2006-202: TEACHING PSYCHROMETRICS: A TIMELY APPROACH USING ACTIVE LEARNING

Craig Somerton, Michigan State University

CRAIG W. SOMERTON Craig W. Somerton is an Associate Professor of Mechanical Engineering and Associate Chair of Mechanical Engineering at Michigan State University. He teaches in the area of thermal engineering including thermodynamics, heat transfer, and thermal design. Dr. Somerton has research interests in computer design of thermal systems, transport phenomena in porous media, and application of continuous quality improvement principles to engineering education. He received his B.S. in 1976, his M.S. in 1979, and his Ph.D. in 1982, all in engineering from UCLA.

Laura Genik, Wayne State University

LAURA J. GENIK Laura J. Genik is currently part-time faculty in the Department of Mechanical Engineering at Wayne State University in Detroit, Michigan. She teaches in the area of thermal engineering, including thermodynamics and heat transfer. Dr. Genik has research interests in transport phenomena in porous media, inverse problems and parameter estimation in heat transfer processes, and computer design of thermal systems. She received her B.S. in 1991, her M.S. in 1994, and her Ph.D. in 1998, all in mechanical engineering from Michigan State University.

Teaching Psychrometrics:
A Timely Approach Using Active Learning

Introduction

In the past decade several mechanical engineering programs have eliminated a required second course in thermodynamics. In doing so, many topics have been cast aside due to the perception that they cannot be taught in a timely fashion in a single course on thermodynamics. One of these topics is air/water vapor mixtures or psychrometrics. Quite simply, many mechanical engineering programs are graduating mechanical engineers who know nothing about the relationships among temperatures (both dry bulb and wet bulb), relative humidity, and humidity ratio. They are not prepared to work in the climate control industry, perform well on the Fundamentals of Engineering Exam, or prepared to take a higher level course in thermal design. Over the years the authors have re-introduced this topic to the introductory thermodynamics class through an active learning exercise that takes two, fifty minute lecture periods. One of the authors has also used this exercise to prepare students in a thermal design course for conducting thermal environmental engineering studies.

This paper continues with a statement of the learning objectives for the topic. The details of the active learning exercise are then presented. Next an assessment of the students' learning is conducted using student performance on graded assignments and a student survey. Conclusions and recommendations complete the paper

Learning Objectives

The authors set the following learning objectives for the topic of air/water vapor mixtures:

1. Students understand the properties for air/water vapor calculations.
2. Students can use the psychrometric chart to determine property values.
3. Students understand the physical processes involved in air processing systems
4. Students can use the conservation of water and conservation of energy equations for air/water vapor mixtures to calculate the performance of devices in an air processing system.

These objectives were developed to address the needs of the practicing engineers, background for thermal design courses, and preparation for the Fundamentals in Engineering (FE) exam.

Active Learning Exercise

An active learning experience covering two 50 minute periods has been developed to achieve the learning objectives. The authors have found that sometimes it is not even possible to commit two class periods to this topic. In these cases, learning objectives 1-3 may be addressed in a single 50 minute period.

