Lab 1b
Cooling Tower Performance and Sensors for Thermal-Fluid Systems

OBJECTIVES

Warning: though the experiment has educational objectives (to learn about boiling heat transfer, etc.), these should not be included in your report.

- To become familiar with the P.A. Hilton H891 Bench Top Cooling Tower and its operating principles.
- Check the accuracy of the temperature sensors (thermocouples) in the cooling tower.
- To measure wet and dry bulb temperatures, apply psychrometric principles to determine relative humidity, and measure humidity.

EQUIPMENT

Name	*Model*	*S/N*
Bench Top Cooling Tower	P.A. Hilton H891	
Thermistor (lab standard)	Omega CL-351A	
Power Supply	Agilent E3620A	
LabView Data Acquisition VI		

The Bench Top Water Cooling Tower has been designed to give students an appreciation of the construction, design and operational characteristics of a modern evaporative cooling system. The unit is also an excellent example of an 'open system' through which two streams of fluid flow (water and air) and in which there is a mass transfer from one stream to the other.

Convincing energy and mass balances are obtained and students can quickly investigate the effects of air flow rate, water flow rate, water temperature and cooling loads on the performance of a cooling tower. You will measure the performance of the cooling tower, and determine the errors of your sensors and uncertainties of your measurements.

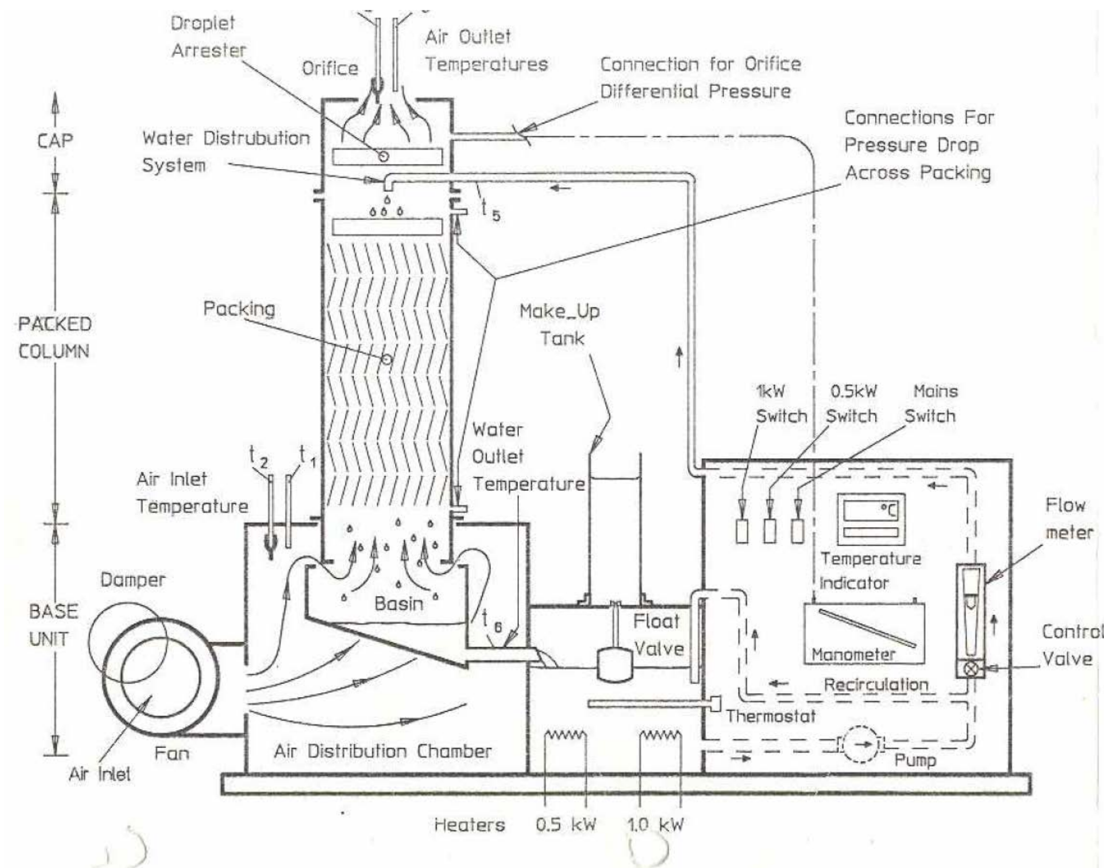


Figure 1: Bench Top Water Cooling Tower

PRE-LAB QUESTIONS

1- What is difference between dry bulb temperature and wet bulb temperature?
2- What is the cooling rate?
3- Describe with examples the difference between an open system and a closed system?
4- What is a psychrometric chart?
5- What is the effect of cooling loads on the performance of a cooling tower?

COOLING TOWER TERMS

Cooling range: The difference between the water temperature at entry to and exit from the tower.

Cooling rate: The rate at which heat is removed from the water. This may be expressed in KW, Btu/h or Kcal/h.

Make-up: the quantity of fresh water which must be supplied to the water circuit to make up for the losses due to evaporation and other causes.

Drift or Carry out: Droplets of water which are entrained by the air stream leaving the tower.

Packing or Fill: The material over which the water flows as it falls through the tower. (so as to expose a large surface area to the air stream)

Approach to wet bulb: The difference between the temperature of the water leaving the tower and the bulb temperature of the air entering.

Drain down: Water deliberately removed from the water system to prevent the excessive concentration of dissolved solids (due to evaporation) and sludge (due to impurities from the atmosphere).

PRECAUTIONS AND WARNINGS

