Incorporating Active Learning into a Thermal System Design Lecture

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Abstract

Many mechanical engineering departments offer a thermal system design (or similar) course for senior students. Some courses have a laboratory component, but many are a lecture only format. This paper demonstrates how active learning—through virtual labs, a semester long project, and in-class assignments—was incorporated into the lecture portion of a thermal system design course to enhance learning and provide the students a laboratory experience without a physical laboratory. These active learning ideas can also supplement the learning during lecture for those courses which have a designated laboratory time. Anecdotal evidence of the activities indicates that students were engaged and enjoyed the active learning activities. Student reflections show that students not only achieved individual learning outcomes—such as analyze thermal system components, design and optimize thermal systems, etc.—but they synthesized them into their project and performed an evaluation, demonstrating they achieved the highest domain in terms of cognitive learning.

Background and Introduction

Thermal system design courses tend to be senior level mechanical engineering courses—either required or as a technical elective—designed to incorporate several aspects of thermodynamics, heat transfer, and fluid dynamics into a single course having an emphasis on design[1,2]. These courses can cover topics that were not covered in fundamental courses as a result of time, and/or go into more detail. Typical topics covered include (but are not limited to, nor do all thermal design courses necessarily cover all) thermodynamic cycles, piping systems, economics, optimization, psychrometrics, heat exchangers, refrigeration systems, power systems, combustion, and numerical heat conduction[1,2].

Including a design emphasis and a design project in a senior thermodynamic course allows for easier integration of the seemingly isolated topics of thermodynamics, heat transfer and fluid dynamics, and will allow for approximation of problems students will see after graduation[1]. Other universities have adopted the use of design projects that are based on a common theme in their capstone thermal courses in order to weave together all the topics presented and make it more interesting for the students[2,3]. A semester long project in a thermal system design course is easily executed in the laboratory portion of the course[4]. However, it is possible to also do a semester long design project in a lecture-only based course as the authors have done and describe later.

Active learning is a broad term and can include a number of different teaching/learning strategies and activities. A general definition of active learning is "any instructional method that engages students in the learning process"[5]. There is evidence that incorporating active learning activities into a lecture does improve student understanding and recollection of concepts[5]; however, "the activities must be designed around important learning outcomes and promote thoughtful engagement on the part of the student"[5]. The authors' use of active learning was designed to get the students thinking about and actually solving problems, rather than passively taking notes. Another example of active learning in the classroom is from Somerton and Genik, who designed worksheets to teach pyschrometrics and reported excellence performance by the students on a quiz covering

psychrometrics[6]. A study comparing virtual labs to physical labs found there is not a bias toward more or less learning based on the laboratory mode[7]. In addition, the study's findings "support the concept that virtual laboratories can facilitate a broader experience for students and can play an important role in engineering education"[7]. It is this viewpoint—and lack of a physical laboratory space—that initially led the authors to design virtual labs for the thermal system design course.

The model for active learning in a thermal system design course was used by the authors for three courses at two universities—one a large research school, and the other a smaller primarily undergraduate institution—in which the course was taught in a lecture only setting. In order to facilitate the activities, the lecture was held in a computer lab for at least one hour per week (out of the 3 hours of lecture time per week, for a minumum of 15 hours per semster), and used Engineering Equation Solver (EES) software. EES was introduced during the first couple of weeks of class so that it could be used throughout the semester. The authors used short in-class assignments, virtual labs, and a semester long project to encourage exploration of the lecture topics by the students.

In-Class Activities

Short in-class assignments can replace examples done in class on the board by the instructor, and allow the students to apply the concepts from lecture in a semi-controlled environment before attempting homework assignments. For the in-class activities—done in a computer lab—the students were asked to complete an engineering analysis, code the equations, and check answers. By working through the analysis on paper and using EES to solve, the students are learning/practicing not only the theory and analysis, but also translating equations into a coded program. Using EES also allows for larger problems to be solved than that could easily be done by hand calculations, including solving problems that require iteration or optimization. Each in-class activity was completed in groups of two. The following are details for two in-class activities: a heat exchanger problem and a piping network design problem.

The heat exchanger problem—shown in Figure 1; full details and handouts are in Appendix A.1—asked the students to determine for a particular application if one large or two equally sized small heat exchangers would be the most economical arrangement if the smaller heat exchangers were more expensive per unit surface area. The students had already been walked through a heat exchanger example in class using the ε-NTU method, and this was the second example, which the students worked through in groups of two in the computer lab. The solution included using the ε-NTU method to find the area of each heat exchanger, do a cost comparison and make a recommendation for the heat exchanger arrangement. The handouts included hints for programming in EES, including how to call and use the ε-NTU routine that is available in the EES library of functions. Since the students needed to start from scratch to program the solution, the 50 minute class period was too short for the students to be able to complete the analysis of both heat exchanger arrangements; however, all the students were able to complete the analysis of the single large heat exchanger. As a result, the students were able to finish the second analysis by themselves as a homework assignment. The solution of the problem was discussed during the next class period.
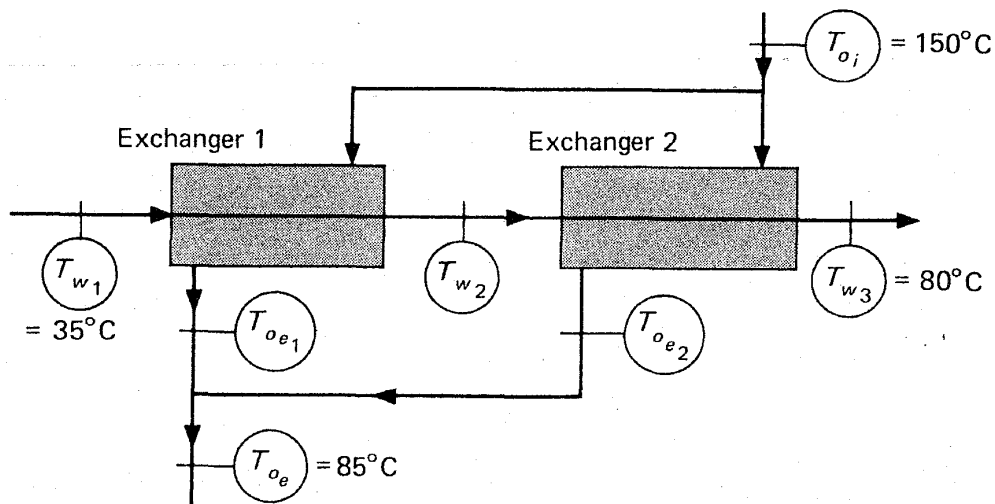
Figure 1: Heat exchanger in-class activity—determine whether one large or two small heat exchangers is best.

