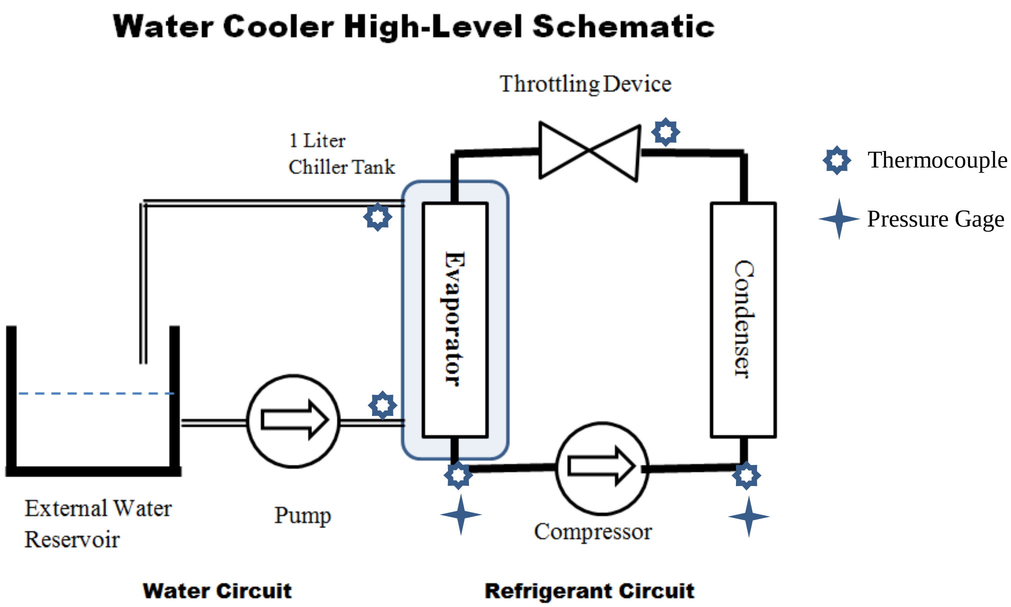
Abstract

Measurements with a repurposed water cooler are used to deepen the student's understanding of thermodynamic principles and their practical application in a commercial refrigeration device. The exercise provides experience with thermal instrumentation, thermodynamic calculations, and sources of difference between real and ideal systems.



Objectives of this laboratory exercise

- Consolidate an understanding of first-law principles as applied to a real-world refrigeration cycle.
- Provide hands-on experience with the implementation of a vapor compression cycle in a commercial refrigeration apparatus.
- Provide practice in use of thermodynamic property tables (or charts).
- Provide practice in doing thermal measurement and calculations, including manipulation and conversion between various unit systems [joules, calories, pressure and absolute pressure, psi, kilopascals, etc.]
- Compare black-box measurements of COP (coefficient of performance) with the results of calculations based on temperature and pressure measurements and the thermodynamic properties of R-134a.
- Practice fitting laboratory data to a simple mathematical model of the water cooler. Completing this part of the exercise requires a three-parameter fit, which will be a stretch goal for many students.

Pre-lab preparation

- Read carefully through this lab instruction.
  - Identify all deliverables to be included in the lab report.
  - Identify materials you are asked to bring with you to the lab and have them in your possession when you arrive.
  - Be prepared to ask questions of the lab instructor about anything you do not understand.
- Understand the difference between gage pressure (psig, or simply psi) and absolute pressure (psia), and how to convert between the two. Pressures that appear in thermodynamics textbooks are usually absolute (psia), i.e., pressures relative to vacuum. Pressures that appear in tables used by A/C technicians are usually psig. When making measurements and when using property tables, be sure you understand which definition of pressure applies.[1]
- Refer to the following online reference
  http://www.ohio.edu/mechanical/thermo/Intro/Chapt.1_6/refrigerator/refrig_problems.html
  Work carefully through the two example problems included in section 4.7:
  - refrigeration system with linear compressor and refrigerant R-134a, and
  - refrigeration system *with an internal heat exchanger*.

  Test your understanding of problem 4.7 by redoing the calculations with the values tabulated here. Use the case of a refrigerator with an internal heat exchanger**. Include your analysis with your lab report.**

Use these pressures and temperatures to redo Problem 4.7 (with internal heat exchanger).				
Pressures	P1 = 20 psi		P2x = 150 psi	
Temperatures		T1x = 68° F	T2x = 194° F	T3 = 95° F

  Answers:

Work done by the compressor	23 BTU/lbm = 169 kJ/kg
Heat transferred in the internal heat exchanger	9.5 BTU/lbm = 22.1 kJ/kg
Heat absorbed by the evaporator	72.5 BTU/lbm = 53.5 kJ/kg
Heat rejected by the condenser	95.5 BTU/lbm = 222 kJ/kg
COP	3.15

  The laboratory exercise builds directly on this example problem. In the laboratory apparatus, the expansion valve of the example problem is replaced by a capillary tube. This design choice is common in small inexpensive chillers.[2]

- Bring a USB memory device (thumb drive) to capture data from the laboratory computer.
- Bring a copy of a p-h (pressure – enthalpy) table (or a p-h chart) for R-134a.