1- Whenever possible, distilled or demineralized water should be used for filling and topping up of this unit. (This is to eliminate problems with scale and unsightly stains resulting from water impurities.)
2- The water and air stream temperature must not be allowed to exceed $50^{\circ}C$.
3- The make-up tank must always be refilled before the depth of water falls below 50 mm.
4- The make-up tank should be allowed to fall to about 50 mm whenever the unit is inoperative for more than two hours. (This is to ensure that any leakage past the float valve does not result in an overflow from the load tank.)
5- The system should be completely drained and refilled with fresh water after approximately 20 hours operation or when the unit is to be inoperative for several days.
6- The pump must not be switched on unless the system is filled with water.
7- The two wet bulb reservoirs must be filled with distilled water.
8- If the water level in the load tank falls below the arrowed position, switch off heaters and investigate the cause.

BASIC UNIT

Water Circuit:
Warm water is pumped from the load tank through the control valve and water flow meter to the column cap where its temperature is measured. The water is uniformly distributed over the top packing deck and, as it spreads over the plates, a large thin film of water is exposed to the air stream. During its downward passage through the packing, the water is cooled, largely by the evaporation of a small portion of the total flow.
The cooled water falls from the lowest packing deck into the basin, from where it flows past a thermocouple and into the load tank where it is re-heated for re-circulation.

Due to the evaporation, the level of the water in the load tank slowly falls. This causes the float-operated needle valve to open and transfer water from the make-up tank to equal the rate of evaporation, plus any small airborne droplets in the air that may have discharged.

Air Circuit:
Air from the atmosphere, pre-heated by external means if desired, enters the fan at a rate, which is controlled by the intake damper setting. The fan discharges into the distribution chamber and the air passes upwards through the packing.

OPERATING PRINCIPLE

Familiarize yourself with the Bench Top Cooling Tower System, noting the locations of the 6 temperature readings to be taken when using the system:

1. The "hot" water enters the top of the tower (note T_5 in system diagram on the front of unit) and is fed into troughs, from which flows via notches onto the packing material in the tower (packings). The troughs at the top of the tower are designed to distribute the water uniformly over the packing with minimum splashing. There are several packings that can be used in the tower; you will probably be using the flat, slat-like material. The packings have an easily wetted surface and the water spreads over this to expose a large surface to the air stream.

