Developing Energy Efficiency and Advanced Decision-Making Course

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Abstract

In today's world we are facing an explosion of population worldwide. This is "the major underlying force on environmental degradation and a threat to sustainable use of natural resources" [1]. As a result, there is a need for much more energy to accommodate these demands. At the same time, the world is facing the problem of extreme impact of these demands on the nature and environment and is in need for developing methods of satisfying these demands. Engineers must become prepared to design and build more products while consuming less resources including energy. This puts additional burdens on the engineering and engineering technology (EET) schools to develop courses and programs to make the concept of energy and energy efficiency more understandable to their students and train and send their graduates to industries well prepared to confront shortage of energy and threats of global weather changing simultaneously. To help reaching these targeted outcomes, it is essential for all the EET schools to develop energy and energy efficiency courses in which students not only become familiar with different industries energy consuming systems and how efficient these systems currently are, but also it is very important to expose their students to whereabouts of opportunities to improve overall system energy consumption. These students also need to become familiar with state-of-the-art research methods and tools, which can help them to investigate these systems and opportunities meaningfully and effectively. These courses should be introduced and taught in early semesters of students' undergraduate enrollment to work as a guiding light throughout the rest of their curriculum to be most effective. In this paper authors discuss the need for developing an interdisciplinary course that targets educating EET undergraduate students in the fields of energy efficiency in different engineering systems and methods of advanced decision-making simultaneously.

Introduction

Based on a Department of Energy report, the building industry consumes almost 76% of total electricity and 40% of all United States primary energy [2]. The major areas of energy consumption in buildings are heating, ventilation, and air conditioning (HVAC); lighting; major appliances; and other uses. These are responsible for 32%, 8%, 19% and 34%, respectively [2]. In each case there is great opportunity for improving the energy consumption. Major contributors to high energy consumption in buildings include via skin losses, HVAC system losses including utilization of equipment and distribution systems with low efficiency, design rate and control of outside air, and lighting control. The Department of Energy Building Technology Office overview in 2019 shows a target of improvement of the commercial building energy efficiency of 20% in the next 20 years [2].

In the meantime, based on a 2014 Department of Energy report [3], total input energy for all the manufacturing activities in United States were equivalent to 20,008 trillion British thermal units (TBtu) in forms of direct fuel, fuel for generating offsite electricity and fuel for generating offsite steam. Total energy loss in all manufacturing sectors added up to 12,676 TBtu. It was roughly 64% loss of total input energy in all manufacturing sectors. Based on this report, the most significant losses happened during creating offsite electricity and during utilizing energy for the manufacturing sites process activities. Such results show both opportunities and necessities for improvement of energy efficiency throughout manufacturing activities.

Energy efficiency is not only one of the most important ways to reduce energy cost and therefore improve the profitability of businesses but also is one of the most important factors to decrease the negative effects of industries on the environment, including global warming phenomena. No matter what branch of the industry we choose to focus our studies on, there is always plenty of opportunities to discover the weak links leading to energy waste and then find solutions for improving them. Students in EET schools are the future leaders of their selected industries, who, throughout their related curriculum, learn the general technical knowledge of their own industries. They also should gain specific knowledge regarding different opportunities for improvement in system performances. The most effective improvements can happen where students are equipped with the most advanced techniques of decision making and can utilize these techniques in searching the better ways of the design and management in their chosen industries. Such strong tools shall be taught in the early years of their enrollment in school since it would help them to look differently to every course and subject that they will be taught in the later years of their studies. An energy efficiency course therefore is a course that should be taught to all engineering students to primarily help them find places for possible energy improvement within their own industries, also to use advanced decision-making tools to make their industries more energy efficient, while keeping eye on the ways that benefit the other disciplines as well.