The first fifty minute period begins with a brief lecture on mixtures and their properties with a specific emphasis on air/water vapor mixtures. A handout or web posting on the definition of mixture properties is made available to students and it is expected that they will have it available in lecture. This handout is given in Figure 1. During this brief (15 minutes) lecture, the basic ideal gas mixture assumption is made clear to the students. After the property definitions are provided, the students are asked to remember the thermodynamic state principle, which for this case would require three properties to be specified in order to fix the state. However, it is shared with the students that since most air processing (HVAC) systems are at atmospheric pressure, it is normally assumed that the pressure of the mixture is at 101 kPa, so that only two additional properties are needed to fix the state of the mixture. The students are then introduced to the psychrometric chart as the way to determine properties. Such a chart is distributed to the class, an example of which is shown in Fig. 2. The chart is reviewed with the class, demonstrating the lines of constant dry bulb temperature (vertical lines), humidity ratio (horizontal lines), relative humidity (sweeping diagonal curves), mixture enthalpy and wet bulb temperatures (diagonal lines running from top left to bottom right), and mixture specific volume (steeper diagonal lines running from top left to bottom right). This is done with an overhead slide, while each student has a copy of the chart in front of them. At this point, an active learning exercise is employed to facilitate the student's ability to read the psychrometirc chart. The handout of Fig. 3 is passed out to the class. The first row of the table is completed by the class as a whole. The class is then asked to work in pairs to complete the table. During this time the instructor may wander around the classroom helping students one on one. After about 15 minutes most of the class would have completed the table. An overhead slide of the table is then completed by the class as a whole. At this point the exercise continues on to the process problems. Again the first one is worked by the class as a whole and the remaining are turned over to be worked by the students. Normally, the class period ends before the class can reconvene as a whole to share their solutions. This can be continued at the second class period or, if only one class period is to be used, solutions can be distributed or posted on the web. Often a homework assignment is made on the topic or the unworked in-class problems can be assigned as homework. The topic is also fair game on exams and the students seem to perform well on these exam problems.

The second class begins with the derivation of the conservation equations (species and energy) associated with air processing devices. The general control volume of Fig. 4 is used. It is emphasized to the students that this is a general control volume and that not all mass and energy flows would exist in a specific air processing device. The conservation of water and energy equations are then easily derived as

Water Conservation

$$\dot{m}_{v,1} + \dot{m}_{\ell,2} + \dot{m}_{stm,3} = \dot{m}_{v,4} + \dot{m}_{\ell,5}$$

Energy Conservation

$$\dot{m}_{air} h_{av,1} + \dot{m}_{\ell,2} h_{\ell,2} + \dot{m}_{stm,3} h_{stm,3} + \dot{Q}_{in} = \dot{m}_{air} h_{av,4} + \dot{m}_{\ell,5} h_{\ell,5} + \dot{Q}_{out}$$

Figure 1 Handout on Property Definitions

Air/Water Vapor Mixtures
Basic Definitions

Mole Fraction (y_i): This is the mole percent of component i in the mixture.

$$y_1 = \frac{\text{number of moles of component 1 in the mixture}}{\text{total number of moles in the mixture}} = \frac{N_1}{N_{tot}}$$

with

$$\sum_i y_i = 1$$

Partial Pressure (P_i): This is the apparent pressure of component i in the mixture assuming that all components are at the temperature of the mixture and fill the volume of the mixture. It is directly related to the mole fraction by

$$P_1 = y_1 P_{tot} \text{ or } y_1 = \frac{P_1}{P_{tot}}$$

Mass Fraction (mf): This is the mass percent of component i in the mixture.

$$(mf)_1 = \frac{\text{mass of component 1 in the mixture}}{\text{total mass of the mixture}} = \frac{m_1}{m_{tot}}$$

Dry Bulb Temperature (T_{DB}): This is the temperature of the air/water vapor mixture that would be measured with a standard thermometer. It is the temperature that is provided in weather reports.

Relative Humidity (ϕ): This is the parameter that is provided in weather reports that is indicative of the moisture content of the air/water vapor mixture. It is actually the ratio of the partial pressure of water vapor in the mixture to the maximum value of water vapor partial pressure. This maximum value is the saturation pressure for water vapor at the temperature of the mixture. Hence it is defined by

$$\phi = \frac{P_v}{P_{sat}(\text{at } T_{mix})}$$

Humidity Ratio (ω): This is the true indication of the moisture content of the air/water vapor mixture. It is nearly the percent by mass of water vapor in the mixture. It is defined by

$$\omega = \frac{\text{mass of water vapor in the mixture}}{\text{mass of dry or pure air in the mixture}}$$

Figure 1 Handout on Property Definitions (continued)

Wet Bulb Temperature (T_{WB}): This is the measurement that is used to obtain the moisture content of an air/water vapor mixture. It involves measuring the temperature of a wet object that comes to thermal and mass equilibrium with the surrounding air. It is found that this equilibrium temperature depends on the moisture content of the air and has been correlated to the humidity ratio.