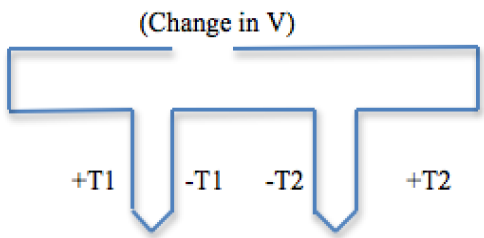
2. The cooled water falls from the lowest packing into the collection basin, and exits the cooling tower into the reservoir (note T_6 in system diagram), where it is heated. The two amber switches on the front of the unit operate the heaters, and note that this allows for three combinations of heating load. In cooling tower applications, the heating load results from a process requiring cooling, such as the condenser coils of an air conditioner. For the Bench Top Cooling Tower, this is a simulated load, and comes in the form of the "load tank".

3. Due to evaporation from the water, an accumulator or "make-up tank" must maintain the quantity of water in the cooling system. The volume of water added to the system can be measured by the loss of water in the make-up tank.

4. Droplets of water (resulting from splashing, etc) may become entrained in the air stream and then be lost from the system. This loss does not contribute to the cooling, but must replenish by the accumulator or make-up tank. To minimize this loss, a droplet arrester, or eliminator is fitted at the tower outlet. This component causes droplets to coalesce, forming drops that are too large to be entrained and these will fall back into the packings.

5. Water flow is controlled by the control valve on the float-type flow meter (rotameter) located at the far right of the unit.

6. To assure that an accurate difference is obtained between the thermocouples, the following setup has been done to obtain the temperature differentials:



With this setting, knowing the temperature at one thermocouple location will enable us to have a much accurate temperature reading. This setting has already been done for thermocouples located at T5 and T3 and the respective temperature differences can observed and recorded in labview.

Air System

1. Using a small centrifugal fan with damper to control flow rate, air is driven up through the wet packings. Air enters the bottom of the tower and flows past a dry bulb temperature sensor (T_1) and a wet-bulb temperature sensor (T_2). At the exit of the cooling (at the top) the exit air dry bulb temperature (T_3) and wet-bulb temperature (T_4) are measured. Note that the wicks on the wet bulb sensor are immersed in reservoirs of water that may require filling. It should be observed that the change of dry bulb temperature is smaller than the change of wet bulb temperatures. This indicates that the air leaving is almost saturated, i.e, Relative Humidity approaches 100%. This increase in the moisture content of the air is due to the conversion of water into steam and the latent heat for this will account for most of the cooling effect.

2. If the cooling load was switched off and the unit allowed to stabilize, it should be found that the water will leave the basin close to the wet bulb temperature of the air entering. According to the local atmospheric conditions, this can be several degrees below the incoming air (dry bulb) temperature.

3. Without a simulated load, the cooling tower would be able to cool the water to a temperature that approaches the wet bulb temperature. This is an “ideal” parameter of this system.

PROCEDURE (DAY 1)

1. Study the operating principle of a cooling tower before working with the bench top model.

2. Identify the adjustable parameters and data acquisition systems built into the system. What three variables can be changed?

3. Download the LabView VI for this lab available on the course website. This VI will be used to record all measurements in the lab. Once the VI is run, it will continuously record data from thermocouples T_1,T_2,T_4,T_5 and the differences in temperature between T_5-T_6 and that between T_3-T_1.The data from pressure transducer will also be recorded in labview. The pressure transducer reports pressure separately from the differential manometer on the test stand. When operating the cooling tower, set the air orifice pressure according to the manometer. Pressure transducer readings will be recorded from the VI once the system has reached steady state and will be compared to the manometer reading.

