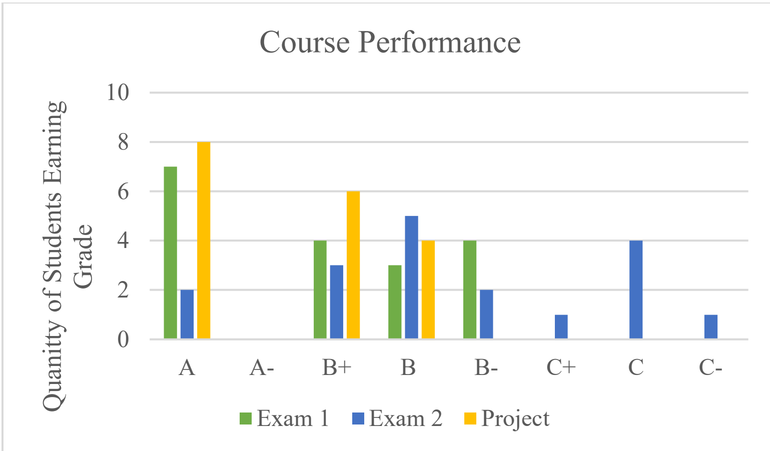

Figure 2: Course Performance Grade Distribution.

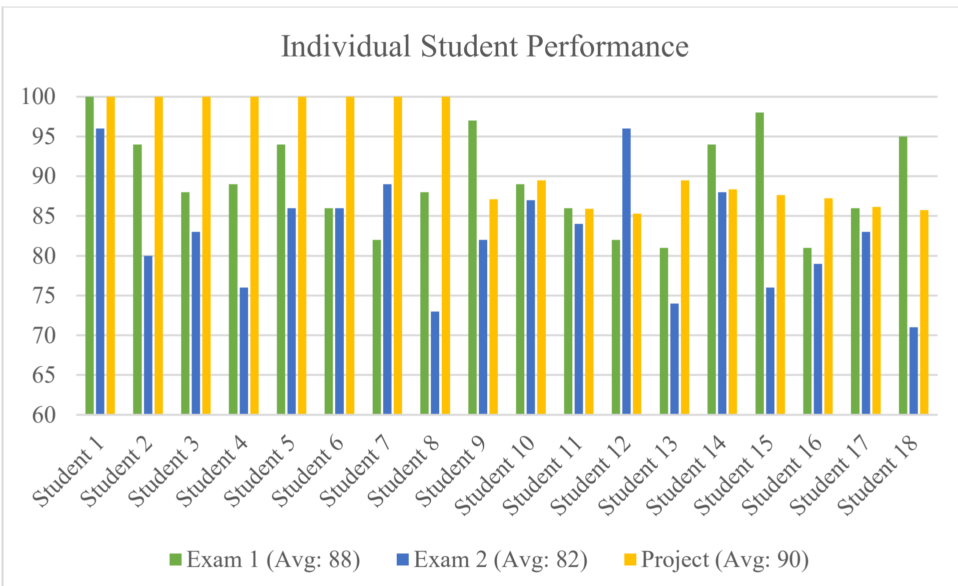

Figure 3: Individual Student Performance Distribution.

Finally, written comments and course-end feedback from students provided valuable data on the success of the project as a course component. Students rated the course above program, division and overall school averages in the following areas of “Adequate time for Questions and Opinions” and “Questions were Challenging”, both related to the project, and rated the course and teacher very highly overall. In the written comments, which are often most telling, the project figured prominently. One comment was “Final project was very realistic and great way to tie everything in the course together…”, a strong endorsement of the impact of the project on that student and likely indicative of the other students in the course. Additionally, the written course-end-feedback contained multiple calls for more time for the project from the students. Significantly, the students did not ask for the project to be scaled back, but instead focused on the time aspect, a clear indication that they were strongly engaged in the project and wished to achieve at an even higher level, likely due to the fact that the project tasks and subject resonated with them.

Observations & Recommendations:

The exercise of taking on a real-world building evaluation in a setting with which the students are familiar was judged to be highly successful and the authors offer the following observations:

- Whether the realistic nature of the project contributed to the team commitment and thus performance is not directly measured, but student feedback and instructor observation does indicate that the teams were more motivated, active and cooperative than is typical and we believe the inspiration derived from taking on a real-world project played a significant role in creating that positive, high-performing team environment.
- The nature and structure of this assignment follows best-practices for Inquiry-Based-Learning, providing a structured opportunity for students to build the scaffolding of their own knowledge of the subject [12] [13]. Particularly, the addition of reports and briefings where the students presented ideas and recommendations that they had generated, researched and refined through direct observation gave the students a sense of professional practice and real buy-in.
- Projects which activate the students directly as agents of their own knowledge creation, in a sense pulling data to them according to self-defined needs rather than acting as passive receivers, provides considerable franchise and satisfaction to students. There is considerable evidence that supports this view [14] [15].
- Overall student engagement in this project was very high; students made a serious effort to achieve success beyond what is normally seen in more abstract paper-based design or analysis problems.

For those contemplating or driving towards developing similar projects, the authors offer the following recommendations based on this work:

- One of the most challenging parts of any real-world exercise is the logistics. Ferrying students back and forth from project sites, funding travel, students missing classes, insufficient time on task in the field; these are all significant obstacles to introducing real-world design in Civil Engineering or Sustainability courses. But, this CAN BE DONE using buildings on campus that students are really familiar with; and it's cheap! For this project, the use of on-campus buildings greatly decreased the "tail on the tiger," allowing for efficient and effective execution of an in-depth field exercise.
- There is real value in evaluating buildings with which the students are familiar. Remember, for the student this is the very first time they are undertaking such a survey, so combining the uncertainties related to their assessment (thinks like: What should I be looking for? What's important?) with the uncertainties of an unfamiliar setting that they have limited access to can really intimidate the student and decrease the value of the field exercise. Knowing the terrain and knowing that they can always return to collect more data if needed removes a lot of anxiety, opening avenues for creativity and design thinking.
- Students might be even further motivated by the feeling that they are contributing to the university community they treasure and could have a real, positive impact. Legitimizing and honoring their recommendations, through meetings with stakeholders, publication in student periodicals, putting together a social media "footprint" for their thoughts and

observations are all great ways to get students into motion and keep them dreaming and reaching for the future – which is likely what they came to college for in the first place.

Conclusion:

It is absolutely possible to create engaging, high-impact, inspirational exercises on the cheap. You can do it – we're going to take a leap here and guess that your campus has buildings too! Go ahead and use them as real-world laboratories for teaching sustainability, civil engineering and building science. Students like and respond positively to this kind of instruction and we believe the students did better because of it. You and your students will be pleased with how rapidly and meaningfully you can engage a complex building-wide problem when that building is on your own campus.

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