An Evaporative Cooling Model for Teaching Applied Psychrometrics

Donald M. Johnson*

ABSTRACT

Evaporative cooling systems are commonly used in controlled environment plant and animal production. These cooling systems operate based on well defined psychrometric principles. However, students often experience considerable difficulty in learning these principles when they are taught in an abstract, verbal manner. This article describes an evaporative cooling demonstration model that has been used successfully in both the classroom and the laboratory to provide students with concrete, hands-on experiences with evaporative cooling and the underlying psychrometric principles. The model incorporates computer-based, real-time data collection and display to visually reinforce the principles being taught and learned. Construction of the model was easily accomplished in approximately 2 hours at a materials cost of less than $40, excluding computer, instrumentation, and electric fan.

Evaporative cooling systems are widely used in agriculture to cool greenhouses and animal production facilities. A typical fan and pad evaporative cooling system is a negative pressure system consisting of exhaust fans at one end of a structure and a porous pad at the opposite end. Water is circulated through the pad and evaporates into the airstream as the warm outside air passes through the pad (Bucklin et al., 1993). The energy for the phase change from liquid to moisture vapor is supplied by the air as sensible heat is converted into latent heat of vaporization. The net result of this adiabatic process is that the air temperature decreases, the humidity ratio and relative humidity increase, and the total heat energy (enthalpy) remains constant (Serway, 1986).

An air–water vapor mixture can be described in terms of seven distinct characteristics: (i) dry bulb temperature, T; (ii) wet bulb temperature, T_w; (iii) dew point temperature, T_{dp}; (iv) relative humidity, RH; (v) humidity ratio, W; (vi) enthalpy, H; and (vii) specific volume, $m^3\ kg^{-1}$ (Table 1). Psychrometrics is the study of the relationships between these seven characteristics in an air–water vapor mixture (Buriak and Osborne, 1996). A psychrometric chart consists of families of lines, curves, and associated scales that relate these seven properties to one another. The point where two known properties intersect on the psychrometric chart is called the *state point*. Once the state point for an air mass has been identified, the remaining five characteristics of the air mass can be determined by reading the appropriate scales on the psychrometric chart.

In the past, I have typically taught psychrometrics in an introductory agricultural systems management course by defining the seven air–water vapor characteristics, introducing the chart, providing guided practice in using the chart, and having students use the chart in solving hypothetical problems related to greenhouse or livestock environmental control. During several semesters, I determined that although a fairly high percentage of students learn the mechanics of chart use and problem solution, most students fail to develop a deep understanding of basic psychrometric principles and relationships.

Students are often confused about and unconvinced of the validity of engineering topics taught in an abstract, quantitative manner and desire direct, concrete experiences with the subject matter (Vander Schaaf and Klosky, 2003). The purpose of this article is to describe an evaporative cooling model used in teaching applied psychrometrics to undergraduate agriculture students. The model is a fully instrumented variation of a basic model described by Buriak and Osborne (1996). Sample data collected by students using the model will also be presented.

MATERIALS AND METHODS

Model Construction and Instrumentation

Construction of the evaporative cooling model began with acquisition and preparation of materials and supplies (Table 2). The total cost for the materials and supplies necessary to construct the model was less than $40. The computer, interface, temperature probes, and fan were already available within the department at an estimated total value of approximately $1800.

The evaporative cooling model is a 61 by 62 by 61 cm cube constructed from 0.64 cm thick exterior plywood with two opposite ends left open (Fig. 1). A 2.6-cm slot is cut in the top of the cube to allow insertion of a 61 by 61 by 2.54 cm thick furnace-type air filter. The air filter is held in place between four strips of 1.9 cm quarter-round molding glued to the interior of the two plywood sides adjacent to the slot. A 46-cm, 3-speed, 120-V AC fan is placed at one open end of the cube to draw air through the filter.