For the piping networks example—problem shown in Figure 2; full details and handouts are in Appendix A.2—the given data included the statics pressures at points 1 and 4; and the lengths, diameters and material of the pipes. The students were asked to first find the flow rate through each branch, and then find the resulting pressure drop in each branch for a desired flow rate. The handout to the students included flow rate, Reynolds number, friction factor, and pressure drop equations. However, the students needed to complete the analysis using their knowledge (and help from the instructor) of piping network pressure drop rules and mass balance rules—such as that the pressure drop across parallel branches must be the same. An EES code that was missing equations from the analysis was provided to the students—to be downloaded from the course webpage—and the students needed to complete the code to solve the problem. A solutions sheet was filled out using the calculated flow rates and pressure drop from EES solution and turned in for credit by the students.
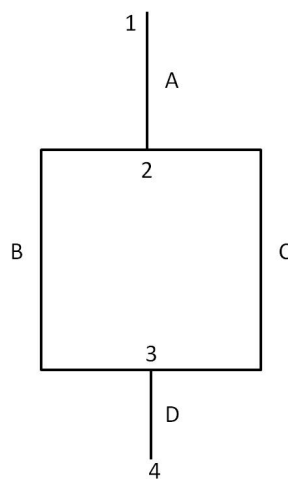

Figure 2: Piping network design in-class activity—determine the flow rate through each branch.

Virtual Labs

Virtual labs are easy to implement in EES, and can be run during the lecture time by the students. A benefit of virtual labs (even for courses having a physical lab) is that costly—both in time and money—scenarios can be explored: such as using different refrigerants in a system, or determining when a system might fail. In addition, virtual labs remove the distractions from trouble shooting laboratory equipment which may "obscure other cognitive objectives"[7]. Each virtual lab was programed in EES by the instructor and utilized the diagram window. The diagram window in EES is a graphical user interface which allows for a schematic or visual representation of the system being investigated and can include radio buttons, check boxes, images, user inputs, and output displays. An executable file was made available to the students, which allowed the students to run the lab but did not give access to the equations programmed to avoid students reprogramming the virtual lab. The following are three examples of virtual labs—Psychrometric, Air handling Unit, and Vapor Compression Cycle Virtual Labs.

