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Developing a Laboratory for Heating, Ventilating, and Air-Conditioning Courses

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Heating, ventilating and air-conditioning (HVAC) systems are an integral part of any building, often comprising 20% to 40% of the total building cost. Clearly, it is difficult to be in responsible charge of the construction of an entire building without also having an understanding of how and why mechanical systems work the way they do. The main difficulty in teaching the fundamentals of HVAC systems to construction management students revolves around the fact that most students have very little background or experience with these systems. Added to this problem is the fact that most texts on the subject matter are very technical in nature, principally written for design engineers and not construction managers. It is believed by many researchers that most students find learning easier, and more comprehensible, if the material is presented visually. This paper discusses two different approaches to providing visual “hands on” teaching methods through the use of a HVAC laboratory.

Key Words: Heating, Ventilating and Air-Conditioning (HVAC), laboratory, visual learning.

Introduction

HVAC systems are actually very simple, straightforward systems. There are no great mysteries on how they operate. At the same time, for those not familiar with mechanical systems, it can appear the systems work by "magic". Inasmuch as a large percentage of all construction management students traditionally come from a general contracting background, it is not surprising then that mechanical systems courses have historically been perceived by the students as some of the most difficult courses in a construction management curriculum.

It should also be kept in mind that construction management education strives to produce a technical manager capable of identifying problems, quantifying problems and then resolving problems in the context of the construction industry. Accordingly, it is necessary that construction managers be able to think "holistically"; that is, be able to see entire systems as a part of a whole building or construction. This is only possible if the students understand the systems themselves. To that end, there is a very fine, but well defined, line between teaching design engineering and teaching the fundamentals of how and why those systems work. Clearly, some design fundamentals have to be taught in order for the student to reach an understanding of why it works. However, we as educators must always be alert to the fact that we are not teaching design engineering. In some respects, we are teaching something far more difficult; technical management.

The need to teach mechanical systems holistically lends itself well to teaching visually in a "hands-on" setting. Most students learn faster, and more comprehensively, when technical material is supported and reinforced with a visual model. Furthermore, this type of learning reinforces the critical thinking perspective we are trying to instill in our construction management students. Linking the analytical "left brain" thinking with the holistic "right brain" thinking, will, ultimately, result in a student more capable of "whole brain” thinking. Combining lecture and lab instructional experiences, or "teaching around the cycle", where the relevance of each new topic is explained, followed by a presentation of the basic information and methods associated with the topic, followed by opportunities for the students to practice the methods and to explore applications (Felder, 1996) seems to be the most effective and efficient means to stimulate a systems approach in the construction management undergraduate.

Laboratories in Construction Management Education

The American Council for Construction Education (ACCE), the accreditation body for university level construction programs, specifically states that "the nature of construction programs imposes a need for special types of space and equipment to introduce the student to realistic construction methods and procedures" (Egger, Varzavand, and Shofoluwe, 1992), formally recognizing the need for construction programs to incorporate laboratory experiences into their curricula. Among those schools accredited by the ACCE, however, the spectrum of available lab experiences is quite broad, ranging from traditional drafting and materials testing (especially soils and concrete), to computer labs where project management software is used to teach scheduling, estimating, and spreadsheet management, to labs where full size building structures are constructed (Egger et al, 1992).

Johnston (1990) describes "Living Labs" as controlled learning centers for the student to experience and appreciate the materials used, labor required, and the equipment of construction along with their relationship to the project site as a key element of a construction student's education. He goes on to say that the traditional soils labs and concrete labs are effective only in teaching the student testing procedures to check the quality of the materials used on site, and fail to demonstrate in any meaningful fashion topics such as the workability of soils as equipment moves it or compacts it, different finishing techniques, or the need for workable concrete. The problem addressed by Johnston is how to best train students in the visualization process that they must have to succeed in the construction industry, and how to create value in the construction education process by enabling students to gain experience without requiring unacceptably high levels of actual on-the-job field experiences.