4. Check wet bulb thermocouple reservoir wells for water (T_2 and T_4). Add water if necessary.

5. Determine the accuracy of thermocouple T_1 relative to a standard:

- Remove T_1 from tower and use the thermistor to calibrate thermocouple.
- Turn on the main power switch to the cooling tower. Use LabView VI to read the output from T_1.
- Take measurements at temperatures spread evenly from room temperature to 50°C for a total of 5 readings.
- Establish a spreadsheet for the readings at each temperature to generate a calibration curve.

6. Perform an accuracy check on the thermocouple in the tower using thermocouple T_1. Reinstall T_1 in the tower and turn the water flow rate adjustment knob to shut the water flow off. Switch on the main power so the pump will run, but no water will flow through the tower. Fully open the damper on the fan. Let the tower stabilize for 10 minutes. Operating the cooling tower with no water flow, only the fan with damper fully open, record the dry bulb thermocouple readings (T_1 and T_3 using LabView -you can use the difference between T_1-T_3 to get the value of T_3) . Ideally, they should have the same readings; similarly the wet bulb thermocouples should have the same values. Record both pairs of temperatures.

7. Compare the mean values of T_1 and T_3 with the mean values of the T_2, T_4, T_5 and T_6 (T_5 can be found using the same process as above – using the difference between T_5 and T_6). If a difference in instrument readings is observed, will this require a possible correction factor to bias the sensor readings?

8. Using the humidity gauge in the laboratory, record the relative humidity level in the room. Remember that the humidity (as well as lab temperature and pressure) needs to be recorded every day that the experiment is being performed.

9. Start the Bench Top Cooling Tower and observe the effects of orifice differential pressure, water flow rate, and all the thermocouple readings.

PROCEDURE (DAY 2)

1. Check wet bulb thermocouple reservoir wells for water (T_2 and T_4). Add water if necessary. Make sure that the thermocouple located at the water outlet in the reservoir touches the water.

2. The make-up tank should be at least half full before starting the cooling tower. Use **DISTILLED** water if fluid must be added to the system. Monitor and calculate the amount of water evaporated during all of the test operations of the cooling tower. This can be done by measuring the cross-section of the make-up tower and finding the change in the water level.

3. Start the Bench Top Cooling Tower and set to the following suggested conditions:

   Air orifice differential pressure: 14 mm H_2O
   Water flow rate: 0.5 GPM
   Cooling load: 1.0 kW

4. Let the tower stabilize for 10 minutes. Go to Step 5 while waiting.

5. While you are waiting for the system to come to steady-state, there should be a power supply on the bench top. Turn the power supply on and adjust the voltage output to as close to 8.22 V as you can. Observe the signal output leads (bundled with the power supply leads) from the pressure transducer and where they are connected to the data acquisition equipment. Be sure they are not touching each other or any other metal and that the connections appear sound. The supply provides power to the pressure transducer. The draw on the power supply should be about 0.01 A (10 mA). You can check the "zero offset error" on the transducer output by disconnecting the pressure tap tube connecting the "high side" pressure transducer port, which should be connected to the tap in the top/exit chamber of the cooling tower. Record this value from the LabView VI. Now reconnect the pressure tap tube. While continuing to wait for the system to come to steady-state, proceed to step 6.

6. While you are waiting for the system to come to steady-state, familiarize yourself with the LabView VI created to acquire data from the cooling tower. The VI has readouts and time-series charts for all six thermocouples as well as

pressure transducer readings. The mean-value for the pressure transducer readings takes into account all data while the VI is running and is a "running average". All other readouts are real-time measurements.

7. Once the cooling tower has reached steady state, start the VI to record the thermocouple and pressure values. Allow the VI to record readings for 1 minute to ensure adequate data.

8. Before proceeding check the make up level of the water, add water as needed to bring the level back to the level at the start of the cooling tower operation in Step 2. Be sure to measure and record how much make up water you add. Increase the cooling load to 1.5kW, let the tower stabilize once again for 10 minutes, and repeat Step 7.