The Psychrometrics Virtual Lab—diagram window shown in Figure 3; full details and handouts are in Appendix B.1—asked the students to compare steam versus water injection into a straight air duct that first had a resistance heater. Questions the students needed to answer included explaining why steam or water injection is recommended. The students will discover that—as a result of the first law of thermodynamics—the same total power input is required for both options, but the final questions challenge the students to consider the actual application. For example, students are asked to consider a retrofit to convert an existing steam injection system to a water injection system and comment if the existing heater can be used. Students will find that for the liquid water injection case the amount of power to heat the air before the liquid water injection is twice as high and therefore either a new properly sized heater or two heaters are required. The corresponding states—1, 2, 3—are plotted real time on the psychrometrics chart.
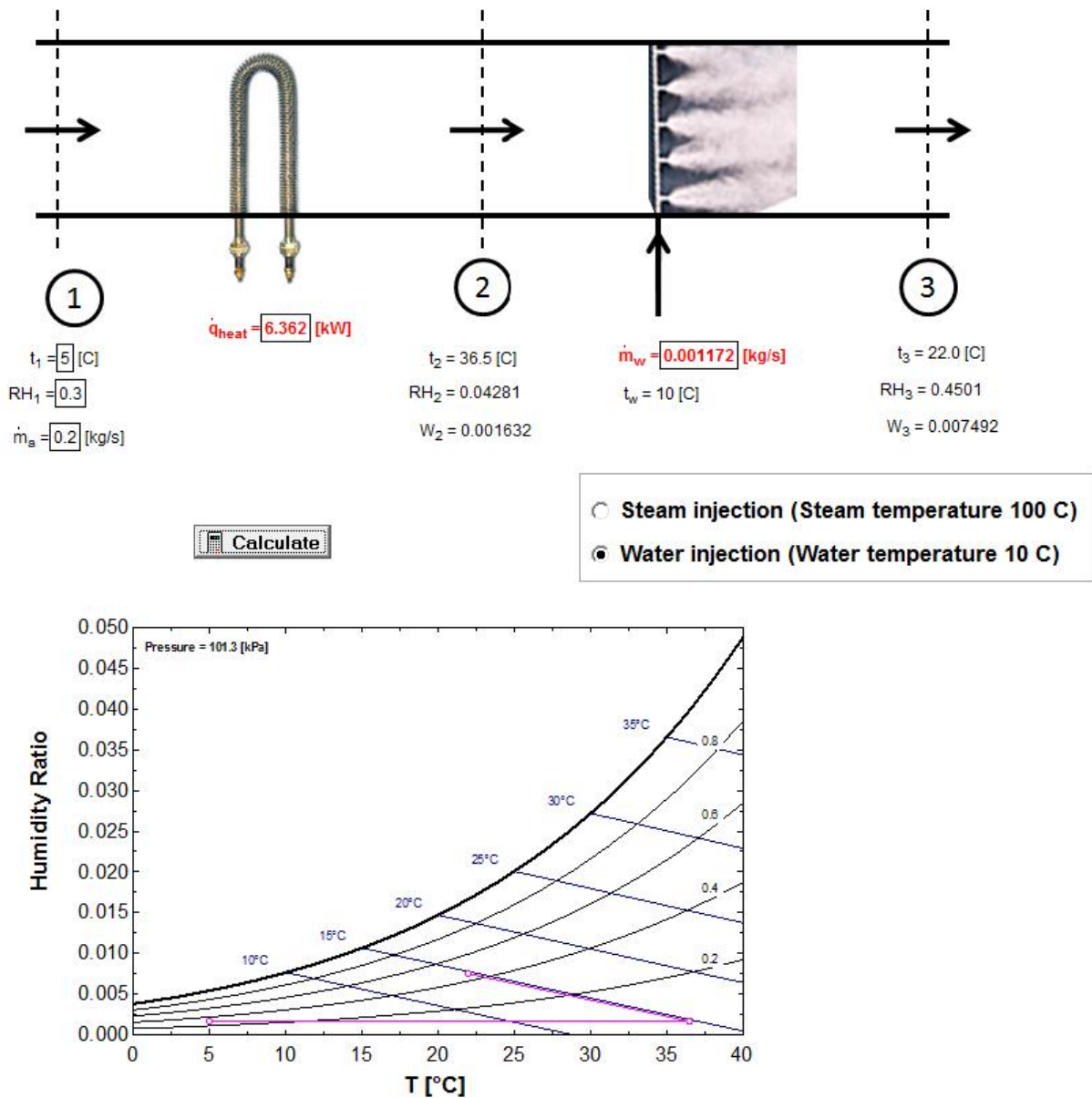
Figure 3: Psychrometric Virtual Lab diagram window

The Air Handling Unit Virtual Lab—diagram window shown in Figure 4; full details and handouts are in Appendix B.2—asked the students to compare an air handling unit being operated in two cities—Anchorage and Miami. The virtual air handling unit is programmed to allow students to choose—besides the location and corresponding outside air conditions—the amount of exhaust air and the setting of a bypass damper to divert a set amount of return air around the cooling coil. As with an actual air handling unit, changing the ratio of exhaust air and/or bypass damper position results in changes of the states and changes in the required energy inputs for the cooling and heating coil—in the real application the building automation system would provide similar information. Although this is a simplified simulation of an air handling unit, students will find that there is an optimum exhaust air ratio and bypass damper setting for each location. One caveat is that for the Miami location, the optimum—lowest energy consumption of cooling and heating coil—occurs

when the temperature after the cooling coil is below freezing. This challenges students to think about the implication of the actual application, namely the potential of frost build up at the cooling coil. Another challenge is to consider the amount of energy saved by the bypass and if students would recommend to install such a feature for an air handling unit in both, one or none of the two locations. Students also will find out that for the Anchorage location a larger reheat coil but smaller cooling coil are required compared to Miami and that they should comment on whether the same unit can be used in both locations. The student were required to write a report on their findings.
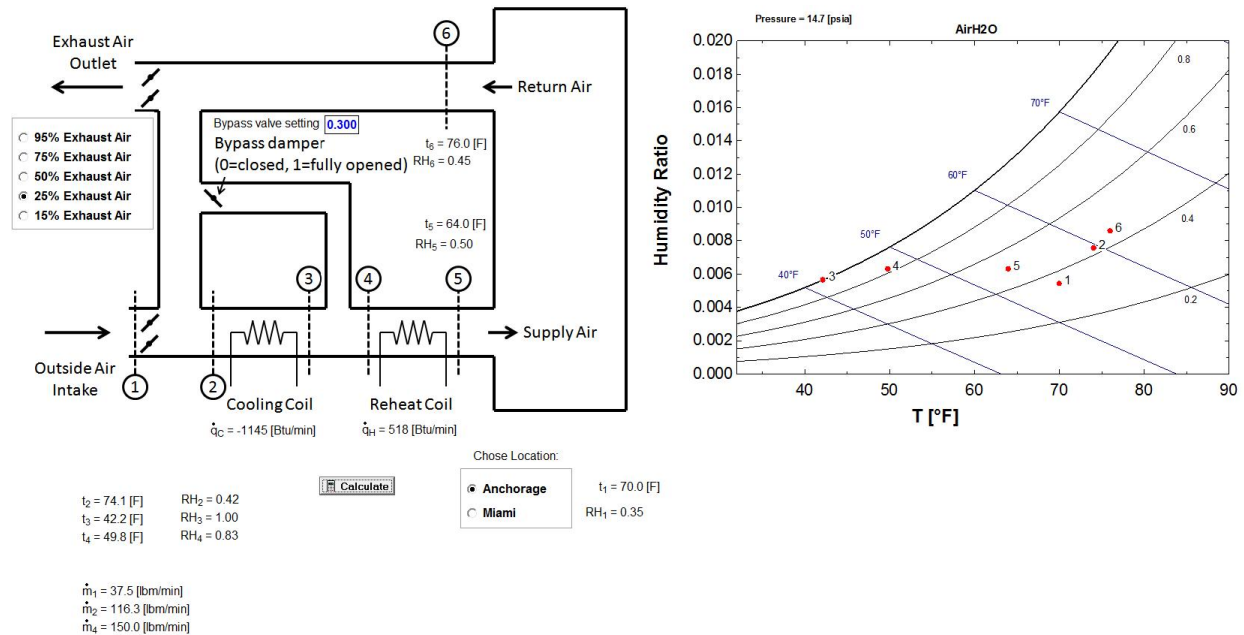