Dry bulb and wet bulb temperatures are measured on the inlet and outlet sides of the filter using four stainless steel temperature probes inserted through 0.96-cm diameter holes drilled in the top of the cube. The two probes measuring wet bulb temperature are wrapped in wetted surgical gauze. A LabPro interface connects the temperature probes to a laptop computer running Logger Pro 3.2 software (Vernier Software and Technology, 2003). The software is configured for real-time meter and graph displays of inlet and outlet dry bulb and wet bulb temperatures.

Laboratory or Lecture Instruction

The evaporative cooling model can be used for either laboratory or classroom instruction. Classroom instruction is greatly enhanced by using a computer projector to display the results. In either case students should be actively involved in the learning process (Fig. 2).

Dep. of Agricultural and Extension Education, 205 Agriculture Bldg., Univ. of Arkansas, Fayetteville, AR 72701. Received 19 Dec. 2003. *Corresponding author (dmjohnso@uark.edu).

Published in J. Nat. Resour. Life Sci. Educ. 33:121–123 (2004).
http://www.JNRLSE.org

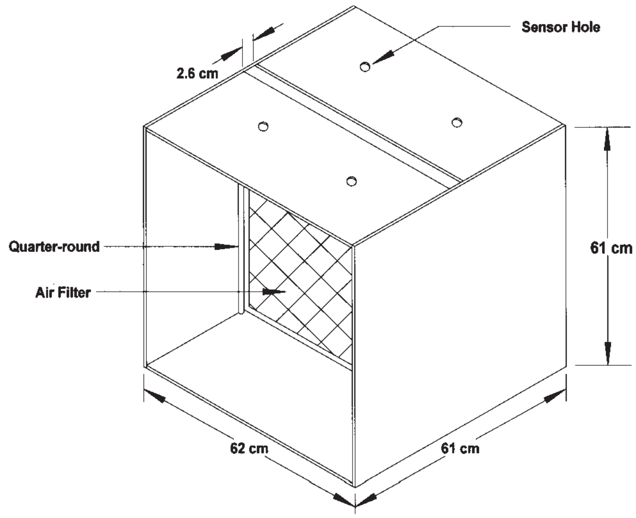

Fig. 1. Evaporative cooling model.

Fig. 2. Students using the evaporative cooling model as part of a laboratory activity.

Table 1. Psychrometric characteristics of an air-water vapor mixture.†

Characteristic	Definition	Unit
Dry bulb temperature, T	Air temperature measured with a s tandard thermometer	°C
Wet bulb temperature, T_w	Temperature of a moving airstream as measured with a thermometer covered with a water-moistened wick	°C
Dew point temperature, T_{dp}	Temperature at which moisture begins to condense from air cooled at constant pressure and humidity ratio	°C
Relative humidity, RH	Ratio of the actual water vapor present in an air mass as compared with water vapor in saturated air at the same temperature	%
Humidity ratio, W	The mass of water vapor contained in moist air per unit mass of dry air	g kg^{-1}
Enthalpy, H	Heat energy content of an air–water vapor mixture	kJ kg^{-1}
Specific volume, m^3 kg^{-1}	The volume of moist air per unit mass of dry air	m^3 kg^{-1}

† Information adapted from Roth and Field (1992).

To begin the activity, start the fan and allow the inlet and outlet temperatures to stabilize and then begin logging and displaying data. After 2 to 3 minutes, remove the air filter from the model and thoroughly wet each side of the filter using a spray bottle filled with water. Replace the filter in the model.

The outlet T decreases rapidly as the water on the filter evaporates into the airstream, converting sensible heat into latent heat of vaporization. Inlet T and T_w and outlet T_w remain constant. Students can be challenged to continue spraying water onto the filter in an attempt to make $T < T_w$ at the outlet. They will quickly determine this is impossible, since T_w defines the lower limit to the evaporative cooling effect. Once the minimum temperature has been reached, continue logging and displaying data until no free water is available and outlet T increases to its original value.

