

The Evolution of 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. This laboratory sequence was first delivered during the 2005/06 academic year (Oppenheim and Grosskopf, 2007). The laboratory sequence has matured and original laboratories have been modified and new ones have been added. A self-assessment form was 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 again during the Fall 2009 and Spring 2010 semesters and was 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 during the 2005/06 academic year. The results for the 2009/10 academic year were 3.51 to 4.51. The laboratories developed consist of field trips, working with equipment and demonstrators, interacting with professional craftsmen and plan reading exercises. Topics covered in the laboratories include system identification, installation and installation concerns, pipe fitting, ductwork, equipment specifications and submittals, plan reading and evaluation of shop drawings, scheduling, trade coordination and mechanical system estimating. The type of laboratory continuously changes throughout the course so that students do not get used to only one method of delivery. The use of traditional field trips is combined with peer to peer instruction, and use equipment trainers, individual efforts and team building.

Key Words: 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) Experiential learning causes students to rely on the evidence instead of upon authority and forces student to think by requiring interpretation of the observed events, rather than memorization of correct responses; encourages questioning of the observed events and the resulting data; and promotes cause and effect thinking. (Haury and Rillero, 1994)

The challenges of teaching a course in Mechanical Construction and the resources available are well chronicled by Orth, 2008. 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 concept of teaching a Specialty Contracting Construction Management course by integrating a series of laboratories into an applied learning experience has been tried at California Polytechnic State University (Korman, Simonian and Johnston, 2008). The experience of working on plans, specifications, material take-off and cost proposals as a team is emphasized. The delivery method discussed in this paper builds on this approach. Students learn through principles and practices traditionally taught in the classroom by hands on applications.

This paper describes how to take mechanical system topics identified by educators and contractors and develop them into actual laboratories 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 lectures serve 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: i**ntroduction to comfort; basic air conditioning definitions and terms; introduction to air-side; r**esidential and commercial equipment; equipment location and installation; r**efrigeration systems; psychrometrics; measuring air flow and air pressure; air distribution; and principles of heat gain/loss in buildings.**

Laboratory Description

The twelve 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 two 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 1and 2 since clearance for access doors during installation is one of the objectives of a plan-reading lab (lab #8). Some of the limitations of lab 1and 2 are the noise levels and cramped conditions in mechanical rooms often make it difficult for students to hear and see. During the fall 2010 semester, students were shown a “fly through” of the mechanical room created in Revit software prior to their visit. The experience of seeing actual operating equipment during the first two laboratories gives students the background to visualize equipment that they see on plans in quieter environment of the laboratory.

Laboratory 3 and Laboratory 11are delivered in a peer to peer format. This is done by soliciting a group of volunteers who are trained and these people in turn train the rest of their classmates. The purpose of the lab#3 is for students to learn how to thread black iron pipe (figure 1) solder copper pipe (figure 2), use compression and flare fittings, make cross-linked polyethylene connections with special bands, and solvent weld plastic pipe (figure 3). This lab also gives students an appreciation for how the people in the trades actually do their work. Nine students from each of the three laboratory sections are trained on how to accomplish each one of these tasks. Training for these twenty seven volunteers takes about 5 hours. These students choose the pipe joining technique that they want to teach and they work with their peers on an individual basis the next day. The students really like this approach.

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 up flow, 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. Observation of the hot and chilled water coils and the blower. Note room constraints on ductwork. Observe the operation of the variable frequency drives on the supply and return air fans.
2	Comparison of plans and actual installation	Use the construction drawings and visit and operating building and observe difference between the drawings and the actual installation.
3	Make piping connections	Volunteer members of the class are trained to solder copper pipe, make flare and compression connections for copper pipe, make connections for cross-linked polyethylene (PEX) pipe, solvent weld plastic pipe and thread black iron pipe connections. These students in turn will train the balance of the class.
4	Installation of Plumbing Fixtures	A plumbing contractor demonstrates the installation of two toilets, a urinal and a sink and discusses the issues that important to a subcontractor to be successful on a construction job.
5	Dry fit Lab	Draw an isometric plan from a floor plan and assemble a drain, waste and vent system and potable water system for a bathroom consisting of a lavatory, sink, water closet and a floor drain.
6	Use of refrigerant equipment trainers	Take pressure, temperature and refrigerant flow rate measurements to determine low side and high side pressure, superheat and sub cooling. 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	Critical reading of an equipment submittal	Submittal review of the installation of a 10 ton system (chilled water and DX) in the sub-basement of the VA hospital.
9	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
10	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.
11	Use testing and balance equipment	Measure static, velocity and total pressure in an air distribution system. Compute pulley size and speed changes for a blower. Use a flow hood and hot wire anemometer to take air flow and air velocity
12	Ductwork	Make different duct seams (Pittsburgh lock, button punch snap lock and standing seam), connection types (drive, hemmed and standing slips) and hang duct.