Figure 4: Air Handling Unit Virtual Lab diagram window

The Vapor Compression Cycle Virtual Lab—diagram window shown in Figure 5; full details and handouts are in Appendix B.3—asked the students to compare an ideal vapor compression cycle to a vapor compression cycle utilizing a realistic isentropic efficiency for the compressor, and to a system using a suction line heat exchanger. In addition the students were asked to explore the effects of choosing different refrigerants—five in this case—on the system performance. This virtual lab provides students with an understanding of the difference between assuming an ideal vapor compression cycle to a vapor compression cycle utilizing a realistic isentropic efficiency. In addition, students learn that using a suction line heat exchanger can enhance the performance of vapor compression cycle—but not for every refrigerant. An actual physical lab with five different vapor compression systems having the option of being run with or without a suction line heat exchanger including all instrumentation is not only costly and difficult to setup, but to perform all the measurements would take several class sessions. The virtual lab allows the investigation to be accomplished in only one class session. The student were required to write a report on their findings.
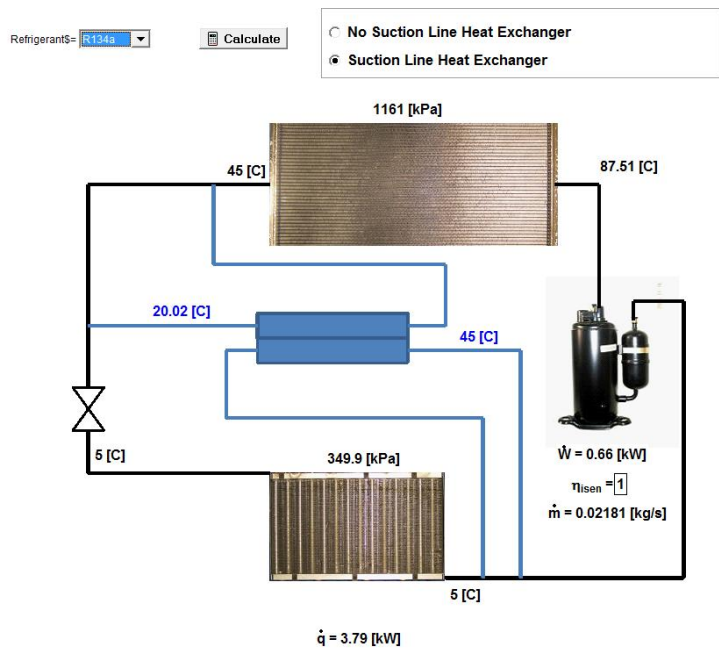
Figure 5: Vapor Compression Cycle Virtual Lab diagram window

Projects

A semester-long project that is guided and worked on during lecture not only gives the students an opportunity to incorporate the lecture topics into one working model, but also gives the instructor time to work with the students in class to answer questions and ensure the students are on the right track toward a solution. A thermal system design course can be organized such that lecture time is used to allow the students to work on their project in class if a designated laboratory time is not available. For the courses described in this paper, class was held in a computer lab when class time was devoted to working on the project (or virtual labs and class activities). The semester long project was broken into smaller, manageable parts or sections and each section was introduced to the class approximately every other week. The sections depended on each other, such that each new section depended on the solution from previous sections. Therefore, students had to keep up with the project in order to continue work on each new section. The project lectures were integrated into the regular lectures such that the topics and knowledge needed for the project were related to the topics discussed during typical lectures. In this way the course flowed nearly seamlessly between project discussion and other lecture topics.

The students worked in groups of two for the project and the same project was assigned to all groups. Although, only one project topic was used each semester, the multiple variables and design decisions that needed to be made by each group resulted in a unique solution for each group. Each group was required to turn in progress reports, and a final report outlining their calculations, design, and recommendations about whether the design should be used.

The authors chose for the semester long project to have the students design a snow melting system for a driveway. The project was broken into the following sections/topics: heat load calculation, 2D conduction model of the driveway and piping system, heat transfer in pipes and pressure drop,

heat pump condenser design, total system pressure drop and pump selection, system control, and cost estimation. The complexity of a design project, and time available in class to devote to the project will dictate the topics and how the project is organized. The students were also required to turn in progress reports throughout the semester, which gave the instructors an opportunity to check the calculations and make sure each group was on track to complete the project.

Discussion and Conclusions

Incorporating active learning into a thermal system design course can give students more hands on experience than a lecture only format. Using the computer lab during lecture for a senior level course was not typical at either school and seemed to work well to be able to teach thermal system analysis using EES. Instead of expecting students to learn and use EES on their own, having the lecture held in a computer lab gave the instructors the opportunity to not only demonstrate how to use the program, but also give the students a chance to ask questions while working on in-class activities or the project. The experience of using in-class exercises indicates that it is best to provide the students with partial code, and have the students add in the missing code from their analysis. This allows the instructor and students to focus on the physical aspects of the problem—for example adding conservation of energy and mass equations correctly—instead of spending lecture time typing in variables names and initial conditions. This also helps the instructor when answering student questions during lecture since, e.g., variable names are consistent among groups. The instructors observed that during the in-class activities the students were all discussing the material with their classmates, and asking questions. In addition, interactions with the instructor were amplified. Compared to the typical lecture time, the students were more engaged during class, and overall it was an enjoyable experience for the instructors.