Dew Point Temperature (T_{DP}): This is the temperature at which water would begin to condense out of an air/water vapor mixture. It corresponds to 100% relative humidity and can be found as the saturation temperature that corresponds to the partial pressure of the water vapor in the mixture.

Mixture Enthalpy (h_{av}): This is the enthalpy of the air/water vapor mixture and can be calculated from

$$h_{a\text{-}v} = h_a(\text{at } T_{mix}) + \alpha \cdot h_v(\text{at } T_{mix})$$

Mixture Specific Volume (v_{av}): This is the specific volume of the air/water vapor mixture.

Figure 2 Psychrometric Chart

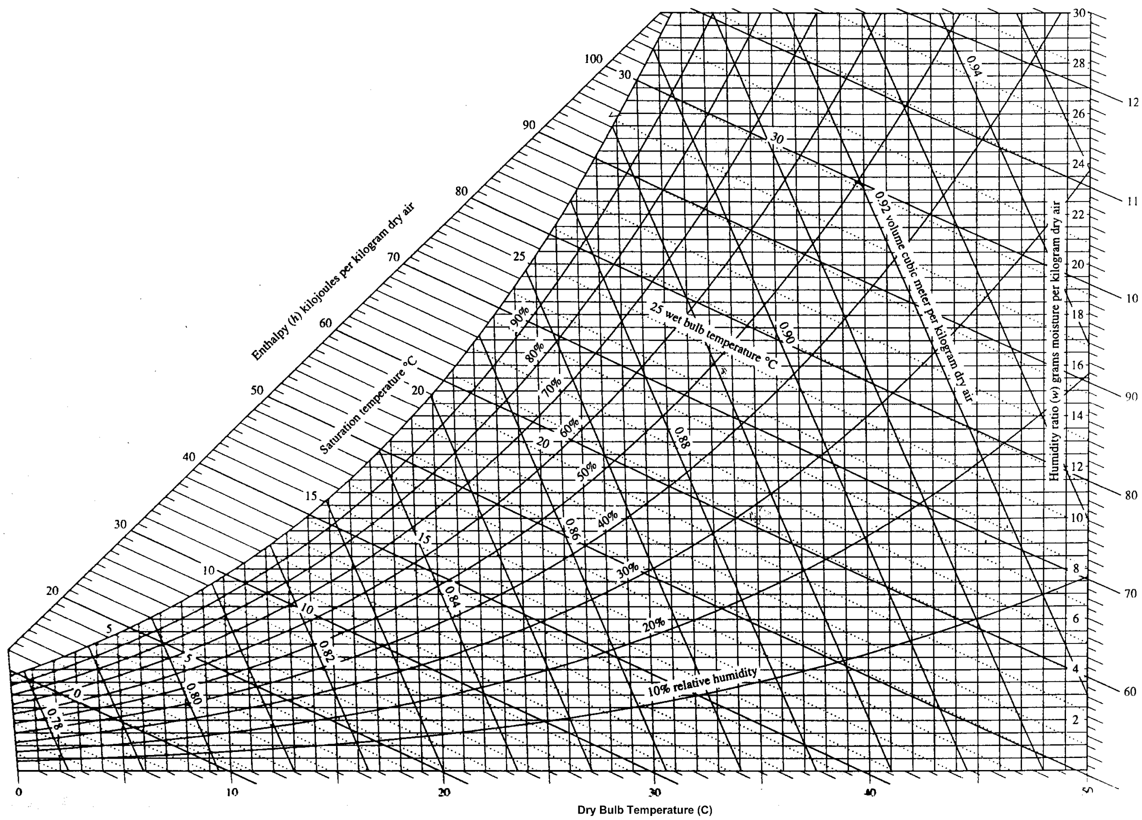


Figure 3 Handout for First Active Learning Exercise

Psychrometric Chart Example

Case	T_{DB} (°C)	T_{WB} (°C)	h_{av} (kJ/kg of dry air)	ω (gm/kg of dry air)	ϕ (%)	v_{av} (m^3/kg)
1	14				60	
2	28	22				
3	21			4.5		
4	34				35	

Processes

Find the change in enthalpy, humidity ratio, and final conditions for the following processes.

