THERMAL MEASUREMENTS INVESTIGATION REPORT

To: [redacted]
From: Jessica Nicholson
Project Title: Thermal Measurements Investigation

INTRODUCTION

This experiment compares several temperature measurement tools by evaluating how closely their temperature measurements match, estimating the actual temperature of each scenario with the average of these measurements, and finding the approximate accuracy of each instrument using several methods of difference calculation. The next evaluation compares two methods of thermocouple temperature measurement, one with an ice bath reference and one with an electronic reference. Psychrometric evaluation then introduces the function of wet-bulb and dry-bulb temperature measurement. Below are the listed primary objectives of this experiment.

- Use several temperature measurement tools to gather readings from the same materials
- Evaluate which instrument or instruments deviate the most from the average and why
- Compare the accuracy and difference between thermocouples with an electronic cold reference junction vs ice water compensation
- Find the relative humidity, humidity ratio, specific volume, and enthalpy of the air based on wet-bulb and dry-bulb measurements as well as how they change with different values

DISCUSSION

Different thermal measurement instruments are used in several scenarios to gather temperature measurements under constant conditions and evaluate the accuracy between these tools. These initial measurements are shown in Table 1. For each condition, the accurate temperature is approximated by taking an average of these temperature measurements. This average roughly reveals which instruments tend to perform the measurements accurately and also which ones deviate the most. The scenario—or temperature of the material—seems to be one factor that impacts the accuracy of each instrument because the least accurate instrument shown in Table 2 is not the same for each condition. Regardless, the IR thermometer is the least accurate instrument for three of the four conditions based on its high deviation from the average temperature measurement. This instrument may experience such inaccuracy because it measures the radiation of surfaces from a distance, so radiation from surrounding sources has an impact on the temperature measurement. The level of this interfering radiation increases the further away the IR thermometer is positioned from the surface it measures. Radiation measured by the IR thermometer may also be an inaccurate reflection of the surface temperature of a material at higher temperatures, which is particularly evident in the thermoweld temperature measurement where the IR thermometer value deviates significantly from the average. The other instruments, apart from thermal imaging, measure surface temperature directly and their results are highly consistent.

For each condition, the difference is observed through calculations of direct difference (C) and fractional deviation in both Celsius and Kelvin (absolute temperature). These calculations are shown by Equations 1 and 2 in Appendix A and used in Table 2. It is better to calculate the observed difference as fractional deviation, because it quantifies the difference between the measured value and the average—or expected—value as a fraction of the average value. This provides an error value that can be accurately compared to other error values because it presents the difference as a proportion of magnitude and therefore considers the impact of the magnitude of the expected value on measures of accuracy. Differences of the same quantity, for example, are less significant for a larger expected or theoretical value and yield a lower error. Fractional deviation is not properly represented on the Celsius scale, because Celsius has negative values above absolute zero. Calculating the error for an expected value in the negative range will yield a negative result that is not valid in measures of fractional error. For expected temperature near 0 degrees Celsius, the error measurement is too high to be representative of the true error of the measurement. Kelvin, however, is a positive scale with 0 being absolute 0. Calculating fractional deviation from Kelvin yields no negative or inflated values.

The thermocouple ice water compensation and electronic cold reference junction temperature measurements are slightly different, but these values are close enough to conclude that they agree. Table 3 shows these results. Since the ice water compensation method yields a slightly higher value, it may indicate that the ice water bath has a temperature slightly higher than 0 degrees Celsius. This may cause the slight increase in measured voltage and therefore air temperature since the ice water bath is the reference that compensates for no electronic reference. The electronic cold reference junction technique is therefore more accurate. The two methods do, however, correspond to similar room temperature measurements of 22.24 C for ice water compensation and 21.75 C for electronic cold reference junction as found from Table 5.

Parameters determined from wet-bulb and dry-bulb measurements are shown in Table 4. These include relative humidity, humidity ratio, specific volume, and enthalpy found from the relative humidity table and psychrometric chart shown in Figures 1 and 2. If the dry-bulb temperature were to increase by 5 degrees F, all of the parameters experience the change shown in Table 4. These changes include a significant drop in both the humidity ratio and relative humidity for an increase in dry-bulb temperature when the wet-bulb temperature remains constant. The specific volume is approximately the same and enthalpy experiences a small decrease.