Next, students examine the data to identify the outlet T and T_w at the points immediately prior to insertion of the wetted filter and at maximum cooling. Plotting these points on a psychrometric chart enables students to better understand the psychrometric principles of evaporative cooling.

Table 2. Materials and supply cost for evaporative cooling model.†

Quantity	Item	Description	Vendor	Cost, $
1	plywood	61 by 244 by 0.64 cm thick exterior grade	numerous	10.00
1	air filter	61 by 61 by 2.54 cm thick furnace-type	numerous	2.75
1	molding	1.9 by 244 cm length quarter-round	numerous	12.00
8	corner braces	5.1 by 5.1 by 0.64 cm wide galvanized metal	numerous	3.00
32	machine bolts with nuts	no. 8 by 1.9 cm length galvanized	numerous	2.35
1 tube	wood glue	quick drying, waterproof	numerous	2.45
2	gauze pads	10.1 cm by 10.1 cm	numerous	1.00
1	spray bottle	1 L with adjustable nozzle	numerous	1.00
1	fan	46 cm, 3-speed, 120 V AC	numerous	25.00
4	temperature probes	stainless steel	Vernier Software and Technology	116.00
1	computer interface	4 analog, 2 digital channel LabPro with USB connection and software	Vernier Software and Technology	220.00
1	laptop computer	Pentium 3 or equivalent processor with USB port	numerous	800.00–2500.00

† Mention of specific brand names does not imply endorsement of product or non-endorsement of similar products not mentioned.

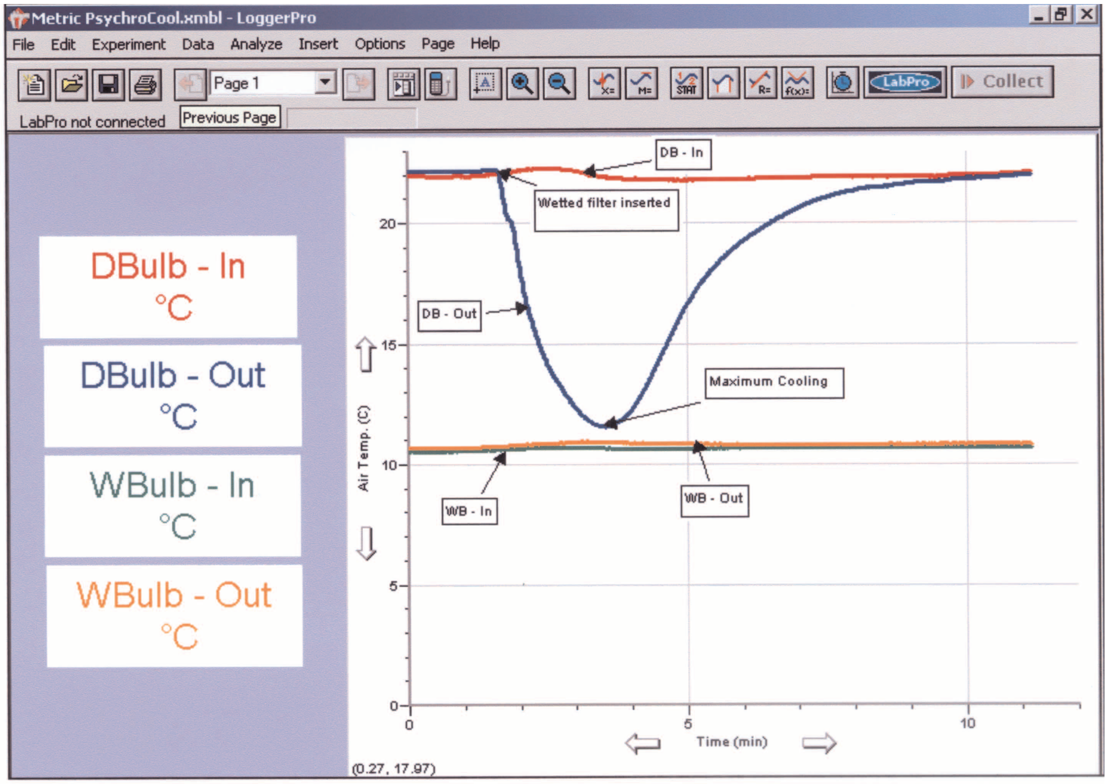

Fig. 3. Example Logger Pro screenshot from evaporative cooling activity.

