Sustainability Learning and Energy Conservation: A Capstone Design Project

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Abstract
Integration of sustainability and its vision across multiple disciplines has become standard in many industries. Sustainability embraces the goals of environmental, social, and economic vitality with the understanding that the needs of the present be met without compromising the ability of future generations to meet their own needs. Sustainability promotes interconnectivity of sources and communities, diversity, relationships between global environmental and economic trends, and holistic thinking which are key ingredients for success in most industries and disciplines. Campus infrastructures are invaluable parts of an institution which support education, research & development, health, recreation, community services, and more. However, these structures consume a huge amount of energy. In FY13/14 ETSU campus structures consumed 52,559,720 KWH of electricity and 180,800 MCF of gas which totaled $5,494,967.39 in energy bills. With rising cost of energy and maintenance, the need for performance improvement of these structures has become essential. Several studies found that sustainability based holistic building energy models can reduce energy consumption by 20% to 40% and can significantly increase occupants’ satisfaction and comfort. There is also a need to equip our students with sustainability related skills and competencies in designs, analysis, programs, and projects. Therefore, the objectives of this project are to: 1) train students in sustainability learning through a hands-on building energy auditing and 2) provide students an opportunity to use their culminating knowledge to develop energy saving solutions focusing on sustainability triple bottom line.
INTRODUCTION

Improving environmental stewardship, conserving our natural resources, and social responsibility are some of the most pressing issues facing our modern world. As populations grow, and finite raw materials are consumed in ever greater numbers, we must find better ways to manage our planet’s resources and to preserve its ecosystems. Campus infrastructures are invaluable parts of an institution which support education, research & development, health, recreation, community services, and more. College and University leaders and decision makers can be instrumental in expanding public awareness of sustainability by providing students positive examples of the cohabitation of natural and built environments. Studies show that an energy-efficient building offers a great possibilities to enhance the working environment, including increasing worker productivity, improving staff retention, indoor air quality, thermal comfort, and natural lighting and may contribute directly to corporate social responsibility through reduced greenhouse gas emissions (Kats et al., 2003; Miller et al., 2009; RMI, 1994; Miller, Spivey, & Florance, 2008).

The health and education of our children are also important issues. High-performance campus buildings provide safer and healthier learning spaces and improve student attendance. They also provide an opportunity to use the building as a teaching tool and to facilitate students’ interaction with the environment (Earthman, 2002; Schneider, 2002). Finally, but not least of all, they can significantly lower operational and life-cycle costs. Many university campuses spend more money on energy each year than on supplies. In FY13/14 East Tennessee State University (ETSU) campus buildings consumed 52,559,720 KWH of electricity and 180,800 MCF of natural gas which totaled $5,494,967.39 in energy bills. By using energy efficiently and lowering a university’s energy bills, millions of dollars each year can be redirected toward improving facilities, lowering operation and maintenance costs/faster payback, and providing educational resources.

Energy efficient campus building design is not just the result of applying one or more isolated design guidelines. Rather, it requires an integrated whole building process throughout the entire project development process. Whole building energy modeling considers the energy-related impacts and interactions of all buildings components, including the building location, envelope (walls, windows, doors, and roof), its heating, ventilation, and air conditioning (HVAC) systems, lighting, controls, and equipment. Several research papers describe energy analysis as a holistic evaluation (Diakaki, 2008; Noailly, 2012; Abaza, 2008). Dahl et al. (2005) and Lam et al. (2004) showed that decisions made early in a project have a strong effect on the life cycle costs of a building. Over the life cycle of buildings, more than 80 percent of the total energy is consumed during the operation phase, and is highly dependent on the building design (United Nations Environment Programme, 2007). Thus, focusing on the operation phase of buildings is crucial to achieve long-term energy savings.

The effective connection of building – its environment, use pattern, internal and external systems and the justification of construction/renovation is crucial for the better understanding on
sustainable and energy efficient project decision-making. In order to provide a robust parametric assessment of the building systems and their energy use, more sophisticated energy simulation tools capable of calculating dynamic thermal systems must be seamlessly integrated with the conventional energy approaches. Current decision making processes for campus building energy improvement projects are fragmented. Energy management systems of campus buildings generate a lot of data (e.g. energy consumption, peak demand, use pattern etc.) however, most often these data are not used/integrated effectively though holistic energy modeling during decision making process. Therefore, there is a pressing need to evaluate and understand the implication of decision making for energy performance of campus buildings during design and operation phases in an effort to increase their energy efficiency, conservation and reducing carbon footprint. Therefore, the objectives of this project are to: 1) train students in sustainability learning through a hands-on building energy auditing and 2) provide students an opportunity to use their culminating knowledge to develop energy saving solutions focusing on sustainability triple bottom line.

**METHOD AND PROJECT DESCRIPTION**

Developing building energy models is a data driven process and its accuracy mostly depends on the level of detail pursued in defining the building. In order to achieve reliable results, most studies suggest performing calculations using a dynamic energy simulation method with appropriate calculation programs (e.g. OpenStudio, eQuest, EnergyPlus). Dynamic energy simulation requires detailed building energy models which are mostly associated with the several pieces of information necessary as input data for the modeling process. Input data required for a building energy simulation can be divided into four areas. These are: 1) Form, 2) Envelope, 3) System, and 4) Operation. The input dataset “Form” requires information regarding the building type (e.g. office, school, hospital, retail etc.), size and general geometry of the building. The second dataset, “Envelope”, regards the construction technologies and the material used in the building, providing a description of the thermophysical proprieties of building envelope. The third dataset “System” concerns the heating and cooling systems, the mechanical ventilation systems, the generation systems and the production from renewable energy sources within the building. The last dataset “Operation” consists of the operational parameters affecting the usage of the building and expressed through a set of schedules (i.e. lighting schedule, equipment schedule, heating temperature schedule, etc.). Table 1 shows these four areas with typical input data required in each area.