CONCLUSION

Through this investigation into accuracy and differences between thermal measurement instruments, each of the initial objectives have been fulfilled. The instruments with the greatest inaccuracies have been identified through fractional difference calculations with an explanation while the comparison between the two thermocouple measurement methods draws the conclusion that the inaccuracy from ice water compensation is present but minimal. The dry-bulb thermometer has an impact on all of the psychrometric parameters given a constant wet-bulb temperature, particularly relative humidity and the humidity ratio. To expand on this experiment, the IR thermometer could be further investigated by making distance from the measured surface an independent variable and evaluating its impact on the temperature measurement. The psychrometric analysis could also include an evaluation into the effects of changing wet-bulb temperature.

APPENDIX A: Experimental Data, Figures, and Equations

Table 1: Temperature Measurements with Different Instruments

	Temperature (C)			
Instrument	Ice cold water	Boiling water	Ambient air	Thermoweld
Liquid thermometer	-1	97.5	23.5	101.5
Thermocouple	-0.4	99.4	23	102.3
RTD	0.1	99.1	24.1	103.5
Thermistor	0.2	97.5	22.5	99.4
IR Thermometer	-2.2	95.9	22.5	49.6
Thermal imaging	-0.1	97.2	22.3	63.1
Average	**-0.57**	**97.77**	**22.98**	**86.57**

Table 2: Greatest Observed Differences from the Average Measured Temperature

	Greatest Observed Difference from the Average for Each Case			
	Ice cold water	Boiling water	Ambient air	Thermoweld
Instrument	IR Thermometer	IR Thermometer	RTD	IR Thermometer
Temperature Difference (C)	1.63	1.87	1.12	36.97
Fractional Difference, Celsius Value	-2.8824	0.0191	0.0486	0.4270
Fractional Difference, Kelvin Value	0.0060	0.0050	0.0038	0.1028

Equation 1: Temperature Difference (C)

$$T_{diff} = |T_{measured} - T_{avg}|$$

Sample calculation:

$$T_{diff,Ice} = |(-2.2) - (-0.57)| = 1.63$$

Equation 2: Fractional Difference (%)

$$Fractional\ Difference = (|T_{measured} - T_{avg}|)/T_{avg}$$

Sample calculation:

$$Fractional\ Difference,\ Ice(C) = (|(-2.2) - (-0.57)|)/(-0.57) = -2.8824$$

Table 3: Comparative Air Temperature Measurements between Two Methods

Ambient Air Measurement	**Voltage (mV)**	**Temperature (C)**
Ice Water Compensation	0.88	22.24
Electronic Cold Reference Junction	0.86	21.75