Although not specifically cited by Johnston, the seminal article in integrating lecture and lab courses in construction materials and methods to more closely simulate the actual construction process appeared in Koehler's and Easley's 1988 article on "Using a Building Systems Approach to Construction Materials and Methods Courses." In that article the authors specifically address the problem of students who "do not have a conceptual understanding of the working relationships between the nature of the materials, the equipment required for application, the method of construction, and the jobsite conditions" (Koehler and Easley, 1988). The approach, described as a building systems approach, attempts to integrate the study of building materials with the study of construction methods to encourage the student to approach the construction process from an integrated systems perspective. The effect of this approach should be a heightened awareness of the graduate as construction manager of the interplay of building systems and processes.

Although first introduced in the late 1980s, and expanded upon in the early 1990s, the integrated, or building systems approach to construction education has been adopted by ACCE schools in only a limited fashion (Egger et al, 1992), and has only primarily focused on general building construction. Limited adoption has been more a function of lack of resources than an academic dispute over the worthiness of such an approach. The focus on general building construction - wood, steel and concrete material and structures, on the other hand, is the result of a long-time focus of construction education on the static construction elements - foundations, structures,......., rather than the dynamic building processes such as the mechanical, electrical, and plumbing (MEP) building systems. The emergence of industry demand for a greatly increased offering in MEP construction management education (Lew and Achor, 1994) and (Alter and Koontz, 1996) forces construction educators to intensify the effort to incorporate a building systems approach as the most effective means of educating students on the dynamic processes of buildings.

Implementation Problems-HVAC Laboratories

In spite of the great need to incorporate lab experiences in the MEP construction management curricula, the relatively new focus on the teaching of mechanical and electrical systems in the context of construction management presents some problems. Historically, mechanical and electrical systems were taught by the respective engineering departments, leading to the attitude in construction management that mechanical and electrical systems were areas for which someone else was responsible. During our careers in construction, most of us have encountered the construction manager of a large commercial project who literally refused to open the plans to the "M", "P" or "E" sheets because they were too confusing or poorly understood.

This attitude has proven itself to be defective. Industry demands for construction managers specifically trained to operate in the mechanical and electrical segment of the construction industry have risen dramatically. Additionally, industry now expects all construction managers to have the ability to coordinate and supervise the mechanical and electrical trades in the construction process. This is not possible, of course, without possessing a strong fundamental knowledge of mechanical and electrical systems.

Due to the only recent focus on mechanical and electrical systems in the construction management environment, there are relatively few mechanical and electrical laboratories developed specifically for construction managers. Many existing laboratories described as mechanical or electrical were often developed within construction technology programs. It should be no surprise then that these laboratories have a tendency to focus more on the *components* of the mechanical systems, rather than the installation, operation, and performance of such systems. Historically, courses in the MEP area were "often classified as technical emphasizing design and operational topics while ignoring the subcontractors project coordination issues and installation methods. The courses should include a focus on materials, methods, sequence, and technical interface phase" (Mouton & Johnston, 1989). Further, the experiments and demonstrations used within these laboratories tends to revolve around those skills required in a technology environment, not a management environment.

This particular problem is accelerated by the texts and other materials generally available to construction management students. The vast majority of all texts were specifically written by design engineers for design engineers. This is not to say these are poor texts. Quite the contrary; they are often excellent texts..... for design engineers. It is no wonder then that many construction management students become confused about the focus of a mechanical systems course and immediately get bogged down in the technical design aspects of the material.

A final problem that plagues most institutions is, of course, resources. Most universities have severe space shortages to speak nothing of the financial shortages that drive many of the problems, and solutions, facing higher education. Simply put, allocating precious resource space for a mechanical systems laboratory, which requires more space than more traditional academic uses, is not a priority at most institutions.

Model Laboratory Implementation

Both Purdue University and the University of Nebraska have spent a considerable amount of time and effort in addressing the problems encountered in teaching mechanical systems within existing construction management programs. We have found, through research, trial and error, experience, and good fortune that students invariably achieve a more comprehensive knowledge of mechanical systems if the text and lecture material is supplemented with visual examples and demonstrations.