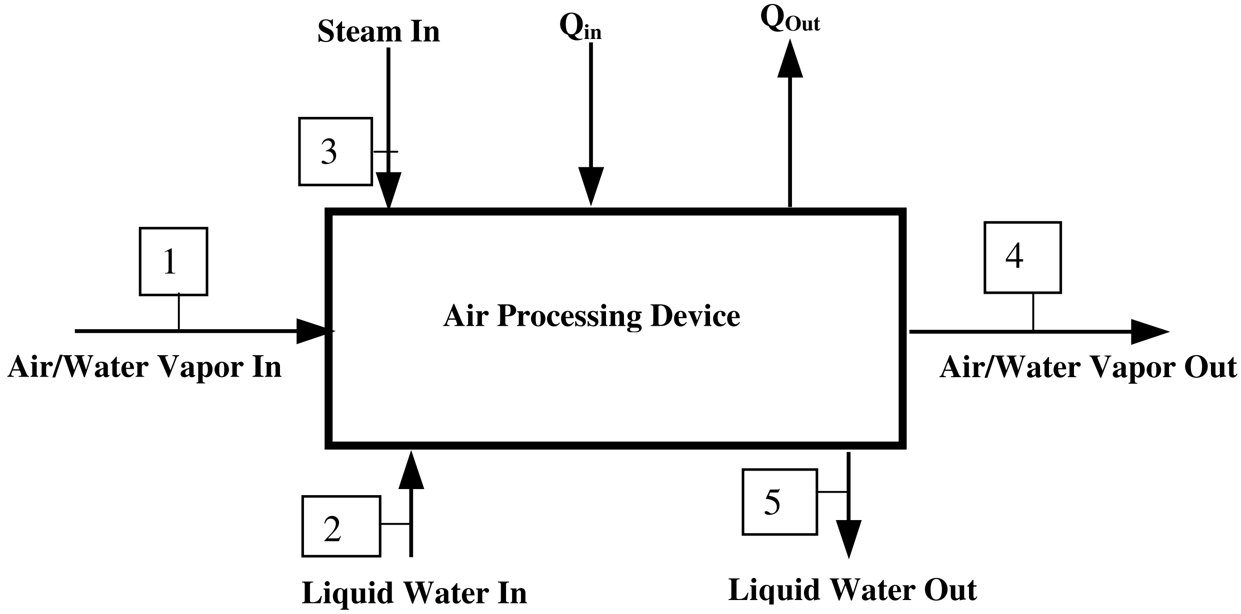
1. Isothermal decrease in humidity from dry bulb temperature of 36°C and 60% relative humidity to 25% relative humidity.

2. Constant moisture content heating from dry bulb temperature of 23°C and wet bulb temperature of 20°C to dry bulb temperature of 32°C.

3. Adiabatic addition of moisture from dry bulb temperature of 30°C and humidity ratio of 10 gm/kg of dry air to 100% relative humidity.

4. Determine the temperature at which air initially at 27°C and 80% relative humidity will have condensation occur.

Figure 4 Control Volume for Development of Conservation Equations



The students are informed that we would like this in a form that is a little friendlier with our psychrometric parameters. We recognize that

$$\dot{m}_v = \omega \dot{m}_{air}$$

Then we write

$$\omega_1 + \left(\frac{\dot{m}_{\ell,2}}{\dot{m}_{air}}\right) + \left(\frac{\dot{m}_{stm,3}}{\dot{m}_{air}}\right) = \omega_4 + \left(\frac{\dot{m}_{\ell,5}}{\dot{m}_{air}}\right)$$