Virtual labs provide students with a laboratory experience without a physical laboratory. But even if there is a physical laboratory available, virtual labs can be useful in supplementing the actual experiments. As shown for the air handling unit and the vapor compression cycle virtual labs, accomplishing the same learning outcomes in the same amount of time is impossible, and it is unlikely that an actual air handling unit and five different vapor compression systems are all available in one laboratory space. The possibility EES provides with the diagram window—to provide students with a graphical user interface—and the integrated physical properties of many fluids and materials makes EES an ideal tool for virtual labs for thermal system related courses.

Based on student feedback—gathered at the end of the courses—students stated overall that they enjoyed the semester long project, the virtual labs, and learning EES. An additional method to further help students in learning from their projects is to have the students write a reflection on the process they used to come to their design solution. The reflection was offered as an option for extra credit. While the project was a group effort, reflections were written individually and approximately 31 percent of the students submitted a reflection. The students who did the reflections indicated that they:

- learned the importance of group work and collaboration
- had fun doing the project
- learned about the relationship between engineering design and economics and how to optimize a system

- learned about project management and time constraints and how they affect the design
- better understanding of the importance of technical writing
- reflected on how to improve their design, something which will be required of them on their job—learn from past designs to improve future designs
- better understanding now of fundamental concepts since they applied them to an actual design
- learned how different variables—mass flow rate, temperature etc.—affect the design
- finishing the project boosted their confidence to tackle future projects
- were proud of their design
- had additional motivation for the course because they designed an "actual" system

The reflections show that students not only achieved individual learning outcomes—such as analyze thermal system components, design and optimize thermal systems, etc.—but they synthesized them into their project and performed an evaluation, demonstrating they achieved the highest domain in terms of cognitive learning. Whereas the student course feedback evaluation forms typically only evaluate the individual achievement of individual learning outcomes, the reflection gives further insight into the level of student cognitive learning, and is therefore recommended to be added as a required part of the project.

In conclusion, active learning was successfully incorporated into the lecture portion of three thermal system design course taught at two universities by using in-class assignments, virtual labs, and a semester long project. In-class assignments allow the students to actively apply the concepts introduced in lecture. Conducting the in-class activities in a computer lab and using EES has been found to be an effective method. By working through the analysis on paper and using EES to solve, the students are learning/practicing not only the theory and analysis, but also translating equations into a coded program. The semi-controlled environment—the instructor being able to help students on the spot—helped students to better understand the concepts before attempting homework assignments. Virtual labs provide the students a laboratory experience without a physical laboratory and allow for more complex investigations which would be cost and/or time prohibitive with actual laboratory equipment. A semester-long project that is guided and worked on during lecture not only gives the students an opportunity to incorporate the lecture topics into one working model, but also gives the instructor time to work with the students in class to answer questions and ensure the students are on the right track toward a solution. Incorporating active learning into a thermal system design course can give students more hands on experience than a lecture only format. The students learn about team work, and professional writing while doing the semester long project, as well as take an active role in their learning for the semester.

Appendix A.1

Heat Exchanger In-Class Activity

Directions

In groups of two solve the following heat exchanger design problem using EES.

Deliverable

Per group, fill out one solution sheet (attached). The answer sheet is set up such that you can fill it out as you go, and gives you a hint to the order of equations you can solve as you determine a solution, i.e. you can solve as you go along, not just at the end.

Problem

A counter flow heat exchanger is used to heat 1.25 kg/s of water form 35 to 80°C by cooling an oil (specific heat of 2.0 kJ/kg°C) from 150 to 85°C. The overall heat transfer coefficient is 850 W/m²°C. A similar arrangement is to be built at another plant location, but it is desired to compare the performance of the single counterflow heat exchanger to two smaller counter flow heat exchangers connected in series on the water side and in parallel on the oil side, as shown in the figure. The oil flow is split equally between the two exchangers, and it may be assumed that the overall heat transfer coefficient is the same as the larger heat exchanger. If the smaller exchangers cost 20% more per unit surface area, which would be the most economical arrangement: one large heat exchanger or two equally sized small heat exchangers?
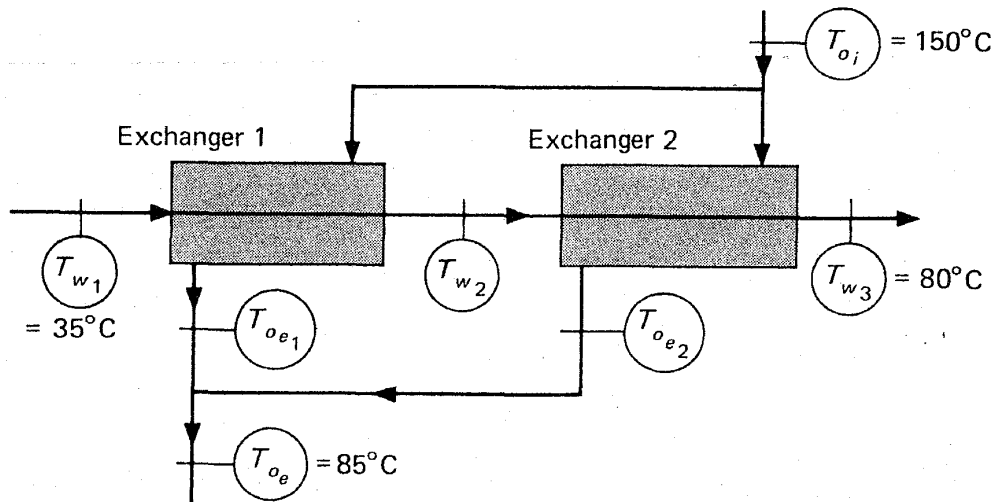
Notes and Hints