The project was a collaboration between Engineering Technology Department and ETSU Facilities Management and it was implemented in the capstone design course ENTC 4600 Technical Practicum. The department of engineering technology offers BS in eight concentrations with an enrollment of about 800 students. ENTC 4600 is a core course for all concentrations of students which has an annual enrollment of about 40 students. The project was one of projects for ENTC 4600, and ETSU Facilities Management acted as a client which had a problem to solve (which is reduction of energy usage). A multi-disciplinary team consists of construction, electronic, interior design and surveying concentration was formed. Students with the help of the Facilities Management’s energy management group conducted a detailed energy audit for the Wilson Wallis Hall according to ASHRAE procedures (ASHRAE, 2011). The students used the energy audit kit to collect various types of data such as temperature, humidity, building envelope performance using infrared camera, lighting, equipment usage, water
consumption, operation schedule, construction, etc. The collected data then fed into a sustainability design, analysis and assessment tool named OpenStudio. The tool is developed by National Renewable Energy Laboratory (NREL) and the US Department of Energy, which supports whole building energy modeling using EnergyPlus and advanced

Table 1: Typical required dataset for building energy modeling

<table>
<thead>
<tr>
<th>Input Data Area</th>
<th>Graphic</th>
<th>Detail Inputs</th>
</tr>
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| **Form**        | ![Graphic](image) | Total Floor Area  
Floor Height  
Orientation  
Aspect Ratio  
Shading |
| **Envelope**    | ![Graphic](image) | Exterior Walls  
Roof/Floor  
Transparent Elements  
Interior Partitions  
Internal Mass |
| **System**      | ![Graphic](image) | HVAC System Types  
Component Efficiency  
Control Settings  
Lighting Fixtures  
Daylight Control |
| **Operation**   | ![Graphic](image) | Location  
Schedule  
Plug and Process Loads  
Lighting Densities  
Ventilation Needs  
Occupancy |

daylight analysis using Radiance (NREL, 2015). This tool was used to create current energy performance of Wilson Wallis Hall and helped students simulate energy saving solutions within the model. The students used their culminating knowledge to develop solution specifications, estimate cost and conduct engineering economic analysis, conduct lighting analysis, identify water conservation measures, strategies to improve occupant comfort, and propose renewable energy measures. Figure 1 shows a flowchart of the project work.

**ASHRAE LEVEL 1 ENERGY AUDIT AND OPENSTUDIO MODEL DEVELOPMENT**
The ASHRAE Level 1 audit is commonly known as a “simple audit”, or “screening audit” and it is the basic starting place for creating energy optimization. It entails brief selection interviews with building operating staff, an overview of the facility’s utility bills and additional data, and an
abbreviated walk-through of the building. The ASHRAE Level-1 audit is focused on the identification of the potential for energy efficiency improvements, understanding the overall building configuration, and defining the type and nature of energy systems.

The project was designed with two components: Theory and Actual Energy Audit. Tom Horan, the energy engineer in the FM, provided a 10-hour workshop for the students detailing building energy systems and energy audit basics. The workshop helped students and other participants build a foundation in this area. Followed by the workshop, student conducted the Level 1 energy audit. Tom Horan led the audit with the students. Before the audit, students were briefed with safety precautions. Students also gathered equipment to be used during the auditing, building layout and data sheet to gather information. Students visited classrooms, offices, computer labs, wet labs, restrooms, mechanical room, and corridor and investigated lighting, HVAC systems, motors, hot and cold water systems, etc, and estimated the occupancy, equipment, and lighting – their energy use density and hours of operation for each space type. Using the information collected in the walk-through survey, students prepared a comprehensive list of energy conservation measures. Students then created an Openstudio Model for Simulation purpose. Figure 2 shows the simplified OpenStudio Model for Wilson Wallis Hall. Figure 3 and 4 shows space types and thermal zones. Figure 5 shows inclusion of schedules, construction sets, and equipment loads. Figure 6 shows simple HVAC systems for the model. Figure 7 shows the output of the simulation.

Figure 1: Proposed Building Energy Modeling and Optimization for Decision Making Flowchart
Figure 2: OpenStudio Model of Wilson Wallis Hall

Figure 3: OpenStudio Model of Wilson Wallis Hall: Space Types
Figure 4: OpenStudio Model of Wilson Wallis Hall: Thermal Zones

Figure 5a: OpenStudio Model of Wilson Wallis Hall: Schedules
Figure 5b: OpenStudio Model of Wilson Wallis Hall: Construction Sets

Figure 5c: OpenStudio Model of Wilson Wallis Hall: Loads
CONCLUSIONS

The capstone project was designed to train students ASHRAE Level 1 Energy Audit. Students attended a workshop on building energy systems and energy auditing basics, and conducted the audit in one of the campus buildings and prepared a list of energy conservation measures. The students also created an OpenStudio Model for energy simulation. The project develops a rapid campus building energy modeling technique that makes modeling faster, cheaper, and more
likely to be used. The project also produces a hands-on educational module to train students in sustainable design, analysis and assessment. Decision makers can also benefit from the results to develop methods that promote energy conservative behavior among the buildings’ occupants, focusing on the behaviors that illustrate high impacts on energy use for effective and fast energy reductions. One limitation of the project is it was simplified to fit within the scope of the capstone project and simulation was conducted based on the estimates which may not reflect actual energy consumption in the building.

REFERENCE