for water conservation and

$$h_{av,1} + \left(\frac{\dot{m}_{\ell,2}}{\dot{m}_{air}}\right) h_{\ell,2} + \left(\frac{\dot{m}_{stm,3}}{\dot{m}_{air}}\right) h_{stm,3} + \left(\frac{\dot{Q}_{in}}{\dot{m}_{air}}\right) = h_{av,4} + \left(\frac{\dot{m}_{\ell,5}}{\dot{m}_{air}}\right) h_{\ell,5} + \left(\frac{\dot{Q}_{out}}{\dot{m}_{air}}\right)$$

for energy conservation where the ratio terms in parenthesis are taken as variables themselves. Next, four of the most common air processing devices are introduced. Again a handout is provided to the students, which is included as Fig. 5. The second active learning exercise is now introduced as shown in Fig. 6. The same procedure is used for this exercise as for the psychrometric chart exercise.

Assessment of Student Learning

Achievement of the learning objectives are assessed through student performance on graded assignments and a student survey. For the senior level thermal design class a fifteen minute, closed book and notes quiz was administered. The quiz is shown in Fig. 7. The quiz was graded out of 10 points and the class results are shown in Fig. 8. We see excellent performance, which would imply that this teaching approach was quite effective for the thermal design course.

The survey of Fig. 9 was administered to both the thermal design class. Results are shown in Fig. 10. The different patterned columns represent the five different statements the students were asked to respond to in the survey. The ratings represent the level of agreement with the statement, e.g., a rating of 4 is strongly agrees while a rating of 1 is strongly disagrees. Then for statement #1 (black column), 45% of the students strongly agreed with the statement. These results also indicate that, in the students' opinion, they achieved the learning objectives.

Conclusions and Recommendations

- An active learning experience is an effective way to teach mechanical engineering students about air/water vapor mixtures and air processing devices.
- The active learning experience can be taught in one or two 50 minute class periods.
- If only one fifty minute class period is available the basic concepts of air/water vapor mixtures and reading the psychrometric chart can be covered.
- Assessment of student learning is obtained by both student assignments and a student opinion survey and demonstrates that very effective learning occurred.

Figure 5 Handout on Common Air Processing Devices

Heating Coils: Air-Water Vapor mixture is heated at constant pressure. The moisture content (humidity ratio) will stay constant. The first law is simply written:

$$h_{av,out} = h_{av,in} + \frac{\dot{q}_{in}}{\dot{m}_a}$$

Cooling Coils: Air-Water Vapor mixture is cooled at constant pressure. The moisture content will stay constant until saturation is reached at which time further cooling will produce condensation. If this point is reached liquid water will leave the system and the air-water vapor leaving the system will have a relative humidity of 100%. The first law is written:

$$h_{av,in} = \frac{\dot{q}_{out}}{\dot{m}_a} + h_{av,out} + (\omega_{in} - \omega_{out})h_{\ell,out}$$

The exit enthalpy of the liquid water should be taken as the enthalpy of saturated liquid at the average temperature between the dew point temperature of the entering air-water vapor mixture and the dry bulb temperature of the exiting air-water vapor mixture.

Evaporative Spray Cooler: A spray of liquid droplets is introduced to the air-water vapor mixture. The liquid evaporates into the mixture giving rise to cooling. The first law is written:

$$h_{av,in} + (\omega_{out} - \omega_{in})h_{\ell,in} = h_{av,out}$$

Steam Humidifier: Steam is mixed with the inlet air-water vapor mixture, so as to increase its moisture content (humidity ratio). The first law is written:

$$h_{av,in} + (\omega_{out} - \omega_{in})h_{stm,in} = h_{av,out}$$

Figure 6 Active Learning Exercise for Air Processing Devices

Air Processing Devices
In Class Exercises

1. A heater is to be used to take air at 10°C and a relative humidity of 20% to 24°C. Determine the heat transfer rate required per kg/s of dry air and the exit relative humidity of the air.