Method

This course will be presented in two parts. The first half of the course contains a quick but holistic review of a few systems of engineering and pointing to the most energy consuming elements of each system. These are systems such as commercial buildings, manufacturing plants, power plants, sport arenas, data centers, etc. In each case a high-level view of the building, plant, and its associated systems will be presented along with discussions about average energy consumption of each system. We also discuss the ways to find the elements with higher energy consumption within each system, such as chillers, turbines, fluid distribution piping, etc. Most engineering systems are in fact built from elements that energy efficiency of it is the focus of one of the engineering disciplines. This interdisciplinary nature of engineering systems helps ET students from different departments (electrical, mechanical, industrial engineering and engineering technology, etc.) become the beneficiaries of this course. By the end of the first section of the course, students will become familiar with the importance of the concepts of energy and energy saving and of course energy efficiency within their own field. Also, they will gained an overall understanding about where to look for improvement of the energy efficiency of the systems. In each case, it will be very helpful to invite a specialist from the industry to share experiences with the students regarding each specific system**.**

Knowing the points in each system that represent opportunities for improvement is only half of problem solving. In the second section of the course, students will become briefly familiar with the state-of-the-art tools of research and decision making, such as uncertainty analysis, neural network analysis, game theory and analytical hierarchy methods. Each method then will be utilized to solve simple industry related energy efficiency projects. These projects will be designed to use the knowledge gained about different systems/industries that were presented in the first section of the course.

Sample of System Energy Analysis

An example of systems that will be analyzed in the first part of the course is commercial building energy systems. A commercial building is a good example because it allows for interdisciplinary discussion of different aspects of the systems, such as mechanical, electrical, special technology, fire protection, and architectural all under one umbrella. In each sub-section there are energy-consuming elements that will be discussed and ways to improve the overall energy consumption of building will be reviewed. Another important learning objective here is the fact that each trade may need to compromise on parts of its energy-saving solutions to help other trades gain on their basic objectives. There will be specific focus on the role of the physical shape of the building and building skin structure to reduce the energy consumption, as well as searching for ways to increase the efficiency of the mechanical system equipment, such as air handling units, fans, and chillers. Also, the importance of electrical lighting, along with efficiency of the data processing systems in buildings will be reviewed.

In each case, the current level of energy consumption in different systems will be discussed as well as ways for improving these levels and how the building control system can contribute to these energy savings. By the end of this section, students will be sufficiently familiar with opportunities and limitations for improvement of energy consumption of the commercial buildings. Therefore, they will recognize which elements or systems they should target their energy reduction focuses and efforts to get best saving results. Of course, this is mainly based on their fields of study within the commercial buildings energy systems, while keeping the limitations of all other disciplines under consideration.

This is only one example of discussed systems in this course. High-level energy analyses for other applications such as power plants, manufacturing plants, etc. also will be done in a similar manner.

Decision-Making Tools

In the second part of the course students will learn how to use advanced decision-making tools. These tools will help them to investigate ways of analyzing the data and create innovative solutions for reduction of energy consumption in engineering applications that they have learned, in the first part of the course. At the beginning of this part, a short overview of decision theory and its sub-sections will be presented to the students. In the literature, decision theory is divided to normative and positive types. Within normative type, which is the domain for engineering studies, there are three sub-sections of decision-making under uncertainty, multi-criteria decision making, and decision support systems [4]. These topics will be reviewed briefly, to help students

to develop a holistic view of this field of study. The following methods will then be discussed briefly in this section that will help students to develop their power of making proper decisions based on applying the presented tools:

1. Introduction to energy and energy efficiency taxonomy basics and teaching students how to develop such taxonomies for different engineering industries.
2. Introduction of concepts of performance-based and prescriptive-based energy efficiency modeling, and how to develop performance indicators for energy efficiency assessment for different industries.
3. Introduction to basics of energy modeling and ways of improving the energy efficiency of different applications such as commercial buildings, manufacturing plants, etc.
4. Introduction to basics of analytical hierarchy process for conditions that one needs to select the optimum solution among the conflicting parameters, such as energy efficiency and cost. "The analytical hierarchy process is a theory of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales. It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgements that represents, how much more, one element dominates another with respect to a given attribute" [5].
5. Introduction to basics of artificial neural networks and how they can help developing artificial intelligence usage in different functions of different industries affecting energy consumption and efficiency.
6. Introduction to basics of game theory to help students develop power of strategic thinking and be able to find the best possible solutions for different engineering problems with a focus on energy saving and efficiency. "As a mathematical tool for the decision-maker the strength of game theory is the methodology it provides for structuring and analyzing problems of strategic choice. The process of formally modeling a situation as a game requires the decision maker to enumerate explicitly the players and their strategic options, and to consider their preferences and reactions" [6].
7. Introduction to concepts of decision making under uncertainty. "Decision making under uncertainty is the process of making decisions about actions with unknown inputs and outcomes" [7].