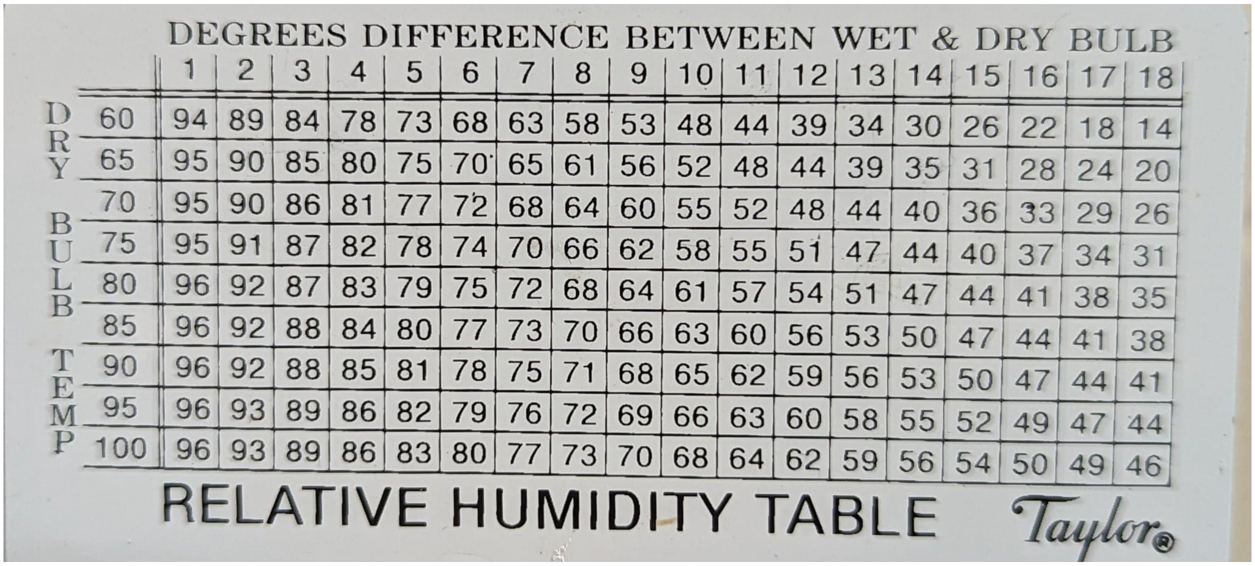
Table 4: Parameters Determined from Wet-Bulb and Dry-Bulb Measurements

Wet bulb (F)	Wet bulb (C)	Dry bulb (F)	Dry bulb (C)	Relative Humidity (%)	Humidity Ratio	Specific Volume (m^3/kg)	Enthalpy (kJ/kg)
62.5	16.94	71.5	21.94	60.6	10	0.85	48
62.5	16.94	76.5	24.72	44.9	8.5	0.855	46.5

Table 5: Temperature (C) to Thermoelectric Voltage (mV) Conversion Chart

Thermoelectric Voltage (absolute mV)

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-40	-1.475	-1.510	-1.544	-1.579	-1.614	-1.648	-1.682	-1.717	-1.751	-1.785	-1.819	-40
-30	-1.121	-1.157	-1.192	-1.228	-1.263	-1.299	-1.334	-1.370	-1.405	-1.440	-1.475	-30
-20	-0.757	-0.794	-0.830	-0.867	-0.903	-0.940	-0.976	-1.013	-1.049	-1.085	-1.121	-20
-10	-0.383	-0.421	-0.458	-0.496	-0.534	-0.571	-0.608	-0.646	-0.683	-0.720	-0.757	-10
0	0.000	-0.039	-0.077	-0.116	-0.154	-0.193	-0.231	-0.269	-0.307	-.0345	-0.383	0
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.351	0.391	0
10	0.391	0.430	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.789	10
20	0.789	0.830	0.870	0.911	0.951	0.992	1.032	1.073	1.114	1.155	1.196	20
30	1.196	1.237	1.279	1.320	1.361	1.403	1.444	1.486	I.528	1.569	1.611	30
40	1.611	1.653	1.695	I.738	1.780	1.822	1.865	1.907	1.950	1.992	2.035	40
50	2.035	2.078	2.121	2.164	2.207	2.250	2.294	2.337	2.380	2.424	2.467	50
60	2.467	2.511	2.555	2.599	2.643	2.687	2.731	2.775	2.819	2.864	2.908	60
70	2.908	2.953	2.997	3.042	3.087	3.131	3.176	3.221	3.266	3.312	3.357	70
80	3.357	3.402	3.447	3.493	3.538	3.584	3.630	3.676	3.721	3.767	3.813	80
90	3.813	3.859	3.906	3.952	3.998	4.044	4.091	4.137	4.184	4.231	4.277	90
100	4.277	4.324	4.371	4.418	4.485	4.512	4.559	4.607	4.654	4.701	4.749	100
110	4.749	4.796	4.844	4.891	4.939	4.987	5.035	5.083	5.131	5.179	5.227	110
120	5.227	5.275	5.324	5.372	5.420	5.469	5.517	5.566	5.615	5.663	5.712	120
130	5.712	5.761	5.810	5.859	5.908	5.957	6.007	6.056	6.105	6.155	6.204	130
140	6.204	6.254	6.303	6.353	6.403	6.452	6.502	6.552	6.602	6.652	6.702	140
150	6.702	6.753	6.803	6.853	6.903	6.954	7.004	7.055	7.106	7.156	7.207	150
°C	0	1	2	3	4	5	6	7	8	9	10	°C