In discussing this problem with practitioners of related fields, most notably those in facility management and technical repair and service, we have found that they are struggling with the exact same problem; i.e., how best to impart a fundamental knowledge of mechanical systems to students with no previous background in the industry. From this recognition of a common problem we realized that if we could effectively teach the fundamental knowledge of mechanical systems to students, it could be used as a platform for specialized education in a number of different, but inter-related fields**.**

Furthermore, we realized that by forming a partnership between several different branches of the construction industry, we could overcome a number of our common problems. Out of this realization came our proposed model for an HVAC laboratory.

Partnering with Campus Facility Management

Seeking out an alliance or partnership with campus facility management may be the optimal choice in creating value for the university when incorporating MEP labs into the curricula. If the construction management department is to offer practical MEP lab experiences it must overcome the obstacles of lack of physical space and limited access to operational MEP systems. Facility managers, on the other hand - campus or otherwise, are constantly seeking to find ways to provide continuing education opportunities on constantly evolving and technically sophisticated MEP systems and controls, and training experiences on non-critical systems for new employees. Finding a way to combine resources to meet these needs provides an obvious marriage between the two parties.

Model Laboratory at the University of Nebraska

The first step in developing a model laboratory is acquiring the space for the laboratory. At the University of Nebraska. through a partnership with Facility Management, the department was able to obtain a working HVAC equipment room to use as a working laboratory.

Modifying an existing mechanical equipment room to serve as a laboratory solved a number of difficult problems. First and foremost, this overcame the problem of acquiring a new space or renovating an existing space, a difficult economic problem, if not a difficult political problem. We found that laying claim to a working mechanical room rarely produces any competition between departments, as would often be the case with the acquisition of more traditional classroom space.

This concept of using an existing mechanical equipment room, or, for that matter, a whole building, as a working laboratory is not new to higher education. For example, the University of Nebraska Board of Regents is currently considering a design for the new Information Science, Technology and Science Building on the Omaha campus that "will be similar to walking through a textbook". This design envisions exposing various structural, mechanical and electrical components of the building and using monitors and stations placed throughout the building to literally turn the building itself into a working laboratory.

The model laboratory should also be of newer design, if at all possible. Typically, a newer design will incorporate equipment and systems of higher efficiency and proven reliability and, clearly, will better represent mechanical equipment rooms the students will actually encounter in the industry. Additionally, a newer equipment room frequently contains space for future expansion that oftentimes is never used. Hence, the laboratory is apt to have more floor space.

The model laboratory should also contain as many different elements of the heating, ventilating and air-conditioning systems as are available on campus. This is usually not a problem, as most universities employ a central system to provide steam and chilled water to remote air handling units. Therefore, most equipment rooms will contain an air handling unit, a simple steam to hot water converter, a pump or two, an air separation system with expansion tank, a condensate pump and other miscellaneous equipment. With the general acceptance of ASHRAE Standard 62-1989 on ventilation, most newer air handling units have ample provisions for outdoor air intake, along with relief air or exhaust air provisions as well.

One distinct advantage of using an existing equipment room as a HVAC laboratory is the flexibility it affords. For example, one concept most construction management students have trouble understanding is how steam "moves" in a system and what role steam plays in the big picture. Having a working steam fired heat exchanger available, along with a cutaway of the same type of heat exchanger or other similar diagram, the student can begin to visualize, in their mind, what must be happening inside the heat exchanger. Now, by adding a high temperature glass steam trap and high temperature glass piping to the condensate drain side of the heat exchanger, the students can actually see the condensation formation and how the condensate leaves the heat exchanger for its' return to the boiler. Finally, by adding temperature and flow sensors to the hydronic side of the heat exchanger, the student can measure the amount of heat transfer to the fluid. The student begins to build the system as a whole in their mind. A change of phase from gas to liquid......., a transfer of energy........, delivering that energy and conditioning an occupied space.........., - mentally, a system is born.

