Energy Efficiency Studies as a Tool for Enhancing Student Involvement

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Abstract

An important growth area for undergraduate engineer education is to train students for roles in the emerging sectors of sustainability and renewable energy. The method for incorporating such new topics into existing curricula is the challenge. At Rowan University, the method used is the Engineering Clinic approach, which draws from a portfolio of projects designed specifically to address a topic. In these Engineering Clinics, students are provided with hands-on experience in a project-based setting. During the Spring 2011 semester, students lead a project focused on analyzing the energy utilization of a multiple building facility and made recommendations for methods to reduce energy consumption and increase the overall efficiency of the campus. The facility's current energy consumption was determined through focused audits that inventoried all portable and stationary equipment, lighting, and HVAC energy use on a room by room basis. Based on this acquired data, seasonal patterns of energy usage were developed and used to guide modeling for possible energy efficiency improvements. Students on this project team learned skills focused on the tools and methods used in the fields of sustainability and renewable energy. This learning built on their core engineering competencies and also added specific content to their curricula that directly supports education in those fields. Students were also given the opportunity to interact with an off-campus client, which provided an additional unique experience that is not typically found in the classroom. This interaction allowed students to further develop their project management and communication skills. This paper will describe the results of the project, assess the methodologies used to educate the students and review the impacts of this approach on incorporating novel content into an engineering curriculum.

Introduction

How can students be taught new ideas in emerging technologies in a timely manner? This is a challenge many universities face, incorporating novel content into their curricula without disrupting existing programs. An Engineering Clinic approach has been adopted to fulfill this challenge at Rowan University. In these Engineering Clinics, students are given the opportunity to use technologies and equipment that are not typically accessible in undergraduate engineering classrooms.

For their clinic project during the Spring 2011 semester, students performed an energy audit of a multiple building facility using techniques and equipment learned in their clinic course. The goals of this project were to inventory all energy users at the facility, create a baseline site energy consumption, research energy conservation techniques applicable to the facility and present the possible efficiency increases to the client.

Background

The Engineering Clinic approach at Rowan University was initialized in 1998[1]. Engineering Clinic is an eight-semester course sequence that is required of all engineering students. This sequence spans the entirety of their four-year undergraduate degree work and accounts for 24 credit hours towards their degree[2].

The clinic sequence begins during the student's freshman year, where students are exposed to key principles of the four engineering fields taught at Rowan University. Various engineering fundamentals are taught during this phase, such as basic problem solving techniques and teamwork. Additionally, students are required to reverse engineer and competitively assess a product to determine its design's strengths and weaknesses[2].

In the Sophomore Engineering Clinic, the main goal shifts to technical communication skills. Students are required to effectively communicate results of an assigned topic. The topics are organized for a small group setting of three to five students, with the intent of multidisciplinary interaction within the organized groups. The students enhance their communication skills by writing various technical documents and performing multiple presentations throughout this year.

For the Junior and Senior Engineering Clinic, students are recruited to work on a specific project in a job fair setting[3]. These projects can last one to four semesters and result in a final design or report for a client. Many of the projects for the engineering clinics have been funded by external sources, thereby requiring student interaction with a real-world client. To achieve the project's final goals, students acquire hands-on experience with novel technologies used in the field. Additionally, the communications required with the real-world client and within the multidisciplinary team, as well as the scheduling of individual tasks by the students, allows them to further develop their project management skills. Details of the engineering clinic have been well documented in many conferences and publications[1,2,4].

Energy Audit Equipment

During the Spring 2011 semester, a group of five undergraduate engineering students and two graduate students volunteered to undertake a general energy audit for a multiple building facility located near the Central Jersey Shore. A general energy audit includes a walk-through of the facility, inventory of all energy users, review of the last twelve months of energy bills, interviews of personnel, development of a baseline energy consumption for the site, comparison of this baseline consumption to actual energy bills, and the economic justification of possible energy conservation techniques. The audited facility is purposed as a family retreat, as it contains over eighty hotel rooms, fifteen dorm-style rooms for adolescents, indoor pool and hot tub, game room, outdoor volleyball and activities area, commercial kitchen, dining room, multiple conference rooms, bookstore, chapel, and gymnasium. It is estimated that the facility can accommodate up to 400 people. The energy audit was inclusive of all the above listed areas, as well as the staff's offices.