2. Air at 35°C and a relative humidity of 10% is to be cooled by an evaporative spray cooler to 20°C using water at 15°C (with an enthalpy of 63 kJ/kg). Determine the amount of water consumed per kg/s of dry air and the exit relative humidity.

3. A cooling coil is used to take air at 0.06 kg/s, 31°C, and 70% relative humidity and cool it to 18°C. What are the heat transfer rate required and the amount of water that must be drained away? You may assume that the liquid water leaving has an enthalpy of 85 kJ/kg.

Figure 7 Quiz for Thermal Design Course

ME 416
Computer Assisted Design of Thermal Systems

Quiz #3
Closed Book, Closed Notes

For each question provide the determine:

- the enthalpy change
- change in humidity ratio

and sketch the process on the attached psychrometric chart.

1. Air at a dry bulb temperature of 20°C and a wet bulb temperature of 15°C is heated at constant wet bulb temperature to a relative humidity at 10%.

2. Air at a humidity ratio of 14 gm/kg of dry air and a dry bulb temperature of 34°C is cooled at constant specific volume until condensation occurs.

Figure 8 Results of Quiz in Thermal Design Class

ME 416
Computer Assisted Design of Thermal Systems

Quiz 3 Results

High:	10
Low:	4
Median:	10
Average:	9.2

Course Distribution

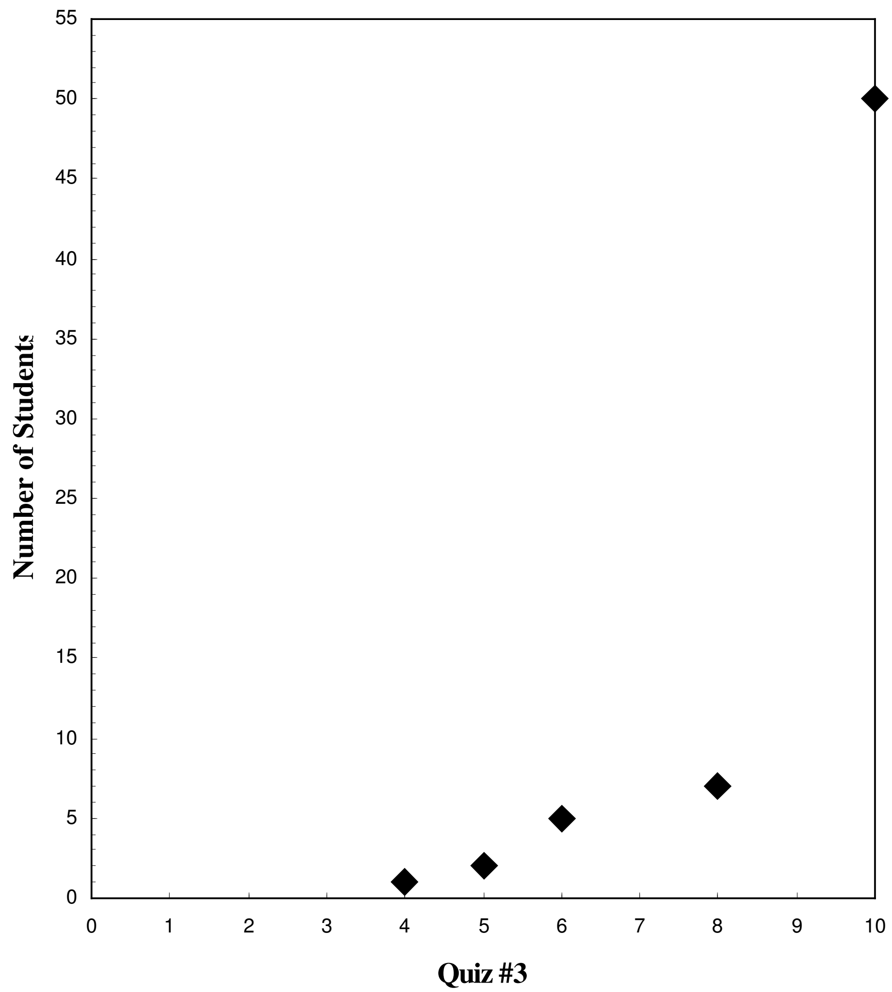


Figure 9 Student Opinion Survey

Survey on Air Water Vapor Mixtures (Psychrometrics)

Please help us in determining how effective the active learning experience was in your learning about air-water vapor mixtures.