1. Don't forget to enter and check units throughout the process.

2. It may be helpful to have two EES documents—one for the large heat exchanger analysis, and one for the two small heat exchangers analysis

3. NTU-ε routine in EES:
   NTU =HX(TypeHX$,epsilon,C_1,C_2,'Ntu')
   epsilon=HX(TypeHX$, Ntu, C_1, C_2 , 'epsilon')

   For most HX types, it does not matter which fluid is C_1 or C_2. This routine takes the inputs of HX type (TypeHX$), ε or NTU, and the two fluid capacitance. It returns NTU or ε, depending on which call you use.

   TypeHX$ =   'parallelflow'
                  'counterflow'
                  'crossflow_both_unmixed'
                  'crossflow_one_mixed' C_1 must be for unmixed fluid
                  'shell&tube_N' where N is an integer 1–9 for number of shell passes
                  'regenerator' can only solve for ε given NTU

   Go to "Help $\rightarrow$ Help for External Libraries $\rightarrow$ Heat Exchangers"for more information on this routine

Solution Sheet

Names: _____   _____

<u>Large Heat Exchanger</u>

q = _____

C_C = _____

C_H = _____

Which fluid is the minimum fluid? _____

ε = _____

NTU= _____

A = _____

<u>Small Heat Exchangers</u>

C_C = _____

C_H = _____

Which fluid is the minimum fluid? _____

$T_{o,e,1}$ = _____

$T_{o,e,2}$ = _____

$T_{w,2}$ = _____

ε = _____

NTU = _____

A_{small} = _____ (per small HX)

A_{total} = _____ (total area for small HXs)

Your recommendation and why:

Appendix A.2
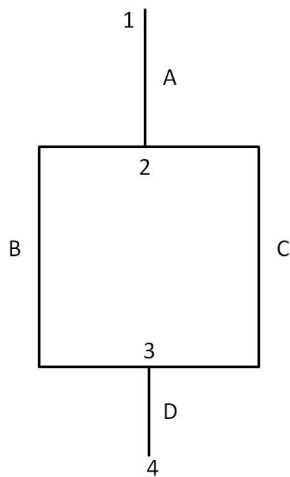
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Piping Networks In-Class Activity

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Rule 1: Pressure drop is the same across loops in parallel.
Rule 2: Flow in parallel must add up to the total flow.

Piping Network Design Exercise

In the section of cast iron water pipe network shown in the figure, the static pressure available at point 1 is 100 m of water, and point 4 is a drain to atmospheric pressure. The lengths and diameters of each pipe are given in the table. You may neglect minor losses.

A:	$L = 10\ m$	$D = 0.1\ m$
B:	$L = 20\ m$	$D = 0.2\ m$
C:	$L = 20\ m$	$D = 0.1\ m$
D:	$L = 5\ m$	$D = 0.15\ m$

Answer the following questions:

1. Find the flow rate through each branch in m³/s.

   Analysis:
   <u>For each pipe:</u>

$$\text{Flow rate and velocity: } Q = VA \;\Rightarrow\; V = \frac{4}{\pi}\frac{Q}{D^2}\ [m/s] \tag{1}$$

$$Re = \frac{\rho V D}{\mu} \tag{2}$$

$$\text{For turbulent flow } \frac{1}{f^{0.5}} = -2.0\log\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{Re \cdot f^{0.5}}\right) \tag{3}$$

$$\text{From energy equation: } \Delta P_{1-2} = \rho f \frac{L}{D}\frac{V^2}{2}\ [Pa] \tag{4}$$

Pressure drop balance:

$$\Delta P_{1,4} = \hspace{10cm} (5)$$

$$\Delta P_c = \hspace{10cm} (6)$$

Mass Balances

At node 2: $\hspace{11cm}$ (7)

At node 3: $\hspace{11cm}$ (8)

Hints for EES coding
Download and save the EES file from compass.

(a) Use all pressures in Pa. Go to Options → Unit System and check Pa in the SI system. What is the pressure from 1–4 in Pa?

(b) Enter Equations 5–8 for the pressure and mass balances.

(c) When you go to solve, you may get an error: the friction factor equation can't solve using the default initial guesses and limits. Go to Options → Variable Info and change the initial guess for each f to 0.001, and the lower limit to 0.0001. Set the lower limits for all Re numbers to 2300, and the initial guesses to 5000.

2. It is desired that the flow rate through pipe A is 0.3 m³/s. Find the resulting pressure drop (in Pa) in each branch.

3. Now is desired that the flow rate through pipe C is 0.1 m³/s. Find the resulting diameter needed for pipe C. Use $H_{1,4} = 100\,m$ from part 1. (Set lower limit for variable D_C in Variable Info to solve.)

