The Laboratory Component of a Climate Control Course in a Construction Management Program

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A laboratory sequence was developed to support a Climate Control course in a construction management program. Studies have been conducted (Koontz and Alter, 1996 and Wentz and Alter, 1997) on topical areas needed to be covered in a course and laboratory dealing with climate control. However, there are no published papers that detail the content and delivery method of series of laboratories to accomplish these topical areas. The laboratories developed consist of field trips, working with equipment and demonstrators and plan reading exercises. Topics covered in the laboratories include system identification, installation and installation concerns, equipment specifications and submittals, plan reading and evaluation of shop drawings, scheduling, trade coordination and mechanical system estimating. The purpose and a detailed description of each laboratory are summarized in the paper. A self-assessment form has been developed to evaluate the effectiveness and the appropriateness of the laboratories. The evaluation system was tested during the Fall 2005 and Spring 2006 semesters and analyzed using a 5 point Likert scale. The results of the analysis show student evaluation of all the laboratories ranging from 3.16 to 4.23 with 1 being poor and 5 being excellent.

Keywords: Laboratories, field trips, plan reading, climate control course, air conditioning course

Introduction

Laboratories provide active learning and enhance the student's ability to remember and understand material. Benefits for students include: motivation to learn; enjoyment of learning; skill proficiency; independent thinking and decision making. In addition, students are better able to articulate what they have learned based on their laboratory experiences. (Dori and Belcher, 2005)

In a construction management program, laboratories serve the valuable function of illustrating in a practical forum the theory and methods of construction. Perhaps the most efficient course delivery method is to integrate the laboratory into the course lecture, such that laboratories support lecture concepts in a timely manner. Textbook reading assignments also need to be coordinated with the laboratory work.

Important topics to include in a course in Climate Control have been identified by surveys conducted by Koontz and Alter, 1996. Koontz and Alter conducted surveys of educators and contractors and the results were compared to arrive at topics for a course in Climate Control. Scheduling and coordination were considered to be the most important topics by both groups. The remaining three of the top five issues listed by educators were piping materials and methods, HVAC equipment and plumbing. Contractors listed scope of work issues, mechanical construction terminology and shop drawing review and understanding as their remaining issues. Wentz and Alter, 1997, supported the results of the Koontz and Alter study and proposed the concept of using an operating mechanical room as a teaching laboratory.

The purpose of this paper is to share how to take these topics identified by educators and contractors and develop the actual laboratories in a coordinated delivery system to support a climate control course in a construction management curriculum. Course goals need to be clearly defined to accomplish this integration of lecture and laboratories. The primary goals of the course are: operation of climate control systems in residential, commercial and industrial buildings; understanding how a refrigeration machine works; understanding the operation of air and water distribution systems; and the estimating, specification, submission, approval, and installation of systems. These topical areas support the results of the Koontz and Wentz studies.

Laboratory Philosophy

The course lecture primarily serves as the vehicle to discuss terminology and theory of equipment and installations. The laboratory is the physical extension of this forum. The laboratories are arranged so that students get to experience the topic as they are covered in the lectures. The delivery method varies (field trips, use of equipment demonstrators, use of test equipment, plan reading) while serving to reinforce other laboratories and the lecture.

The order that topics are covered in the laboratory needs to be coordinated with the lecture so that the two methods of delivery compliment each other. The lectures cover: introduction to comfort; basic air conditioning definitions and terms; introduction to air-side; residential and commercial equipment; equipment location and installation; refrigeration systems; psychrometrics; measuring air flow and air pressure; air distribution; and principles of heat gain/loss in buildings.

Laboratory Description

The ten laboratories conducted are described in Table 1. The order of the laboratories shown is the sequence that they were covered during the semester. The first three laboratories are meant to introduce students to what mechanical equipment looks like and some of the considerations of installing this equipment. For example: students see the suction and liquid line of a split system air conditioner during the first lab. Later in the semester, students will learn the purpose of these lines, how to size them and how the lines change function if the system is a heat pump. The actual operation of the refrigeration system is only briefly discussed because this will be covered in more detail in a later laboratory and in the lecture. The air handler for a 40,000 ft^2 academic building is also visited on the first field trip. Provisions for outside air, air return and air supply are identified along with chilled and hot water lines. Connection points to the campus chilled-water and hot-water systems are identified. Clearances are noted for access doors on the units visited during lab 1, 2 and 3 since clearance for access doors during installation is one of the objectives of a plan-reading lab (lab #4). Some of the limitations of lab 1, 2 and 3 are the noise levels and cramped conditions in mechanical rooms often make it difficult for students to hear and see. The experience of seeing actual operating equipment during the first three laboratories gives students the background to visualize equipment that they see on plans in quieter environment of the laboratory.