Learning Objectives

Learning objectives for the students that take the course are in-line with the requirements of ABET and can be summarized as follows:

1. Having ability to apply knowledge, techniques, skills, and modern tools presented to them in this course to solve complicated problems appropriate for their disciplines using critical thinking, with special focus on systems energy efficiency.
2. Having ability to design and improve systems, components, or processes while meeting specific needs for complicated problems appropriate for their disciplines, with special focus on systems energy efficiency.
3. Having ability to function effectively as a member as well as a leader in different industries after graduation.

Summary

The course will introduce possible opportunities for energy saving and efficiency in different engineering industries. It represents a holistic view of a few industries/systems that would help students of different engineering departments understand the relatedness of energy usage and efficiency. Each student learns how to achieve individual goals of energy efficiency for equipment and systems of interest, while cooperating with, compromising, and helping the students from other departments to achieve optimum efficiency of their systems of interest. By doing this, the contents of the course advocate the students to look for solutions that are not only effective for improving the efficiency of the systems in their own disciplines but also to help the students of the other disciplines to improve their associated systems efficiency. To do so, they will be trained how to think and make great decisions by learning how to use state-of-the-art decision-making tools. This course is an essential first step for all the students to learn the big picture view of the industries that they will be working and leading in the future, the available opportunities contributing to preventing energy waste, and tools to evaluate and offer solutions where it is possible.

Material that students will learn in this course will help them throughout their years of study by giving them an additional window to look at each of their advanced engineering courses more effectively, as well as an ability to research if they choose to continue their educations beyond undergraduate studies. Above all, this course will help them during their professional working years to be able to look at energy efficiency opportunities with a different set of glasses. It should be noted here that the course contains a large quantity of topics and systems to cover. To cover all these topics effectively, it might be required to design the course as a four-credit hour course or even divided it to two different courses. Also, to the best of the authors' knowledge, such course with similar contents and depth has not been presented before. For this reason, it takes a great amount of effort to design this course, and of course it requires interdisciplinary cooperation among the professors from different disciplines to make this course as effective as possible.

References

1. M. M. Maja and S. F. Ayano, "The impact of population growth on natural resources and farmers' capacity to adapt to climate in low-income countries," *Earth Syst Environ*, vol. 5, 271-283, 2021. https://doi.org/10.1007/s41748-021-00209-6.S.
2. A. M. Bouza, "DOE building technologies office overview," 2019. [Online]. Available: https://www.gsa.gov/cdnstatic/Bouza%20-%209-12-19%20BTO%20overview.pdf.
3. "Manufacturing energy and carbon footprint, sector: All manufacturing" (NAICS 31-33), 2014. [Online]. Available: https://www.energy.gov/sites/prod/files/2019/06/f64/Manufacturing%20Energy%20Footprint-2014_Latest_compliant.pdf.
4. P. Zhou, B.W. Ang, and K. L. Poh, "Decision analysis in energy and environmental modeling: An update," *Energy* vol. 31, no. 14, 2604-2622, November 2006. doi: 10.1016/j.energy.2005.10.023.
5. T. L. Saaty, "Decision making with the analytic hierarchy process," *Int. J. Services Sciences*, vol. 1, no. 1, 2008, 83-98.
6. T. L. Turocy and B. von Stengel, "Game theory," CDAM Research Report LSE-CDAM-2001-09, October 8, 2001. [Online]. Available: http://www.cdam.lse.ac.uk/Reports/Files/cdam-2001-09.pdf.

7. Khazaii, J., *Advanced decision making for HVAC engineers, Creating energy efficient smart buildings.*" New York: Springer, 2016.

Biographies

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