DEGREES DIFFERENCE BETWEEN WET & DRY BULB

DRY BULB TEMP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
60	94	89	84	78	73	68	63	58	53	48	44	39	34	30	26	22	18	14
65	95	90	85	80	75	70	65	61	56	52	48	44	39	35	31	28	24	20
70	95	90	86	81	77	72	68	64	60	55	52	48	44	40	36	33	29	26
75	95	91	87	82	78	74	70	66	62	58	55	51	47	44	40	37	34	31
80	96	92	87	83	79	75	72	68	64	61	57	54	51	47	44	41	38	35
85	96	92	88	84	80	77	73	70	66	63	60	56	53	50	47	44	41	38
90	96	92	88	85	81	78	75	71	68	65	62	59	56	53	50	47	44	41
95	96	93	89	86	82	79	76	72	69	66	63	60	58	55	52	49	47	44
100	96	93	89	86	83	80	77	73	70	68	64	62	59	56	54	50	49	46

RELATIVE HUMIDITY TABLE Taylor®

Figure 1: Relative Humidity Table (F)

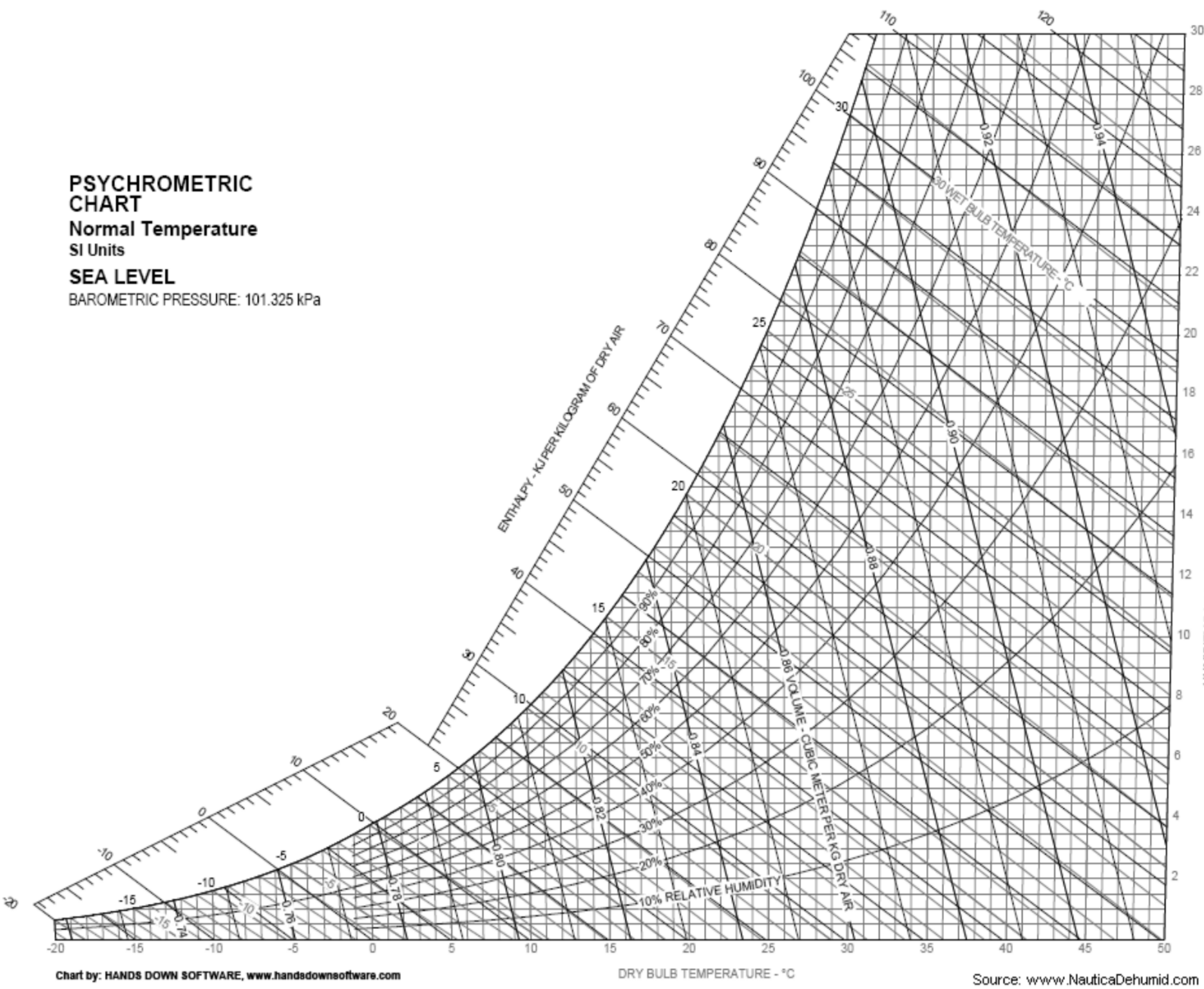


Figure 2: Psychrometric Chart

APPENDIX B: Experimental Setup

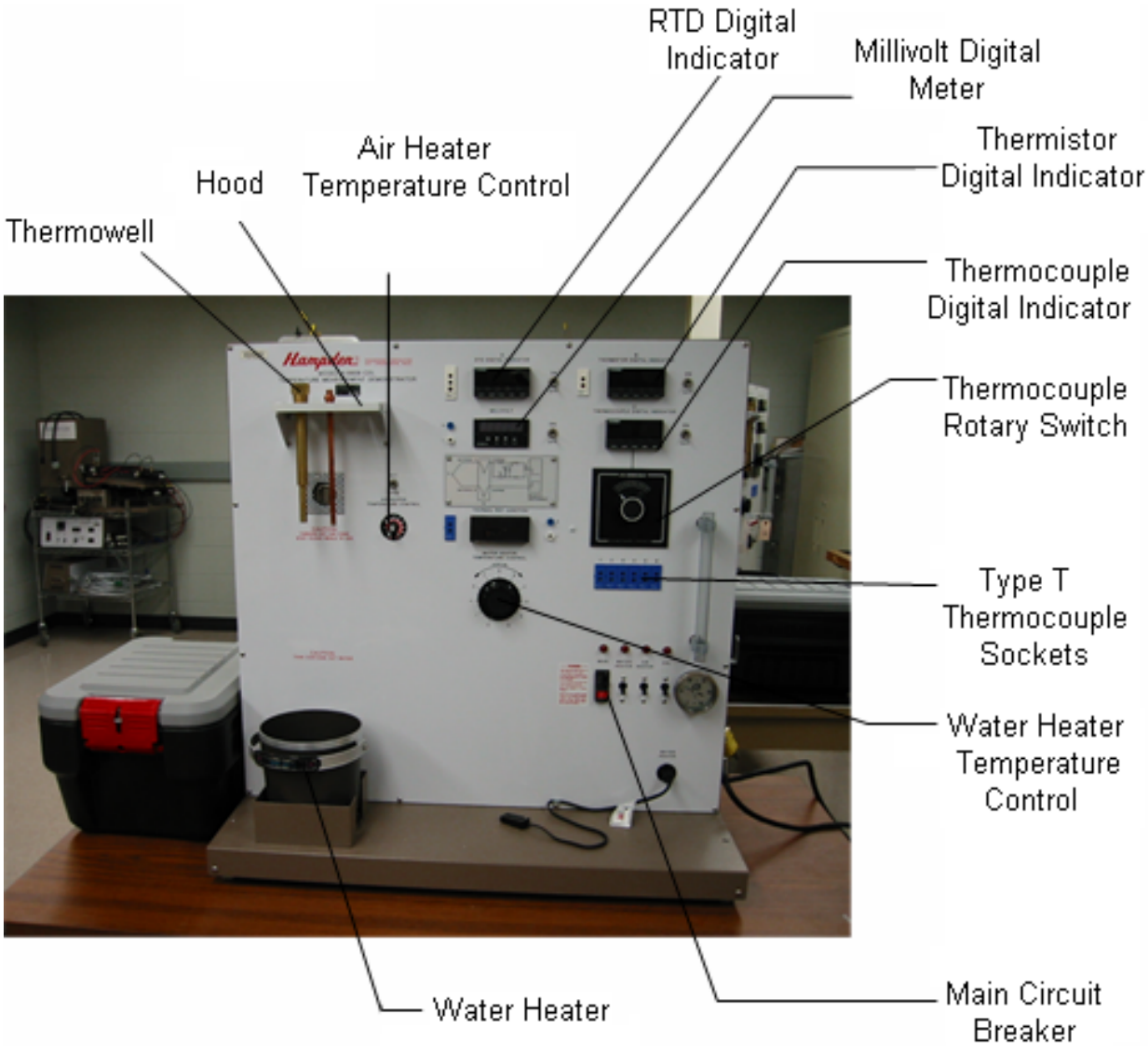


Figure 3: Main Control Panel and Components

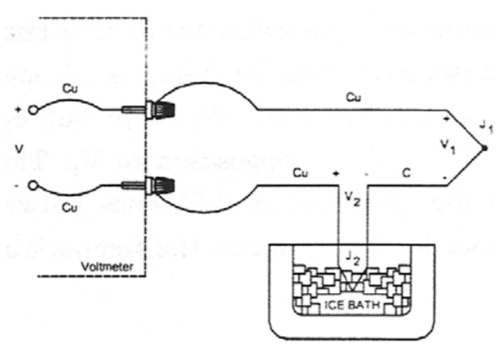