Figure 1: Student volunteers teach peers how to thread pipe

Figure 2: Students instruct their peers on how to solder

Figure 3: Students show their peers on how to solvent weld pipe

Not only do the students really understand the techniques of the trades they will be supervising, but they learn some very practical skills. This approach is very time intensive; however, the payoff for the students is worth it. Another peer to peer lab (laboratory #9) is conducted toward the end of the semester using the equipment to test and balance air distribution systems. Student can only volunteer for one of the peer to peer labs so that more people have the opportunity. The training time commitment is the same.

Laboratory #3 (the peer to peer piping lab) is the first in a series of three laboratories for plumbing and pipe work. A plumbing contractor visits the students in the Charles Perry Craft Awareness Center at the Rinker School along with one of his superintendents and a helper for laboratory #4 (see figure 4). The superintendent actually demonstrates to the students how to install a water closet type toilet, a flush-o-meter type toilet, a lavatory and a urinal. Besides doing the installation, the installers discuss coordinating with the other trades. While all this is going on, the plumbing contractor is giving the students a specialty contractor's perspective on submittals, schedules, and shop drawings.

The dry fit laboratory (#5) gives students the opportunity to combine elements of the Piping and Fixture demonstration labs. Students are given a floor plan. Groups of three students draw an isometric of the floor plan, then they assembly the entire drain, waste and vent system and potable water system (see figure 5).

Lab #6 varies the pace of the laboratory experience and allows the student to take initiative on the operation of refrigeration equipment (see figure 6 and 7). The refrigeration lab (lab #6) and the psychrometrics lab (lab #9) 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.

Figure 4: A plumber and his helper demonstrate how to install fixtures in Laboratory #4

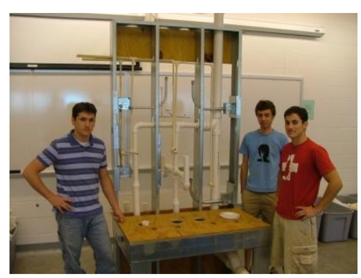

Figure 5: Students dry fit a drain, waste and vent system and plumb the potable water

Figure 6: An equipment trainer with a glass evaporator and condenser

Figure 7: An equipment trainer using an instrumented 0.5 ton refrigeration unit

The chiller plant (lab #7) has six 1200 ton centrifugal machines (figure 8). 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.

In the submittal lab (lab #8), 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.

In the psychrometrics lab (Lab #9), students take air flow data, and dry-bulb and wet-bulb measurements entering and leaving a direct expansion cooling coil (figure 9). 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. This laboratory consists of the student taking data from an operating machine to answer a series of questions. These laboratories are done individually and require the student to apply fundamentals they were taught in the lecture. When complete, the students have an unshakeable knowledge of how manufacturers test determine the seasonal energy efficiency ratio of air conditioning equipment

Figure 8 Pictures taken in front of one of the 1200 ton chillers make popular sovereigns

Table 2 Rate the Lab Form

Please rate the labs and guest lecturers (please consider how the lab contributes to the course, the different lab delivery methods and whether it is well executed)	Excellent	Above average	Average	Below average	Poor	Comments, suggestions and/or improvements for the individual labs/guest speaker
Introduction to Direct Expansion and Chilled Water Equipment Field trip to see the DX air handler and condensing unit in the MEP lab and the air handler for Rinker Hall						
Field Trip with Drawings Field trip to the School of Theatre and Dance (Constans Theatre) with the construction drawings						
Piping lab Soldering, pipe work (threaded, compression, flare), threading pipe, plastic pipe						
Installation of Plumbing Fixtures Tharp Plumbing **-** Installation of two toilets, an urinal and a sink						
Dry fit Lab Draw isometric and assemble a DWV and potable water						
Submittal Review Lab Submittal review of the installation of a 10 ton system (chilled water and DX). Concerns include equipment size constraints for installation, size of the equipment slab and access door issues.						
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 See the operation of six 1200 ton centrifugal chillers						
Psychrometrics Lab Use instrumentation for air flow, dry bulb and wet bulb temperatures to determine heat load handled by evaporator in an operating system						
O2B Kids Reading plans of a building using 100% outside air units to feed 100% recirculation heat pumps – emphasis on understanding equipment schedules						
Equipment Lab Measure static, velocity and total pressure in an air handler. Compute pulley size and speed changes for a blower. Use a flow hood and hot wire anemometer to take air flow and air velocity measurements						
Ductwork Fair Mechanical **-** Make, connect and hang ductwork.						

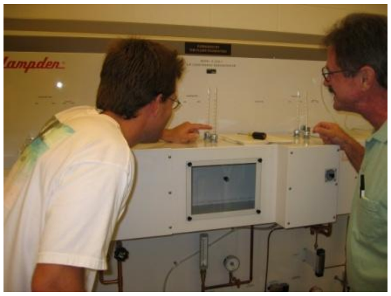

Figure 9: Use instrumentation for air flow, dry bulb and wet bulb temperatures to determine heat load handled by evaporator in an operating system

The equipment schedule lab (lab #10) 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.