In the submittal lab (lab #4), students are shown a short (ten slide) presentation of the installation of a 10-ton air handler with a chilled water and a direct expansion (DX) coil. This system is being used for the telecommunications room in a hospital and redundancy in the system is considered to be critical. Since students are already familiar with what equipment looks like, they are able to bridge between the installation photographs, the provided submittal of the equipment and the construction plans. Students have the task of answering a number of questions for the installation of the unit. Questions involve a critical examination of the equipment submittal to the get unit dimensions from different views because the equipment needs to be installed in a location with limited access. The location of chilled-water and hot-water piping connections, condensate line connections and location of access doors needs to be checked to insure that everything can be installed without conflicts.

Lab #5 varies the pace of the laboratory experience and allows the student to take initiative on the operation of refrigeration equipment. Students visit a manufacturer's web site to observe the availability of information on-line. This also gives the student the chance to explore refrigerants used, capacities and configurations available, and acoustical information. The refrigeration lab (lab #6) and the psychrometrics lab (lab #8) are done with an equipment trainer. In the refrigeration lab, students take pressure, temperature and refrigerant flow rate data and create a pressure-enthalpy diagram for a 0.5 ton refrigeration unit. From this information, students are able to calculate system coefficient of performance and energy efficiency ratio. In the psychrometrics lab, students take air flow data, and dry-bulb and wet-bulb measurements entering and leaving a direct expansion cooling coil. These data are plotted on a psychrometric chart and the coil sensible, latent and total capacity is calculated. The amount of condensate collected from the cooling coil is taken in a measuring cup and this quantity is compared to calculated amount of moisture condensed by the evaporator coil. The calculated amount of condensate is determined with the measured air flow rate and the change in absolute humidity across the coil.

Table 1 Description of Laboratories

Lab	Purpose	Description
1	What air conditioning systems look like and the size of equipment and space constraints of mechanical rooms.	See the components of a 1.5 ton direct expansion split system. Items observed include: checking name plate information, determining that unit is upflow, filter rack, condensate pan and condensate line, type of evaporator coil and piping, suction and liquid line, expansion valve, and the direct drive blower. Observe the operation of an air handler for a 40,000 ft^2 building. Note the louver for outside air, return air duct and enthalpy wheel for heat recovery. Open the access doors for air filters and note the manometer for determining static pressure drop across the air filters. Identification and observation of the hot water heating coil and the chilled water coil. Opening the access door for observation of the blower. Note room constraints on ductwork. Observe the operation of the variable frequency drives on the supply and return air fans.
2	Continue the introduction to what chilled water air handlers look like and how they operate.	Students observed the photographs of the installation of an air handler with chilled water coil with 115 tons of capacity in lecture. This was installed as a retrofit in a 41,000 ft2 academic building. They saw the staging of the materials and watched the installation on a slide presentation in lecture. The field trip was to see the air handler in place. Students also visit a four zone multizone air handler that uses pneumatic controls. The outside air and return air locations are identified and the mixing box for the air streams is noted. The filter rack and the belt driven centrifugal fan are observed. The hot and cold deck and the dampers for control of the hot and cold air to each of the zones are then seen. Finally the condensate line is located and the depth of the trap is noted.
3	Connection between installed equipment and the construction drawings.	Five sheets of the construction drawings are shown on 11 by 17 inch sheets. Each student is given a copy. The purpose of the field trip is to start making connections between construction drawings of the facility and the actual installation.
4	Critical reading of an equipment submittal and an introduction to plan reading.	Submittal review of the installation of a 10 ton system (chilled water and DX) in the sub-basement of the VA hospital. Concerns include equipment size constraints for installation, size of the equipment slab and access door issues.
5	Visit manufacturers web site to observe product line and critical analyze vendor information.	Student research on a residential unit. Considerations include: efficiency, refrigerant, comfort and sound.
6	Use of an equipment trainer to reinforce concepts discussed in the lecture.	Take pressure, temperature and refrigerant flow rate measurements to determine low side and high side pressure, superheat and subcooling. Determine refrigeration capacity, COP and EER.
7	A perspective on the size and complexity of mechanical systems	Field trip to see chiller plant with six 1200 ton operating chillers.
8	Use test equipment to determine psychrometric properties of air	Use instrumentation for air flow, dry bulb and wet bulb temperatures to determine heat load handled by evaporator in an operating system and calculate condensate removal compared to actual removal
9	Read mechanical schedules on plans	Reading plans of a building using 100% outside air units to feed 100% recirculation heat pumps – emphasis on understanding equipment schedules.
10	Estimate duct cost	Checking for adequate space in equipment room when only single phase power is available and three phase units are specified. Calculate duct weight and cost. Check unit air flow versus delivered air flow to rooms.