9. Before proceeding check the make up level of the water, and add water as needed to bring the level back to the level at the start of the cooling tower operation in Step 2. Set the tower to the following suggested conditions:

Air orifice differential:	20 mm H_2O
Water flow rate:	0.5 GPM
Cooling load:	1.0 kW

10. Let the tower stabilize for 10 minutes. Once the cooling tower has reached steady state, start the VI to record the thermocouple and pressure values. Allow the VI to record readings for 1 minute to ensure adequate data.

11. Before proceeding check the make up level of the water, and add water as needed to bring the level back to the level at the start of the cooling tower operation in Step 2. Increase the cooling load to 1.5kW, let the tower stabilize for 10 minutes, and repeat Step 10.

ANALYSIS

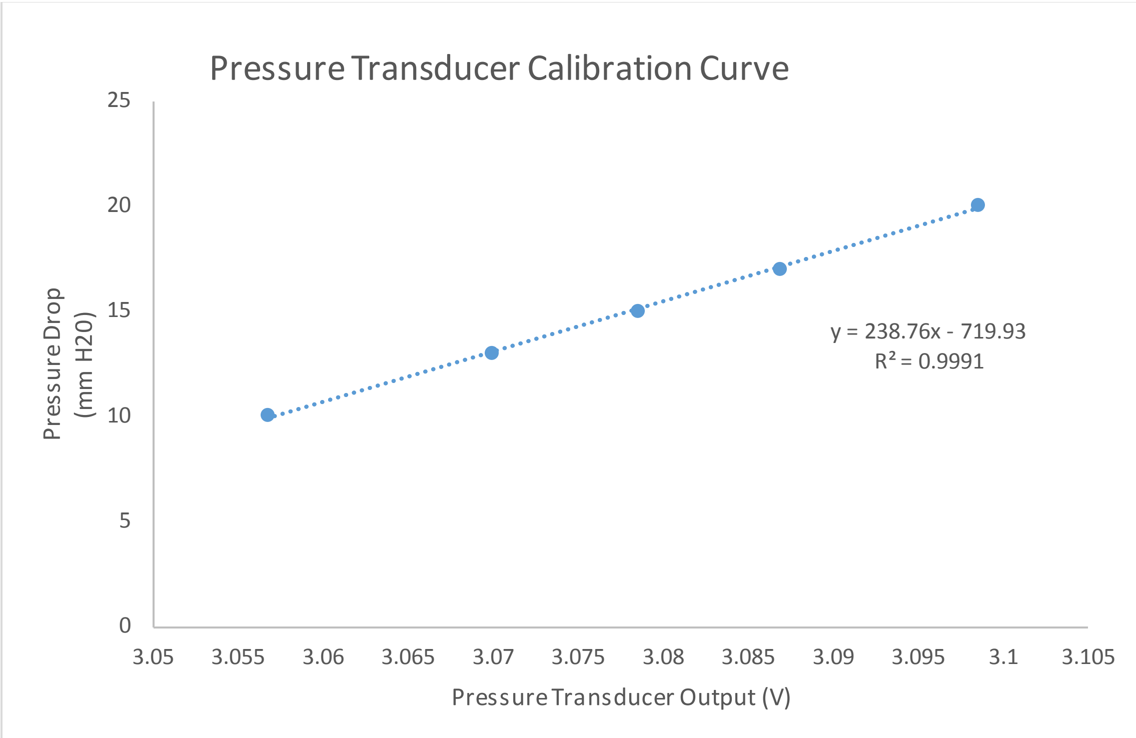
1. Calculate the precision and bias errors as well as total error for the thermocouples. Remember, the bias error is systematic and is the difference between your standard and the mean of your measurements. The precision error is random and represents the 95% confidence interval for your mean value of your measurements. Total error is calculated by adding bias and precision error totals in quadrature.

