Training Engineers for Managing Intelligent HVAC Systems in Modern Office Buildings

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ABSTRACT

In today's changing climate and economy, managing and minimizing energy usage in office buildings is beneficial not only to our environment, but also to the economy. By training and educating a new generation of engineers for managing efficient, sustainable, and economic building energy management systems, we can help to provide solutions to our energy issues, and to reduce our environmental impacts. There is a need to create "hands-on" training and developmental tools, related resources, and educational curricula for four-year degree undergraduate programs in the University of California in the area of building energy systems. In particular, there is a need for classes teaching HVAC and building energy management systems including design, functional testing, operations and maintenance, monitoring, trouble-shooting, diagnosis, optimization, commissioning, and retro-commissioning. UC Merced is an ideal place to create such a "hands-on" curriculum because all the buildings on campus are highly instrumented with sensors and actuators and serve as living laboratories.

This paper discusses our experience to date in developing a curriculum and related resources, including challenges and achievements, our current activities, and our plans for upcoming projects and products, including the use of the educational software tool Learn HVAC as applied to the HVAC control systems on the University of California, Merced campus.

Introduction

Heating, ventilation, and air conditioning (HVAC) is a technology for indoor environmental comfort that is widely implemented in modern buildings. The interrelations of the three components of HVAC provide human comfort and acceptable indoor air conditions for industry needs as well. Energy management systems incorporate HVAC as well as other environmental factors in buildings such as lighting, fire detection, and other electrical loads. According to the U.S. Department of Energy 2009 Building Energy Databook, building construction and renovation (valued at $1.22 trillion) contributed 9.2% to the GDP in 2006 and employed approximately 8 million people. Buildings' total energy expenditures cost $392 billion, and used 72% of nation's electricity, 54% of natural gas, and 38.9% of nation's total energy consumption (U.S. Department of Energy 2009). Currently, HVAC accounts for 57% of the energy used (valued at $223 billion) in U.S. commercial and residential buildings, and employs around 1.1 million people (U.S. Department of Energy 2009). The complexity of HVAC and energy management systems can create large margins of error and loss of efficiency, generating the potential for more than 20% waste in energy consumption (Roth et al. 2005).

With such a large market, there is an evident need to produce highly trained engineers skilled in HVAC and building energy management systems including design, functional testing, operations and maintenance, monitoring, trouble-shooting, diagnosis, optimization, commissioning, and retro-commissioning. In order to fulfill this need, universities and technical colleges must modify current programs and create new curricula to meet the

growing demands of this field. The need is critical for universities and technical colleges to train future engineers for future conditions of the HVAC industry.

Degree Programs Currently Available to Mechanical Engineering Students

Several universities and colleges have already been offering a concentration in HVAC technology. Laney College, a community college in Oakland, California, and Sacramento city College in Sacramento, California both offer two year certifications and Associate of Science programs for students looking to pursue careers as refrigeration technicians, heating, ventilation, air conditioning technicians, equipment and system installers, operations and maintenance technicians, controls technicians, and energy specialists (Laney College 2010). Students seeking to transfer to four year institutions in pursuit of engineering degrees can also use the two year Associates Degree as a concentration in HVAC and energy management systems within the chosen engineering discipline.

Several four-year universities also offer concentrations in the Mechanical Engineering discipline on HVAC and building energy management. For example, California Polytechnic State University, San Luis Obispo, offers a Mechanical Engineering degree with a concentration in HVAC. In this program, students take courses on the fundamentals of HVAC systems, HVAC air and water distribution systems, and building heating and cooling loads after completing introductory courses in Thermodynamics, Fluid Mechanics and Heat Transfer. In these courses, students learn the inner components of HVAC systems, design of components, sizing of fans, boilers, pipes, and other individual aspects, as well as estimation of energy usage and operating costs. Courses such as Refrigeration Principles and Design are also offered, leading up to the HVAC senior design project course, in which students complete a senior design project in the field of HVAC (California Polytechnic State University, San Luis Obispo 2010).

Proposed Four-Year Program on Building Energy Management Systems

Educational Objectives

To consider what is needed to train a better HVAC engineer, let us first consider what the engineer's skills and talents will be used for and what skills and resources that engineer will need to have for future HVAC systems.

Buildings vary in size. The more complicated HVAC systems belong to buildings with the largest space, with labyrinths of utility rooms, offices, and laboratories. These systems will turn on and off both automatically and with user overrides. There are mechanisms to control the temperature and conditions of individual rooms, and air handling units responsible for supplying air to multiple rooms. These components will be tied together electronically, monitored by sensors, and synchronized to take disjoint elements and organize them into a cohesive entity. These collaborative components will need to be maintained. There is a need to find parts that are not functioning properly. The HVAC system must perform well for any outside weather condition. The buildings are not empty cube shaped behemoths, but rather complicated organisms with fans, chillers, vents, insulation, thermostats, people, electronics, furnaces, and a lot of air.

UC Merced is composed of 29 buildings ranging in size and function, and is continually growing. There are a collection of smaller dormitory suites, large dormitory halls, dining facilities, and large structures containing combinations of offices, class rooms, lecture halls, libraries, and laboratories. In the Science and Engineering Building, there are two wings of three stories containing offices, classrooms, computer laboratories, and

experimental laboratories, each offering unique control schemes to minimize energy use. The buildings at UC Merced are highly instrumented with sensors for monitoring performance of the energy systems that govern them. Building operators can monitor the supply and return air temperatures and flows through the system, dampers, valve positions, room temperatures and dozens of other parameters.