The first step for this project was to obtain an understanding of the process and goals of an energy audit. Students were given access to energy audits performed by prior engineering clinic teams at the university[5,6]. Additionally, a report prepared by a former graduate student at the university, which details energy efficiency analysis and techniques for buildings, was reviewed[7]. In reviewing these reports, students acquired knowledge of the steps required to perform an energy audit and insight into the possible energy consumers that may be observed at a facility, such as various types of lighting sources. A brief review of the former graduate student's report was performed to assess if the material was understood by the students.

With a basic knowledge gained on the process of conducting an energy audit, the students turned their attention to familiarizing themselves with the equipment available to aid in the audit. The students were shown the available equipment and suggested to make an inventory of that equipment. The inventory of instruments was used to determine how many and what type of instruments were available for use. This inventory was also used to determine if additional equipment or technologies needed to be purchased.

The operation of the instruments was purposely left for the students to determine. This method allowed for the students to develop a more detailed mastery of the instruments, in contrast to having the instrument's basics being shown to them. To understand the operation and capabilities of the instruments, students reviewed the manuals for each instrument. Students decided to each pursue a different instrument, so that redundancy of research was not done to maximize time.

A variety of instruments were available to the students for use in this energy audit. Kill-a-watt® and Watts-up?® meters are used to determine the energy consumption, in kilowatt-hours (kWh), for a piece of equipment over the time the meter is in use[8,9]. Kilowatt-hours are the standard electrical consumption parameter in the United States and are the reported unit on monthly electricity bills. These energy consumption meters require minimal setup, as the meters are designed for use by the average home owner.

For our audit purposes, the duty cycle needed to be acquired for certain equipment. The duty cycle can be determined using a Watts-up?® meter, where an adjustable duty cycle low limit record point is entered and stored in the meter. The duty cycle is then calculated by the meter for the amount of time the equipment exceeds the low limit and is reported as a percentage. To set up this duty cycle parameter, the students researched the manual to determine how to manipulate the duty cycle for the audit's needs. The duty cycle low limit is initially set for 100 Watts at the factory, but could be raised or lowered depending on the equipment's load requirements.

The most critical instrument utilized in the energy audit was Onset's HOBO® data loggers[10]. These units are capable of storing up to 43,000 data points over a specified period of time. The interval of data sampling is adjustable from one second to eighteen hours, which can allow data collection for over one year. Students needed to be cognizant of the on/off cycle of the equipment to be monitored. If a long interval between data sampling was chosen but the cycle to be analyzed occurred on quick intervals, data would be missed.

The HOBO® data loggers are capable of recording data for the following parameters: ambient temperature, relative humidity and light intensity. These instruments can be used to determine a variety of information, such as room occupancy hours using the light intensity data, room HVAC demands using the temperature and relative humidity data, or a motor's duty cycle using the instrument's external temperature probe directly affixed to the motor. The obtained data is used to determine the actual operating hours of equipment, and thus the total energy consumption for monitored areas or equipment.

Students reviewed the operations manual to learn the operation of the HOBO® data loggers. As a basic understanding was acquired from the manual, students next connected these instruments to a computer loaded with Onset's HOBO® software to experiment with the capabilities of the instruments. Along with adjusting the parameters in the data logger, the battery level and proper operation of each inventoried data logger was verified.

The final instrument used by the students was a light intensity meter. This instrument is slightly different from the HOBO®'s light intensity, as this instrument's primary function is to accurately measure light, whereas the HOBO® is used to gain a general understanding of area lighting use. A variety of light meters are available at the university, so students reviewed the manuals for all three instruments to determine the capabilities of each model. Upon initial investigation of these instruments, one model of light meter was reading approximately 20% lower than the other two models. With only three meters available, the students could not confidently determine which instrument was reading correctly. Students researched to find if a quick way to verify the operation of the meters was available, such as using a camera's flash, but determined the only way to verify the instrument's operation to the level of accuracy we needed was to have a unit calibrated. An Extech light meter was sent to its factory for a calibration check[11]. The instrument was found to be within 2% of the actual light intensity at the factory, so calibration was not needed. This instrument was then compared to the other meters by placing all of the sensors in very close proximity on a table. The instruments read within 2% of each other except for the one model of meter that continued to read approximately 20% less. Since the accuracy of that instrument was deemed to be insufficient when compared to the calibrated meter, that meter was stored away and will not be used in this audit.