Solution Sheet

Names: _____   _____

<u>Part 1</u>

Q_A = _____

Q_B = _____

Q_C = _____

Q_D = _____

<u>Part 2</u>

$P_{1,4}$ = _____

P_A = _____

P_B = _____

P_C = _____

P_D = _____

<u>Part 3</u>

D_C = _____

Q_B = _____

EES code given to students to complete to solve piping network problem:

g = 9.81[m/s^2]

"Givens"
L_A = 10 [m]
L_B = 20 [m]
L_C = 20 [m]
L_D = 5 [m]

D_A = .10 [m]
D_B = .20 [m]
D_C = .10 [m]
D_D = .15 [m]

H_14 = 100 [m]

{DELTAP_14 =   "[Pa]"} "Finish and uncomment this equation"

"Properties"
rho=Density(Water,T=10,P=101325)
mu=Viscosity(Water,T=10,P=101325)
e = 0.00026 [m] "roughness for cast iron"

"Pipe A"
V_A = 4/PI *Q_A/D_A^2 "[m/s]"
Re_A = rho*V_A*D_A/mu "[-]"
1/f_A^0.5 = -2.0*log10(e/(3.7*D_A)+2.51/(Re_A*f_A^0.5))

DELTAP_A = f_A*rho*L_A/D_A*V_A^2/2 "[Pa]"

"Pipe B"
V_B = 4/PI *Q_B/D_B^2 "[m/s]"
Re_B = rho*V_B*D_B/mu "[-]"
1/f_B^0.5 = -2.0*log10(e/(3.7*D_B)+2.51/(Re_B*f_B^0.5))

DELTAP_B= f_B*rho*L_B/D_B*V_B^2/2

"Pipe C"
V_C = 4/PI *Q_C/D_C^2 "[m/s]"
Re_C = rho*V_C*D_C/mu "[-]"
1/f_C^0.5 = -2.0*log10(e/(3.7*D_C)+2.51/(Re_C*f_C^0.5))

DELTAP_C = f_C*rho*L_C/D_C*V_C^2/2

"Pipe D"
V_D = 4/PI *Q_D/D_D^2 "[m/s]"
Re_D = rho*V_D*D_D/mu "[-]"
1/f_D^0.5 = -2.0*log10(e/(3.7*D_D)+2.51/(Re_D*f_D^0.5))

DELTAP_D = f_D*rho*L_D/D_D*V_D^2/2

"Mass Balances"

"Pressure Balances"

Appendix B.1

<div align="center">

Psychrometrics—Virtual Lab #1

</div>

This exercise is about playing (yes, engineering can be fun!) around with virtual air conditioning devices and thereby learn more about the conditioning of moist air.

You are encouraged to work in groups of two but you must turn in this lab handout individually.

Name: _____

Heating and Humidifying

For this exercise your job is to set the resistance heater and water mass flow rate of a heating and humidifying air conditioning unit to condition the incoming moist air.
Download and Open the file *Heating and Humidifying*. Set the inlet dry bulb temperature,t_1, to 5°C, the inlet relative humidity, RH_1, to 0.3 (30%) and the inlet dry air mass flow rate,$\dot{m}_a$, to 0.2 kg/s.

There are two option to increase the water content of the moist air, water or steam injection. Let's start with steam injection and change the amount of heat the resistance heater adds to the moist air, $\dot{q}_{heat}$, in kW, and the mass flow rate of the steam injected, $\dot{m}_w$, in kg/s. Change these values until you reach the target condition at the outlet of the air conditioning unit, state 3, of:

$$t_3 = 22°C \pm 0.2°C$$
$$RH_3 = 0.45 \pm 0.01$$

Record your values in the table below:

<div align="center">

Steam injection

$\dot{q}_{heat}$, kW	
$\dot{m}_w$, kg/s	

</div>

Now switch to water injection and again change the amount of heat the resistance heater adds to the moist air, $\dot{q}_{heat}$, in kW, and the mass flow rate of the water injected, $\dot{m}_w$, in kg/s, until you reach the target condition from page 1.
Record your values in the table below:

Water injection

$\dot{q}_{heat}$, kW	
$\dot{m}_w$, kg/s	

Comparing the two different injections methods, steam vs. liquid water, comment on the difference, e.g., which method requires more heat addition, which has the higher water mass addition?

The injection of water at 10°C (which is the assumed temperature of tap water) is essentially free of charge (neglecting the cost of the water itself). However, power is necessary to heat the 10°C liquid water to a saturated steam at 100°C.

1. Calculate the power necessary, in kW, to generate the steam.

2. Add this amount to the power you determined is necessary to be supplied to the resistance heater and compare to the water injection case and comment.

Show all calculations below and make sure to mention what tables you have used to calculate your values.

Compare again the water vs. steam injection case, but this time have an eye on state 2, the condition of the moist air after the resistance heater (you might want to go back and reenter your values to record the state 2 condition for each case). Comment on your findings. If heat loss from the air conditioning unit is expected, e.g., the unit is located outside, which injection method would you recommend and why?

A customer wants to convert his existing steam injection system to a water injection system. Can the existing resistance heater be used? If so, explain why. If not, how should the existing system be modified to meet the customer need?

Appendix B.2

Psychrometrics—Virtual Lab #2

You work for a company that distributes air handling units to condition office spaces. A new model of an constant-air-volume with economizer air handling unit is to be delivered to costumers in Anchorage, Alaska and Miami, Florida. Your job is to analyze how to run the unit most energy efficient.

Work in groups of two for this lab. Hand in one report. The report is due Monday, October 15th, at the beginning of the lab.

Name: _____

Name: _____

A simulation of the unit is provided to you. Download and open the file *Office space conditioning unit*. Study the schematic and familiarize yourself with the different states. You notice that this AH unit has a special feature, a bypass option so that part of the return air can bypass the cooling coil. The supply air, state 5, and the return air, state 6, are fixed based on the requirements of the conditioned space:

	Supply Air	Return Air
Temperature (°F)	64	76
Rel. Humidity	0.50	0.45

The two locations, Anchorage and Miami, have the following outside air conditions:

	Anchorage	Miami
Temperature (°F)	70	82
Rel. Humidity	0.35	0.60

1. Economizer Setting

Since there are two degrees of freedom here, the setting of the percent outside air and the bypass ratio, set the bypass ratio to 0 (all air flow passes through the cooling coil). Determine the percent outside air for each location which results in the lowest power consumption. To determine the power consumption, add the power required for the cooling coil and the reheat coil (note that the negative sign of the cooling coil power requirements is a result of the sign convention and does not mean that power is generated!).