The chiller plant (lab #7) visited has six 1200 ton centrifugal machines. It is one of four plants connected to a campus chilled-water loop. The chiller field trip is conducted by the plant operator. The operator shows students the chilled water loop pointing out primary and secondary pumps. The condenser water loop is also shown. Loop temperature and pressure measurements are read off instrumentation and compared with the computer monitoring system in the operator's office. Operation and maintenance of the centrifugal chillers are also explained. Ventilation requirements for the plant are also discussed since the chillers use R-123. Students have the opportunity to walk inside the cooling tower and observe the sump, distribution piping, and condenser water draining through the clay tile baffling system.

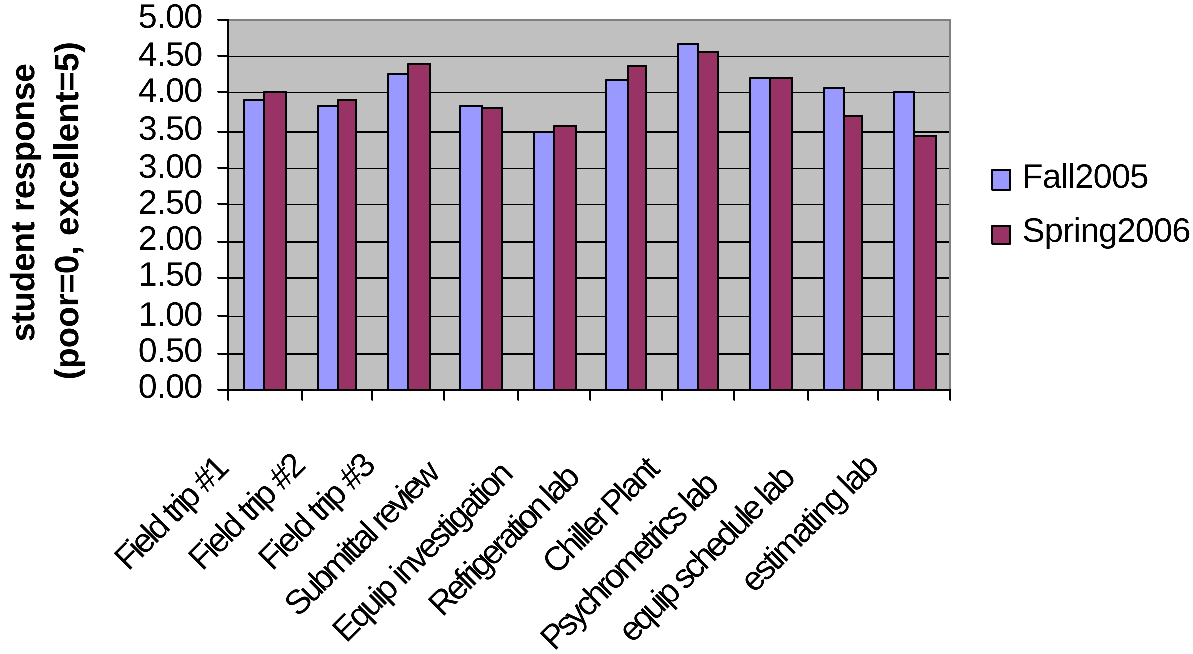
The equipment schedule lab (lab #9) is a plan-reading lab of a child day care establishment that uses 100% outside air units to supply pre-conditioned air to 100% recirculation direct-expansion units. The students are shown slides of the equipment on the building roof and then they locate the equipment on the roof plan on the drawings. The building has two floors. The second floor uses unitary units and the first floor uses split units. The students locate the air handlers for each split unit on the first floor. The students use the schedules to verify electrical information, psychrometric data, fan information and delivered air to zones.

In the estimating lab (lab #10) the students measure the duct work used on a community center, compute the weight of the duct and then price out the ductwork. This lab also involves three-phase air conditioning equipment (specified) to be installed in a location where only single phase power is available. The students need to reconcile how this will affect equipment selection and ultimately mechanical room size.

Results - Rating the Labs

A questionnaire was developed to rate the laboratories to improve them. Results from the Fall 05 and Spring 06 semesters are shown below. The student responses were multiplied by 5 for excellent, 4 for above average, 3 for average, 2 for below average and 1 for poor. The resulting point value was divided by the number of participates to get a value to rate the lab.