Both facility management and industry can build off of this same systems foundation. Again, as an example, facility management has a great deal of difficulty training their new technicians how to troubleshoot and repair various steam devices, such as steam traps. With the addition of a by-pass line around the high temperature glass steam trap, the addition of a float and thermostatic trap or perhaps a bucket trap, and facility management has their own test stand suitable for teaching their service technicians how to troubleshoot and repair steam traps. The difference in using a model laboratory for this purpose is that the knowledge of how to troubleshoot and repair steam traps is built upon the fundamental knowledge of how and why steam works, thus preparing the facility management service technician to apply the same knowledge to a wide variety of steam devices. In this manner, the HVAC laboratory serves a dual purpose.

Model Laboratory at Purdue University

Purdue's existing curriculum supports the full scale construction of a wood frame, steel frame, and concrete structure each semester. Currently the mechanical and electrical specializations incorporate lab experiences into those structures each semester. This provides opportunities for all students involved to recognize an integrated building systems approach combining the traditional structures approach to the construction management lab experience with the dynamic interface of the installation of electrical and mechanical systems. At this time due to curriculum, space and time constraints, the effective value of incorporating electrical and mechanical lab experiences is limited to an integrated materials and methods approach. While important, and effective in providing specialty subcontracting management experiences for the student, fully operational systems experiences are severely limited.

For several years now, the department has looked at various equipment room spaces in the building housing the department, and has been offered space within the building to create a mechanical/electrical lab. Significant MEP contractors and major equipment suppliers have been involved in the brainstorming process to create the optimal laboratory setting. Some of the criteria considered important include the opportunity to install and operate mechanical and electrical building systems in full scale models, the ability to provide education in specialized MEP systems, and the ability to examine the benefits and detriments of the various choices of systems from installation, operational, and maintenance perspectives. After continuing examination the ad hoc committee tasked with creating the lab decided that the existing spaces offered were too limiting for the objectives desired.

With three major construction associations representing over 7000 companies supporting the development of construction management specializations in electrical and mechanical construction, however, and a goal to continue to be successful in providing quality education to undergraduate and graduate students, and practicing professionals, the department has identified a need for a new laboratory and continuing education facility. The facility will be used for teaching mechanical and electrical construction management and continuing education for Purdue students, Purdue Physical Facilities personnel, Construction Associations continuing education programs, and individual construction firm's customized training programs.

Some of the criteria and characteristics of the new facility are:

- The facility will be a joint effort between Purdue Physical Facilities and the School of Technology.
- The proposed size of the facility will be between 30,000 and 40,000 square feet with large, open, and flexible spaces with high bays, classrooms, continuing education training rooms, and computer instruction capabilities.
- All students in the major will have classes in the facilities.
- The facility will incorporate the use of state of the art communications and voice/data transmission to the "home office".
- Professional assistants will be hired to assist with both lab and continuing education functions.
- Design and construction costs will be minimized, with the primary funding coming from the construction industry.
- The facility will be used for undergraduate and graduate education, outsourced training for major mechanical and electrical equipment manufacturers, and construction industry continuing education training.

Both the Nebraska and Purdue models offer benefits and restrictions, but both also serve to illustrate effective approaches to actively incorporating mechanical and electrical laboratories into the construction management education curricula. Other ACCE departments should not consider Nebraska and Purdue simply fortunate enough to have the resources available to have construction laboratories "in which the student can actually build a project and observe construction management concepts" (Andersen & Andersen, 1993), and commiserate about those construction programs with limited resources. They should actively seek out partnerships with campus physical services, creatively offering to add value to both entities. All campuses have underutilized equipment rooms simply waiting for creative exploitation.