2. Optimize Unit for Anchorage

Using the percent outside air setting which resulted in the lowest total power consumption for Anchorage, change the bypass valve setting by increments of 0.05. Open MS Excel and record for each bypass value the cooling coil, reheat coil, total power consumption and temperature at state 3.

3. Optimize Unit for Miami

Using the percent outside air setting which resulted in the lowest total power consumption for Miami, change the bypass valve setting by increments of 0.05. Open MS Excel and record for each bypass value the cooling coil, reheat coil, total power consumption and temperature at state 3.

Report

Write a report about your analysis. Include and answer the following questions in your report:

1. What is the best economizer setting (percent outside air) for each location and what are the total power requirements?

2. Generate two plots, one for Anchorage and one for Miami, using MS Excel (or any other program which produces acceptable engineering graphs). Plot on the x-axis the bypass ratio and on the left y-axis the temperature at state 3 and the total power consumption on the right y-axis.

3. By analyzing your plots, what is the optimum bypass valve setting for the AH unit in Anchorage? What is the optimum bypass valve setting for Miami?

4. Analyze the usage of the bypass valve. How much less total energy is required when using an optimized bypass valve setting compared to only use an economizer (bypass valve closed)? Where is the power savings greater, in Anchorage or Miami? Since a bypass will increase the cost of the unit, would you recommend installing a bypass for both locations, only one location, or at no location (without knowing more information to perform an economic analysis, let's assume that if the energy savings using a bypass are higher than 5% it is economical feasable to use a bypass).

5. Focusing on the two coils, would you recommend to use the same cooling coil and reheat coil in both locations? Keep in mind that the size of a coil needs to be adjusted based on the power requirements.

Appendix B.3

Refrigeration—Vapor Compression Cycle Analysis

Work in groups of two for this lab. Hand in one report. The report is due Monday, October 29th, at the beginning of the lab.

Name: _____

Name: _____

In the previous laboratory activity you took a closer look at the thermophysical properties of refrigerants. Now you will be investigating how different refrigerants will perform in a vapor compression system. The system choosen is comparable to medium sized window AC unit.

A simulation of a vapor compression cycle is provided to you. Download and open the file *Vapor Compression Cycle*. Study the schematic and familiarize yourself with the different states. On the top left you can change the refrigerant that is being used from a pull-down menu. You can also select wether you want to include a suction line heat exchanger or not in your cycle. Below the compressor you can change the isentropic efficiency of the compressor.

To compare the different refrigerants, a cooling capacity of ($\dot{q}$) 3 kW is assumed for each refrigerant without using a suction line heat exchanger (3 kW is a tyical cooling capacity of a medium sized window AC unit). Further, a constant evaporation temperature of 5°C and a constant condensing pressure equivalent to the saturation pressure corresponsing to 45°C is assumed for each refrigerant. The exit state of the condenser is saturated liquid and the exit state of the evaporator is saturated vapor. In case a suction line heat exchanger is used, the outlet temperature on the low pressure side of the suction line heat exchanger is identical to the condenser exit temperature, essentially this is a suction line heat exchanger with an efficiency of 100%. Pressure drops in the pipes and heat exchangers are neglected.

1. Ideal Vapor Compression Cycle

The first investigation is to study an ideal vapor compression cycle without suction line heat exchanger and a compressor isentropic efficiency of 1. Set the isentropic efficiency to 1 and chose *No Suction Line Heat Exchanger* and record in an Excel table the cooling capacity and compressor power for each refrigerant.

2. Effect of Isentropic Efficiency

Now repeat the above but using a more realistic isentropic efficiency of 0.5 (typical values are 0.4 to 0.5 for small hermetic compressors found in window AC units). Record in an Excel table the cooling capacity, the compressor power and the mass flow rate for each refrigerant.

3. Effect of Suction Line Heat Exchanger

Using an isentropic efficiency of 0.5, now select the *Suction Line Heat Exchanger* option. Record in an Excel table the cooling capacity and compressor power for each refrigerant.

Report

Write a report about your investigation. Include and answer the following questions in your report:

1. Include a bar chart comparing the COP values for each refrigerant for the case without suction line heat exchanger and isentropic efficiency of 1 and 0.5.

2. Include a bar chart comparing the refrigeration capacity per mass and compressor work per mass for each refrigerant for the case without suction line heat exchanger and an isentropic efficiency of 0.5.

3. Include a bar chart comparing the COP values for each refrigerant for the case without suction line heat exchanger and with suction line heat exchanger and an isentropic efficiency of 0.5.

4. Include a bar chart comparing the cooling capacities for each refrigerant for the case without suction line heat exchanger and with suction line heat exchanger and an isentropic efficiency of 0.5.

5. What is the effect of the compressor isentropic efficiency on the system performance?

6. Which refrigerants provides the highest/lowest COP when no suction line heat exchanger is used?

7. What can you conclude from comparing the refrigeration capacity per mass and compressor work per mass for each refrigerant?

8. Which refrigerants benefit from using a suction line heat exchanger in terms of COP?

9. How is the cooling capacity affected when using a suction line heat exchanger?

10. For which refrigerants would you recommend using a suction line heat exchanger and why?

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