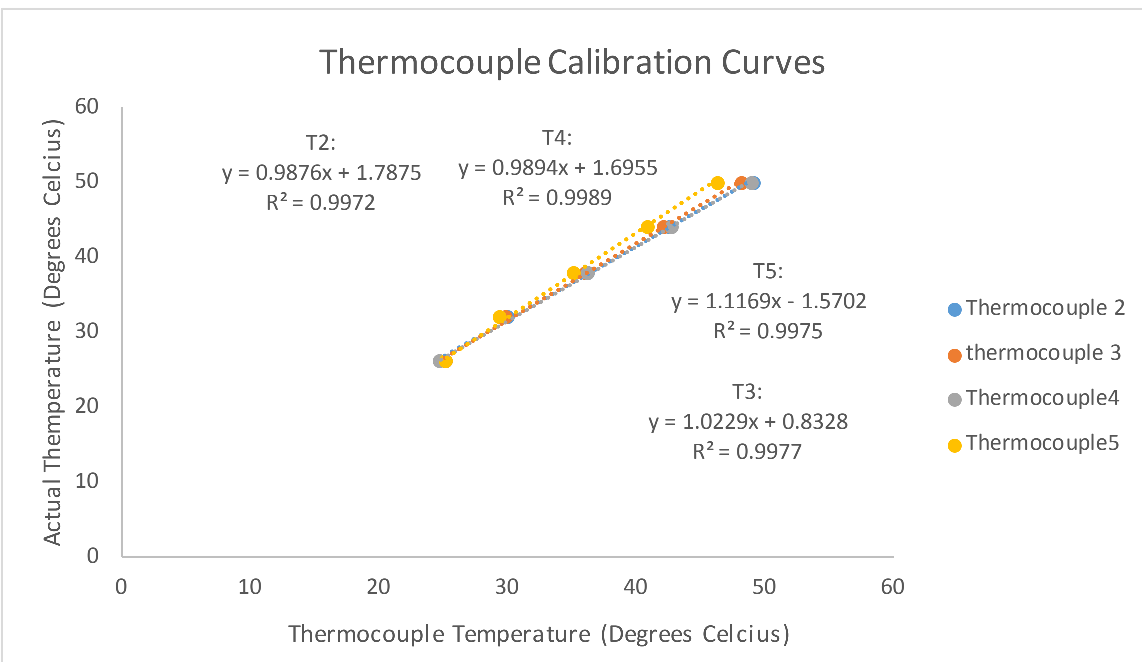
2. Using a psychrometric chart given at the end of this handout, determine the relative humidity in the room for each setting at which the unit was run using the wet and dry bulb inlet air temperatures (averaged). Is the room becoming more humid as the testing progresses (systematic), or does it appear to be random?