Figure 1 Rating the Laboratories



Conclusions and Recommendations

The laboratory sequence, method, and evaluation developed for a climate control course can be modified for courses with both a similar and different focus in a construction management curriculum. The key element is identifying the fundamental concepts of the course and identifying different mechanisms to convey the information in a laboratory forum.

The description of the laboratories shown in Table 1 is an example of how to articulate topical concepts and to help the instructor organize his/her thoughts. Writing out the purpose and description of each laboratory helps the instructor decide on appropriate topics, order and delivery mechanism. The method of delivery and changing the delivery mechanism is very important. Students respond differently to different stimuli. Also, different students respond differently to the same stimuli. This conclusion was supported with individual student responses to the self-assessment document developed for this study.

Small groups are necessary on field trips. Group size for lab #1, #2 and #3 was between 15 and 20 students. The large size of these groups compromised the effectiveness of these laboratories given the noise and cramped conditions in mechanical rooms. Consideration needs to be given in course scheduling to break up a large class into small groups (approximately 5 students) for the purposes of field trips.

Plan reading exercises are most effective when the students are fully involved while trying to solve a problem. The problem can be estimating, scheduling or installation of equipment, using the plans as the tool to accomplish the means.

Student survey results showed that equipment demonstrators (lab #6 and lab #8) were very effective in conveying concepts. Equipment demonstrators (both purchased and site fabricated) are an essential element in creating an effective laboratory program.

Table 2 Rating the Labs form

Please rate the HVAC labs (please consider how the lab contributes to the course and whether it is well executed)	Excellent	Above average	Average	Below average	Poor	Comments, suggestions and/or improvements to the individual labs
Field trip to see the DX air handler and condensing unit in the MEP lab and the air handler with a chilled water coil.						
Field trip Academic Building air handler and the Architecture Building Air Handler						
Field trip to the School of Theatre and Dance with the construction drawings						
Submittal review of the installation of a 10 ton system (chilled water and DX) in the sub-basement of a hospital. Concerns include equipment size constraints for installation, size of the equipment slab and access door issues.						
Equipment Investigation Student research on a residential unit. Considerations include: efficiency, refrigerant, comfort and sound.						
Refrigeration lab. Take pressure, temperature and refrigerant flow rate measurements to determine low side and high side pressure, superheat and subcooling. Determine refrigeration capacity, COP and EER.						
Chiller Plant field trip to see operating chillers and cooling towers						
Use instrumentation for air flow, dry bulb and wet bulb temperatures to determine heat load handled by evaporator in an operating system and calculate condensate removal compared to actual removal						
Reading plans of a building using 100% outside air units to feed 100% recirculation heat pumps – emphasis on understanding equipment schedules						
Checking for adequate space in equipment room when only single phase power is available and three phase units are specified. Calculate duct weight and cost. Check unit air flow versus delivered air flow to rooms.						

Table 3 General Student Comments

Lab	Student reaction
1	Great lab, however, would it be possible to turn off the fan so that we can hear?
2	Demonstration of negative pressure. Equipment room visits were the most beneficial as it takes you from the plans to three dimensions.
3	Good mixture of plan reading with the equipment of a building tour. Good to see how the HVAC system was incorporated into the Architectural design.
4	Very practical and useful for future purposes.
5	Would have been better to investigate an actual piece of equipment, rather than a virtual piece of equipment. Great idea to investigate a site. Relatively easy – break from going to regularly scheduled lab time.
6	Good for homework practice. Learned the most here. Helped with test. Lab where measurements were taken was the most educational. This lab was great because it directly corresponded to what we were doing in class.
7	Really neat. Put it all together. Very helpful for test to actually see a chiller.
8	Good for homework practice. Helped with test.
9	Not as fun as the others. Reading the plans and looking at the specs was the most beneficial.
10	Not as fun as the others. Helped with test. Felt that the plan reading labs represent what we are going to be doing with HVAC in our future jobs.

References

Dori, Y. and Belcher, J. (2005). How Does Technology-Enabled Active Learning Affect Undergraduate Students' Understanding of Electromagnetism Concepts? *The Journal of the Learning Sciences*, 243-279.

Wentz, T. and Alter, K. (1997). Developing a Laboratory for Heating, Ventilating and Air Conditioning Courses. *Proceedings of the 33rd Annual Conference of the Associated Schools of Construction*, 119-126.

Koontz, J. and Alter, K. (1996). Improving an Existing Course in Mechanical Construction. *Proceedings of the 32nd Annual Conference of the Associated Schools of Construction*, 49-54.