1. I understand the various properties of air-water vapor mixtures, such as wet bulb temperature, dew point, and humidity ratio.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
4	3	2	1	0

2. I can use the psychrometric chart to determine property values.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
4	3	2	1	0

3. I can solve the following problem:
   Determine the relative humidity, humidity ratio and enthalpy for air with a dry bulb temperature of 23°C and a wet bulb temperature of 16°C.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
4	3	2	1	0

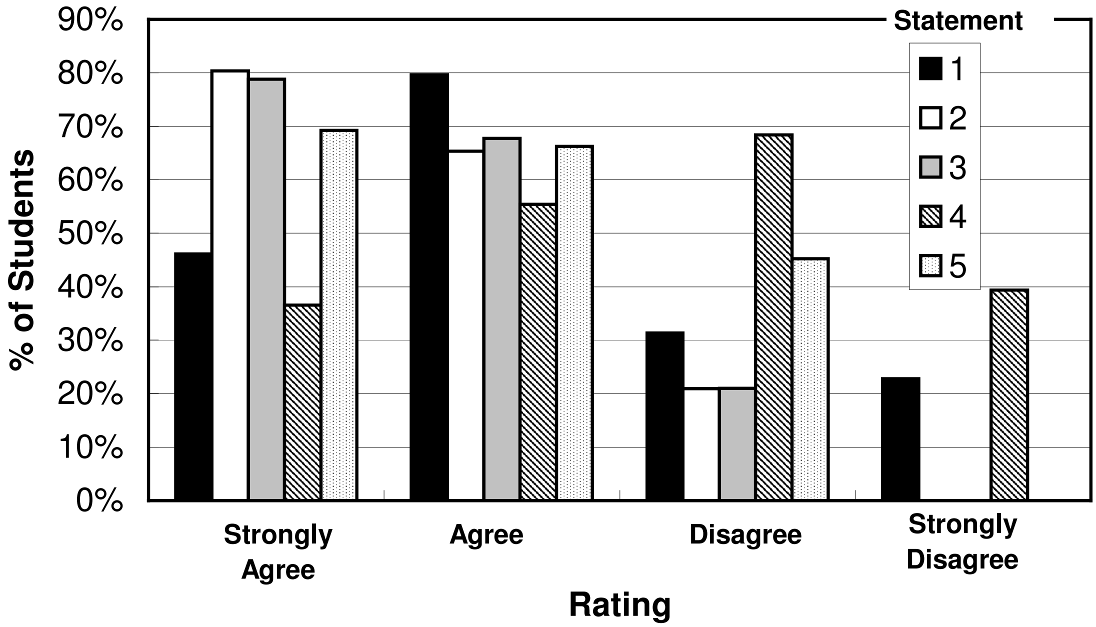
4. I can solve the following problem:
   A cooling coil is used to take air at 0.06 kg/s, 31°C, and 70% relative humidity and cool it to 18°C. What are the heat transfer rate required and the amount of water that must be drained away? You may assume that the liquid water leaving has an enthalpy of 85 kJ/kg.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
4	3	2	1	0

5. I can solve the following problem:
   Determine the change in enthalpy and humidity ratio as air at 40% relative humidity and a dry bulb temperature of 8°C is processed to a dry bulb temperature of 22°C and a wet bulb temperature of 18°C.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
4	3	2	1	0

Figure 10 Survey Results



Average Results

Question	Average Rating
1	3.38
2	3.78
3	3.77
4	3.08
5	3.63