Laboratory #11 is another peer to peer laboratory. Student volunteers are trained on using different pieces of equipment and they in turn train their fellow students. In figure 10, the volunteer demonstrates the use of a pitot tube and a micro-manometer to take pressure measurements on a mock air handler. Students gain a better understanding of motor and fan pulley sizes for an air handling system by simulating it with the gear ratios on a bicycle in figure 11. Students perform testing and balance operations in figure 12.

Students have a chance to rate the laboratories using the form shown in Table 2. Even though students rate each lab independently, often a bias of all the labs compared to each other all at once causes students to compare labs.

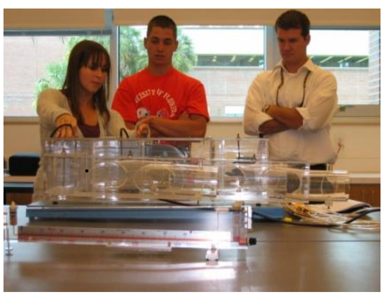

Figure 10: Students instruct students on static, velocity and total pressure with a model air handler

Figure 11: Students use a bicycle to understand speed changes as a function of gear

Figure 12: Students use a flow hood to take air flow measurements from the supplies and returns

Evaluation of the Laboratory Sequence

Six labs were conducted during both the 2005/06 and the 2009/10 and the ratings are compared in figure 13. Six new labs have been added to the sequence since 2006.

In every case the ratings of the same lab in 2009/10 was lower than it was in 2005/06. This is an interesting result because one would hope that the lab would improve over time. An alternative explanation is that the labs are compared to each other, and those labs that have been added since 2006 seem to be more relevant/memorable to the student. The older labs are more of the conventional type labs found in a Construction Management Curriculum. The newer labs incorporate a different delivery style. The lowest rated lab was the O2B Kids lab in spring 2010. This is an essential plan reading lab that emphasis reading mechanical schedules. The rating on this lab was still better than average, and the fact that its numerical rating was less than that of some of the newer labs does not mean the concepts should not be covered. However, it is possible that the material could be delivered in a more creative manner. This is something to look into for next year.

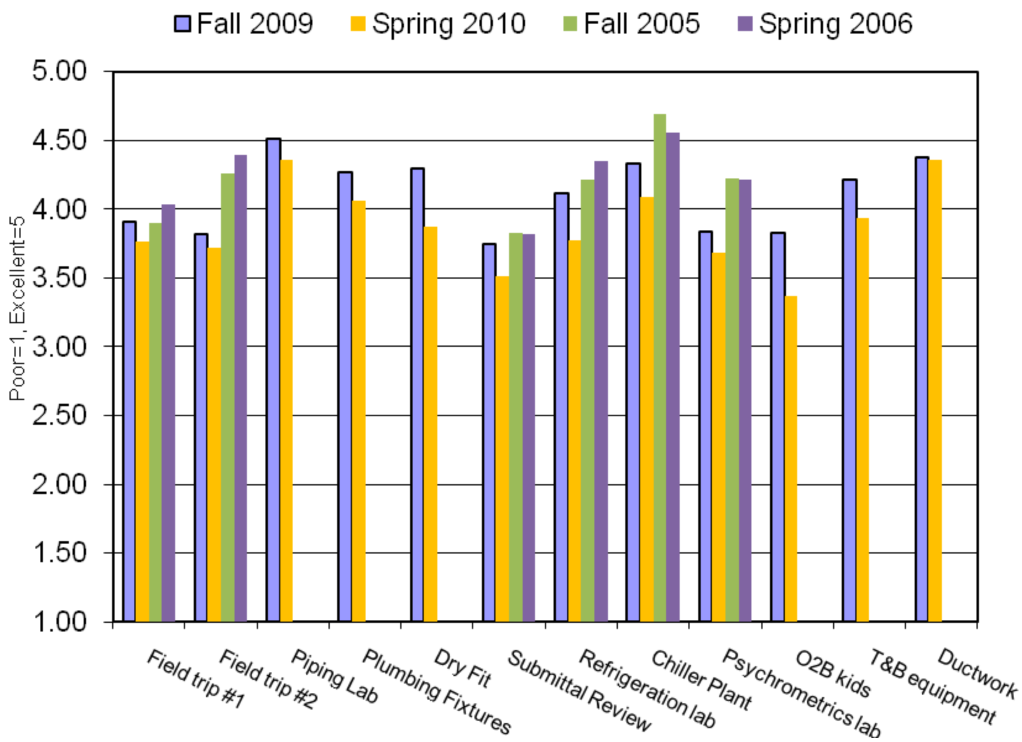

Figure 13: Ratings of the Laboratories for the 2006/07 and the 2009/10 academic years.

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