Figure 4: Thermocouple (Ice Bath)

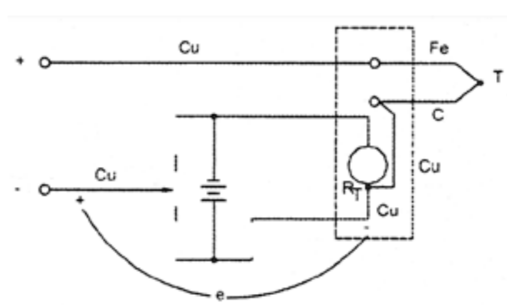


Figure 5: Thermocouple (Reference Junction)

APPENDIX C: Experimental Uncertainty

Several factors in this experiment may contribute to uncertainty in the results, particularly in the temperature measurements of each scenario with each thermal instrument. These considerations are listed below.

- Only one temperature measurement trial was taken for each thermal instrument and scenario, so any precision error will have not been detected and led to inaccurate results.
- The instruments, particularly the thermocouple, RTD and thermistor, took time to reach a steady-state value and experienced slight fluctuation in the temperature reading even after reaching a steady state. This may have caused data acquisition bias error and affected accuracy.
- For measurements of the ice bath temperature, the temperature may change from the 0 C expected value over the time of the experiment due to melting ice. This may have impacted the accuracy of later measurements including the measured mV value using the ice bath reference thermocouple.

APPENDIX D: Time Spent on Experimental Process

Table 6: Time Spent on Experimental Process

Activity	**Day(s)**	**Time(s)**
Collect temperature data with each instrument for each scenario	9/2	11:00-12:30 pm
Record voltage from both thermocouple configurations	9/2	12-30-12:45 pm
Read wet-bulb and dry-bulb thermometers for psychrometric evaluation	9/2	12:45-12:50 pm
Calculate average temperature of each scenario and differences to identify the most significantly deviating instruments	9/28	9:00-9:45 pm
Find temperature values corresponding to thermocouple voltage measurements and properties for psychrometric evaluation	9/29	7:30-8:30 pm
Conclude findings and write report	9/28-9/30	Various
Finalize appendices	9/30	8:00-9:30 pm

APPENDIX E: References

N/A