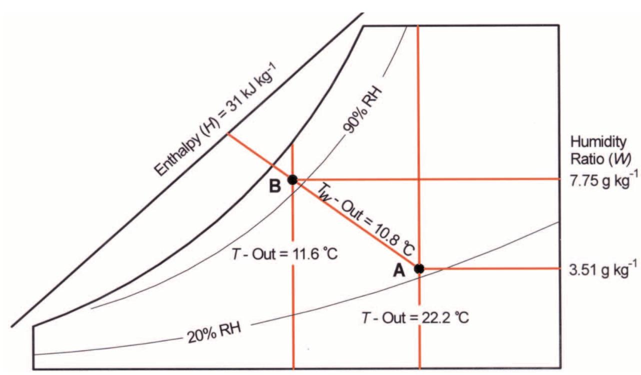

Fig. 4. Simplified psychrometric chart showing state points, relative humidities, humidity ratios, and enthalpy for air masses before evaporative cooling and at peak cooling.

RESULTS AND DISCUSSION

The evaporative cooling effect is illustrated graphically in Fig. 3. The outlet T decreased from 22.2°C to a minimum 11.6°C after insertion of the wetted filter. Note that outlet T > T_w, indicating that outlet RH < 100%.

Plotting state points on the psychrometric chart (Fig. 4) for the outlet air mass at point A, immediately before inserting the wetted filter, and point B, the point of maximum cooling, provides insight into the evaporative cooling process. As shown, RH increased from 21 to 91% and W increased from 3.51 to 7.75 g kg^{-1}, whereas the enthalpy remained constant at 31 kJ kg^{-1}. Thus, it can be shown that evaporative cooling converts sensible heat to latent heat with no change in the total heat energy present in the air mass.

CONCLUSIONS

The use of this inexpensive model allows students to gain hands-on experience with evaporative cooling and to better understand the psychrometric principles involved. Although no formal evaluation of the model's effectiveness has been conducted, anecdotal data indicate that the model is more effective than the previous mode of instruction. Student comments have been favorable and indicate that using the model helps prove the validity of theoretical concepts. I have noted students are more active in the learning process, ask more spontaneous questions, and provide evidence of a deeper understanding of psychrometrics than they did before the evaporative cooling model was incorporated into the class.

REFERENCES

Bucklin, R.A., R.W. Henley, and D.B. McConnell. 1993. Fan and pad evaporative cooling systems. Circ. 1135. Florida Coop. Ext. Service, Gainesville, FL.

Buriak, P., and E.W. Osborne. 1996. Physical science applications in agriculture. Interstate Publ., Danville, IL.

Roth, L.O., and H.L. Field. 1992. An introduction to agricultural engineering: A problem solving approach. 2nd ed. Kluwer Academic Publ., New York.

Serway, R.A. 1986. Physics for scientists and engineers. 2nd ed. Saunders College Publ., Philadelphia, PA.

Vander Schaaf, R., and J.L. Klosky. 2003. "Show me the money!" Using physical models to excite interest in mechanics [Online]. Proc. Am. Soc. Eng. Ed. Annu. Conf., Nashville, TN. 22–25 June 2003. Available at www.asee.org/conferences/caps/document/2003-338_Final.pdf (accessed 15 Dec. 2003; verified 9 July 2004). Am. Soc. for Eng. Educ., Washington, DC.

Vernier Software and Technology. 2003. Catalog. Vernier Software and Technology, Beaverton, OR.