The light intensity instruments are used in the energy audit to determine if excess lighting is present in a room, therefore unnecessarily increasing the site's energy consumption. The operation of the instrument is quite simple, as the meter instantaneously reads the light intensity in the direction the sensor is facing. Light intensity values obtained in the audit were compared to the recommended lighting values for specific rooms as determined by the Illuminating Engineering Society of North America (IESNA), and lighting reduction recommendations were made for excessively lit areas[12].

To assure competency with the meters and instruments before deployment at the audit facility, students tested the instruments in the Center for Sustainable Design's lab to record and analyze data from over a weekend. To acquire the room's occupancy data and HVAC demands, two HOBO® data loggers were placed in the lab. Students verified the operation of the Extech light meter by analyzing the light intensity in the lab's office area and compared the results to the IESNA lighting standard. To familiarize themselves with the Watts-up?® meter, the students placed the meter on a pump in the lab that is only turned on during unoccupied times. This will allow for the kWh consumption and duty cycle to be determined with this meter.

Upon returning from the weekend, students downloaded and reviewed the data. An unexplained temperature swing was observed every morning around 4AM, where the temperature in the room increased from 72˚F to 78˚F. The students agreed that this was likely due to the start up of the heating system every morning after being turned off overnight to conserve energy. The data from the Watts-up?® meter revealed a duty cycle of 85%. This duty cycle was confirmed by calculations, as the time the pump was turned on and off was known. The light intensity was determined instantaneously and was found to be within the appropriate range for an office environment per the IESNA lighting standard. This weekend data collection function was used to assess if students had acquired adequate knowledge on the operation of the instruments. With an acceptable understanding of the instruments and their operation, the students began the energy audit process.

Energy Audit Process

The students had reviewed prior energy audits and an energy efficiency report developed by a previous graduate student. Using the techniques depicted in those references, the students were prepared to begin the energy audit process. The process required to complete an energy audit consists of: site overview visit, inventorying of all equipment, determination of equipment operating hours, calculating the site's total predicted energy consumption, developing energy conservation goals by researching applicable energy consumption techniques and alternative equipments, and lastly, creating a technical report for the client.

To aid with tracking of the project's goals, the students were shown how to develop a Gantt chart. The final goal for this project was to create an energy audit report for the client by April 25th, 2011. With this endpoint defined, students were able to assign end dates for the other known subtasks. The students determined to include the following tasks on the Gantt chart: preliminary visit date, first audit date, second audit date, equipment inventorying, energy bill analysis and the final report date. As more information was gained throughout the project, additional tasks were added to the Gantt chart. The deadline for each task was determined by the students, as this was done to allow them to develop their project management skills in determining how to schedule subtasks to meet a project's final deadline.

To start the audit process, a site overview visit was organized. During this overview visit, the students were shown all of the buildings at the facility and also given ideas on how the facility operates and consumes energy. Students were also given the chance to interview the client at this time, to gain an understanding of the client's needs. The visit concluded with the students scheduling the first audit working day with the client. Due to the size of the facility, it was communicated to the client that multiple visits would be required to completely understand the operation of the facility and to complete the equipment inventory.

The first goal of the working day visits was to create an equipment inventory for every piece of equipment, portable or stationary, on the site. Students quickly broke the facility into sections to optimize time. Every room at the facility was examined and all energy users in each room were recorded. The major items included in many of the rooms were lighting and wall-mounted air conditioning units. Other equipment encountered and inventoried included: ATM machine, office equipment, computers, hot water tanks, showerhead flow rates, audio system equipment and vending machines.

A large variety of unique equipment was observed in the commercial kitchen. The kitchen included a walk-in freezer and refrigerator, two pizza-style ovens, four baking ovens, multiple commercial sized mixers and an automated dish washing unit. The model numbers for these equipments were recorded so that their energy consumption and alternative equipment, such as newer energy efficient models, could be researched at a later time.

The heating for the majority of rooms was accomplished via baseboard hot water heating. This heating system used natural gas fired boilers and water circulation pumps. To estimate the fuel and electrical consumption of the heating devices, the model numbers of the boilers were recorded so they could be researched later to acquire the instantaneous energy demand. The students thought about a method to acquire the operating hours of the boilers and circulation pumps, which were used to calculate the amount of energy they consumed. To determine the operating hours of the circulation pumps, the students used the external temperature probe for the HOBO® to acquire the pump's motor duty cycle. When the pump's motor is running, heat is generated and a temperature increase should be seen in the data collection. The HOBO®'s data collection interval was adjusted accordingly to record the motor's duty cycle, as the motor appeared to run for approximately five minutes, and then shutoff for approximately two minutes. This long cycle time meant we could use a longer interval time between data collection, as we were unlikely to miss any cycles that could occur with short times and high frequencies.