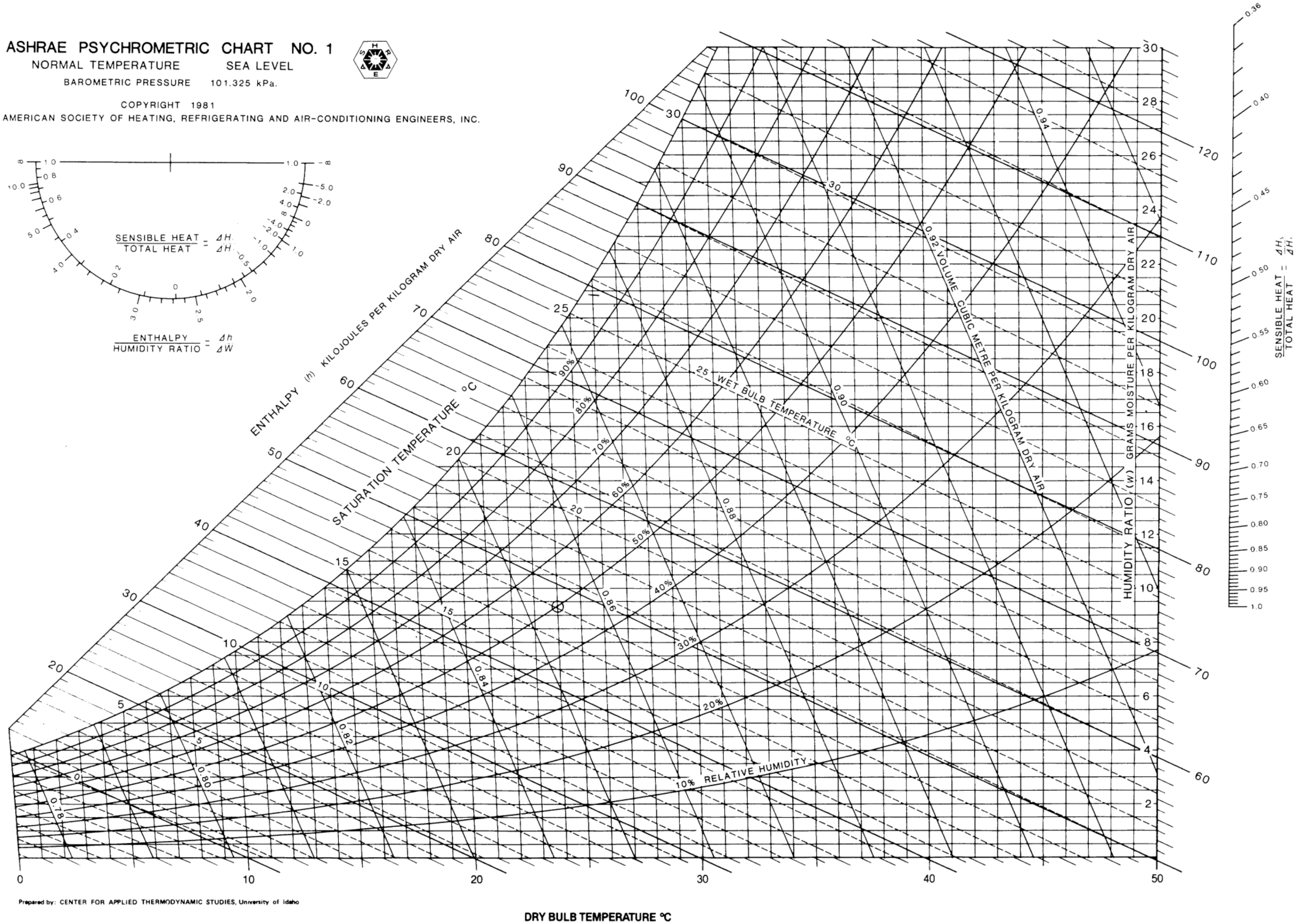
3. Calculate the effectiveness of the cooling tower by calculating the difference between the water exiting the cooling tower (T_6) and the wet bulb temperature of the air entering the cooling tower (T_2). This is known in cooling tower terminology as the "approach temperature". Is it physically possible for the approach temperature (T6 –T2) to be less than 0?

4. Compare and comment on the results between the cooling tower operating conditions. What test matrix of variables was used? Which variables were held constant (or controlled)? Which were varied? Comment on any other interesting tests that might be run, measurements which didn't make sense, and any other engineering observations about the experiment.

APPENDIXA FIGURES






ASHRAE PSYCHROMETRIC CHART NO. 1
NORMAL TEMPERATURE SEA LEVEL
BAROMETRIC PRESSURE 101.325 kPa.
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AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔHt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO (W) GRAMS MOISTURE PER KILOGRAM DRY AIR
RELATIVE HUMIDITY
DRY BULB TEMPERATURE °C
Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho

Chart 1*b*

ASHRAE PSYCHROMETRIC CHART NO. 1

NORMAL TEMPERATURE

BAROMETRIC PRESSURE 29.921 INCHES OF MERCURY

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SEA LEVEL

Chart 1a