Partnering with Industry

Partnering with industry is critical to the success of any model laboratory. As written (Payne, 1997) the tangible benefits of industry/academe partnerships in the field of engineering education, equipment manufacturers, contractor associations, and individual contracting firms will have a vested interest in the endeavor to create successful mechanical and electrical construction labs. All will want to influence what and how construction management students are taught, all will want to keep abreast of trends in construction management education and research, and all will want to determine the best schools from which to recruit future employees.

Industry will want to be involved in the design and development of the laboratory, inasmuch as industry will also be using the laboratory for their own teaching purposes, such as the example previously given concerning the repair and troubleshooting of steam traps. Major HVAC manufacturers have approached Purdue in a quest to outsource some of the technical dealer training required in order to keep their dealers current on the latest HVAC technologies. Consider the symbiotic benefit to the undergraduate students should this occur. Additionally, industry is also an invaluable resource for many of the components of the laboratory that would not otherwise be available. For example, manufacturers are often very generous with displays, equipment cutaways, literature, submittals, and other materials that can be used to good effect in a laboratory setting.

With the lab, manufacturers and physical plant employees will be able to examine the attributes of various alternate products and materials. As in the steam trap example discussed above, with a few minor alterations in the steam trap test stand industry representatives can demonstrate the differences in the various types of steam traps and their relative advantages and disadvantages depending on the application.

Curricula

With the addition of laboratory experiences in the mechanical and electrical construction education experience a tremendous amount of flexibility in the curricula is introduced. This flexibility manifests itself in many different ways. With just a minimum of mechanical equipment, technical demonstrations and experiments can easily be developed for many fundamental HVAC processes, including psychometrics, heat transfer, pumping and fan laws, air delivery and conditioning, temperature control, and HVAC systems selection.

In addition to basic technical instruction the lab setting allows you to physically demonstrate and experience value engineering options and constructibility studies that are technically based and economically derived, encouraging the students to "develop a relevant decision process that will serve their professional needs as a negotiating conduit between Owner's Architect/Engineer, the General Contractor, and the Specialty Subcontractor" (Mouton & Johnston, 1989).

Well prepared and executed lab experiences will go beyond the purely technical elements of mechanical and electrical construction. Lab exercises should be designed to include all elements of the construction management process including:

- Cost & resource estimates.
- Scheduling requirements including manpower loading.
- Pre-fabrication opportunities & advantages.
- Scope identification.
- Safety awareness.
- Preparation of comprehensive materials, tools, and equipment lists.
- Recognition of the technical information and project documents required in the installation of similar projects.

- Preparation of an outline of the sequence of the entire process and the specific steps of the construction activity.
- Design of a checklist to monitor the quality of the construction process and product.

Benefits and Outcomes

There are numerous benefits in utilizing an HVAC laboratory in a construction management curriculum. Clearly, the first benefit accrues to the students in that they are gaining a much broader and applicable education, in a format that will be easier for them to understand and comprehend. Students interviewed after concluding a mechanical systems class which utilizes a visual approach to learning, rarely fail to mention the importance of actually seeing the devices and systems they are studying.

A second important benefit is obtained by industry. Not only do they have access to construction management students with a solid background in the fundamentals of mechanical systems, they also have access to a laboratory that can help further their own industries development.

A third, and perhaps tangential benefit that has been observed revolves around the development of a student's understanding of what is involved in laying out, constructing and installing the various aspects of a mechanical system. Hand in hand with this new understanding, the student inevitably gains a new respect for the craftspeople responsible for the installation of the work. From this basis of respect, the student will find it much easier to understand, communicate and, therefore, manage those workers.

Recommendations

As funding resources become more limited throughout our society, it is imperative that we as educators find better, more cost effective ways of teaching. Using the environments that surround us is one way in which we can increase our effectiveness without increasing our costs in delivery.

Additionally, we have to become more adept at using all of the resources available to us. Particularly those resources, such as the mechanical and electrical construction industry, that are currently under-served by higher education.

Finally, greater effort needs to be made in solving similar problem in related industries by promoting partnering agreements. By combining the resources available in industry, education and management, far more is possible than if each attacked their own problems separately.

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