The duty cycle of the boiler was more difficult to obtain. Since the boilers were natural gas fired, no motors existed, therefore the duty cycle needed to be obtained by a method different than affixing a temperature probe to a motor. Students decided to place the HOBO®'s external temperature probe near the bottom of the boiler, where the area was open to allow air to feed to the boiler's flame. At this location, a distinct temperature increase was observed when the boiler was fired. Students carefully mounted the HOBO® and temperature probe in this area, with consideration given to not damage the probe or HOBO® due to excessive heat exposure. Students observed that the frequency of boiler's firing cycle was relatively quick. Therefore, a quicker data sampling interval would be required to accurately depict the duty cycle of the boilers. The HOBO®'s data was downloaded on the next site visit, and analyzed to determine the boiler's operating hours.

After completing the documentation of all equipment at the facility, the equipment was entered into a spreadsheet to determine the total energy consumption of the facility. To determine this energy consumption, the instantaneous energy rate, such as kW or voltage multiplied times amperage for electrical equipment, or BTUs for gas-fired equipment, needed to be multiplied by the hours of operation for each piece of equipment. This results in the energy consumption of kWh or BTU/hr per piece of equipment. For equipment where only the model number could be obtained, the model was researched online to estimate its energy consumption.

For determining specific room's energy consumption, HOBO® data loggers were left in occupied rooms to collect data. This data was later downloaded and analyzed. An analysis of the light intensity and temperature data was performed to estimate the hours of operation for lighting and HVAC for the room. The estimates obtained for these various rooms were used as standard operating conditions for each type of room, such as hotel room, dorm room or office. To calculate the site's total energy consumption, the standard conditions were extrapolated to every room at the site. With the potential energy consumption for each room known, the actual energy consumption was determined by using the annual occupancy for each room. Students had the opportunity to interview the maintenance supervisor for assistance in determining operating hours for some unique equipment, and to obtain 2010's occupancy data.

The equipment energy consumptions were summed for the entire facility and compared to last year's energy bills. With some of the equipment's energy consumption being estimated, a large deviation between the calculated and actual energy consumption existed. The deviation was reduced to below 5% by making adjustments to estimated equipment. This created a baseline energy consumption for the facility. This result is used to aid in determining the possible energy conservation techniques. It is typically more efficient to research energy conservation techniques for the larger energy consumers first, as calculated during the baseline study for the facility.

To examine the adequacy of lighting at the facilities, students used the Extech light meter. The light intensity was documented in a few rooms of the hotel as well as in the hallways. Students quickly realized that the lighting in many areas was just adequate, with almost zero excess lighting. One area of the chapel did result in excess lighting, when the observed result was compared to IESNA's recommended standards. A recommendation to reduce the amount of fixtures or bulbs in that area was made in the project's final report.

To work efficiently, students decided to break the equipment research into individual research topics. This was done because the students realized they were researching similar topics at the same time. The splitting of the equipment into separate areas allowed the students to directly focus on a certain aspect of the project and also gave each of them a quantifiable responsibility. The areas the students decided to split the research into were: HVAC, water heating, pool and hot tub, lighting, building structures and exteriors, and kitchen & office equipment. The intent was for the students to acquire energy conservation techniques and alternative equipments for their specific area to allow achievement of the project's goals. These topics were added to the project's Gantt chart, and the students determined the deadline of individual topic research reports to be in one and a half months, or two weeks before the final report was due.

Using the energy consumption baseline calculated for the facility, students developed and justified energy conservation techniques for their specific topic areas. With the results from their individual topics, and the results from the equipment inventory and baseline energy calculation, the energy audit report was assembled for the client. The students were continuously assessed throughout the project, based on their involvement and input, as well as through the content of their individual research topic reports.

Summary

To incorporate novel content into the engineering curricula at Rowan University, the

Engineering Clinic approach is used. For upper classmen, these clinics typically involve the responsibility of completing a project for a client in a set timeframe. This allows for students to enhance their project management skills, which includes client communications, meeting of goals in a timely fashion and scheduling of intermediate goals in the form of a Gantt chart. Additionally, students were exposed to techniques and equipment not typically used in a classroom setting, such as HOBO® data loggers. With a hands-on approach of learning these techniques and equipments, the likelihood of the students retaining these skills is increased. Further research is needed to verify this hypothesis.

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