The future HVAC engineer with a four year bachelor degree must be able to design, analyze and manage this complex system. The engineer will need to understand human comfort, and will need to have a thorough knowledge of temperature and humidity as it affects human comfort. The engineer must be able to identify inefficiencies in the system, and recognize the potential for energy savings. The engineer must know different options for insulation materials and other related knowledge, and be able to make keen selections. The engineer will know how to move air, and how to stop it. The engineer must know the standard practices of heating and cooling in order to develop more innovative and efficient systems for the future. The engineer must know transducer technologies for sensors and actuators. The engineer should know how to optimize the placement and number of various sensors in order to effectively monitor the building energy performance. They will also know signal processing in order to better understand how the building performs through the data from sensors. Above all, our engineer will need to be an innovative thinker, who possesses the skills and knowledge to solve the complicated problems of future energy efficient buildings.

In order to train the engineer capable of performing all of these tasks, we must offer a four year engineering curriculum with a number of technical core courses on HVAC systems. This set of specialized skills is not presented at this time in the typical four year degree program of a Mechanical Engineering curriculum.

In summary, the proposed four-year program will train students who will be able to design, analyze and manage modern HVAC systems with high energy efficiency, who will have a working knowledge on thermal, mechanical, electrical and control engineering disciplines, and who will know how to integrate all these engineering disciplines to create and manage new efficient building energy management systems.

Certainly many of the technical aspects of training engineers for HVAC and energy management are well suited for lectures, and many of the fundamental courses already instated will play a key role. Thermodynamics, Fluid Mechanics, and Heat Transfer will all be key courses for an engineer working with a thermo-mechanical system. A course in material science that covers insulation materials will be important in making efficient structures and systems. Courses in control systems are a common requirement in mechanical engineering curriculum. An ambitious program could include additional courses in feedback controls, advanced controls, signal processing and sensors. These courses will provide engineers with the knowledge of complex control systems and sensor technologies to create more efficient systems with better fault detection. Computer software and the Internet will also play a key role in an educational program of HVAC and building energy management. Software packages capable of designing, analyzing, simulating and visualizing complicated systems will increase the learning capabilities of engineers in HVAC and building energy management.

Courses for the four-year degree program. The proposed four-year degree program for a Mechanical Engineer with an emphasis on HVAC would include the same general education as traditional engineering programs, with courses covering general electives as well as basic courses in physics, calculus, chemistry, and engineering. In addition to these courses, the following technical courses could compose a concentration on HVAC within the ME curriculum:

1. Thermodynamics
2. Fluid Mechanics
3. Heat Transfer
4. Material Science
5. Feedback Controls
6. Advanced Control Systems
7. Signal Processing
8. Sensors
9. Introduction to HVAC
10. Building Heating and Cooling Loads
11. Mechanical and Electrical Design of HVAC (computer lab with HVAC CAD software)
12. Simulations of HVAC (computer lab with HVAC simulation software such as LearnHVAC)

Learning Software

Software tools are essential in modern engineering curricula. Not only do they provide the students with the latest technologies used in the industry, they also give a virtual "hands-on" experience so that engineers will develop a better sense of building energy management systems as a whole. The software tool can also help teach HVAC fault detection methods.

The past few decades witnessed the revolution of design and manufacturing both in education and industrial practice introduced by CAD and Finite Element tools. Such a winning combination of design and simulation software for HVAC systems can also significantly improve the education and industrial practice of HVAC. It is desirable to have HVAC CAD software that would enable the user to import and design various features of HVAC systems into a model, along with the ability to change these components in a way that allows the designer to view their creation and change it before settling on the best design.

In addition to the software that allows the user to design rapidly, a simulation package to test the design is indispensable. In the same way that CAD and Finite Element are able to bring about incredible changes to the manufacturing industry, an HVAC CAD together with simulation software with computational fluid dynamics, heat transfer, and thermodynamics packages will greatly improve the educational program and change the HVAC industry.

UC Merced uses Automated Logic Control (ALC) systems with WebCTRL produced by Automated Logic Corporation, an automation system with a user-friendly graphical interface backed by databases to manage HVAC systems (Automated Logic Corporation 2009). ALC allows the operator to track data trends throughout buildings, zones, and single units. Similar programs like Computrols Building Automation System, Alerton Building Suite, and Delta Control's Operator Workstation are widely used in building energy management to monitor rooms and systems (Alerton 2008; Computrols 2010; Delta Controls 2010). These programs collect vast amounts of real time data that can be used to verify models, monitor system performance, or detect faults. Similar software could be used for students to learn and understand the tools available in industry for monitoring and tracking the state of HVAC systems.

LearnHVAC is a free, open source computer-based educational tool designed to introduce fundamental concepts of HVAC and building energy management to students and industry employees. LearnHVAC introduces basic concepts to engineering students early in their education, while also offering the complexities of real life building energy management

systems (Learn HVAC 2008). These different types of software are extremely useful in assisting the student. It is desirable to have software with the following capabilities:

1. Introduce HVAC system design and features;
2. Allow faults to be simulated;
3. Provide CAD libraries for HVAC design;
4. Simulate HVAC systems dynamically;
5. Incorporate real-time data in simulations and monitor the building energy performance.

It is highly beneficial to allow students to use the software with these features concurrently with the courses while they are learning the HVAC principles.

Conclusion

With growing populations and changing climates, it is critical to minimize energy usage in order to reduce the environmental impact of buildings. It is the responsibility of the engineers who design, operate, and maintain the HVAC system in buildings to develop new solutions to the complex energy issues. To educate future engineers with the capability to design, analyze and maintain HVAC systems in modern buildings, we need to create the curriculum with the right technical content and software tools. The expansion of CAD tools for HVAC design together with visualization and powerful simulation packages will be an important component of the new curriculum that will help to enhance capabilities of future engineers.

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