---

[1] The pressure gages attached to the apparatus are specialized for use in refrigeration systems, and in particular for use with refrigerant R-134a. They have both a pressure scale and a temperature scale. The temperature scale indicates the saturation temperature for the indicated pressure. Compare the pressure-temperature relationship on the gages to the pressure-temperature relationship in your table of thermodynamic properties. Are they different? If so, why?

[2] For comparison of expansion valves and capillary tubes, see http://www.thermal-edge.com/unit-features/thermal-expansion-valve/ . This is one of several websites that discuss the relative advantages of the two throttling devices. The primary advantage of capillary tubes is that they are less expensive.

CAUTION: During operation, the condenser (back grill) and internal components of the water cooler become uncomfortably hot. Prolonged contact with the skin can result in a burn.

Prepare the water chiller for operation

- Become familiar with the overall layout of the apparatus: the water cooler, the plastic water reservoir[3], and the aquarium pump.
- ***With the apparatus unplugged and cool***, trace the flow of refrigerant from the compressor to the condenser, through the filter, through the capillary tube, through the evaporator (chiller tank), and back into the compressor. Note that the capillary tube and compressor suction line (return from the evaporator) run in contact with each other for a portion of their length. This contact implements the heat-exchanger referred to in the thermodynamic analysis.
- Using the container provided and water from the lab sink, fill the plastic reservoir with 3 gallons of water. Mix cold and hot water until the temperature is warm to the touch, like a warm bath. Further on in the experiment you will measure the water temperature, but you can obtain useful results with a range of starting temperatures. So no particular initial temperature is requires. [Teaching fellow] Make sure the hoses are correctly connected between the pump and the water chiller.
- **DO NOT TURN ON THE WATER COOLER AT THIS TIME**.
- Plug in and turn on the aquarium pump. It may take twenty minutes for the pump to fill the tank in the chiller. You will know that it is full when you see water flowing from the water return line, with few bubbles. While the tank fills, re-read this laboratory instruction, and familiarize yourself with the location and appearance of the components of the apparatus:
    - The compressor
    - The condenser
    - The refrigerant filter
    - The capillary tube
    - The chiller tank
    - The high-pressure and low-pressure gages
    - The water flow-meter
    - The AC power meter. (In a subsequent step you will plug the chiller into the power meter, and the power meter into the wall outlet.)

Become familiar with the data logging system.

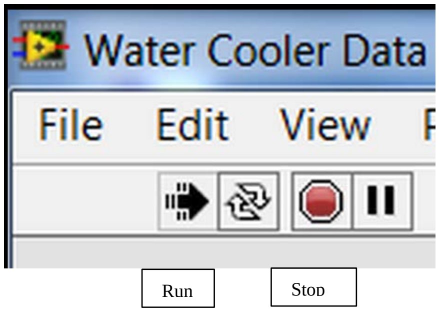
- Log onto the PC which supports data gathering:
    - Username: ME304WaterCoolerLab
    - Password: Fall&2014
- On the Windows desktop, click on *WaterCooler Lap Application* to open the LabView virtual instrument.
- Become familiar with the user interface screen (front panel). The screen is an image of the thermodynamic cycle of the water cooler. The instrument will automatically log temperatures.

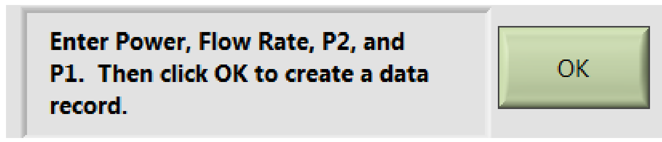
---

[3] Playmate maxcold beverage carrier

You will have to read and manually input readings from the two pressure gages, the power meter, and the flow meter.

- Observe the Run and Stop buttons at the upper left corner of the computer screen. Click on the Run button to *create a preliminary data log*. At this point, the data scanning software will be active. Date, time, and elapsed time indicators will show live values. The six temperature indicators will show measured temperatures. You will have the opportunity to enter pressures, power, and water flow rate manually. For pressures, enter 35 and 200 for high and low side respectively. (These are arbitrary values.) For power enter 98 (watts). For flow rate enter 8 (gph). Now near the bottom right corner of the screen, click “OK.”

  The system will ask you to enter the name of a file to capture the measured data. You may select WaterCoolerData.xlsx or enter a name of your own creation. Now click “OK” a couple of additional times, with the clicks separated by about five seconds.
- Click the Stop button to terminate data logging. Using Windows Explorer, find and use Excel to open the file you just made. Observe the structure and contents of the file.
- In a few minutes you will start to record real data. [IMPORTANT] Once you start, do not open the file again until you have completed the lab. Although Excel recognizes files created by LabView, LabView does not recognize files created by Excel. If you open your data file and save it in Excel, then the next time you click “OK,” LabView will overwrite it (rather than append new measurements to it.)

Data Logging and In-Process Checks (Do the steps in the order suggested.)

CAUTION: During operation, the condenser (back grill) and internal components of the water cooler become uncomfortably hot. Prolonged contact to the skin can result in a burn.

- Activate the LabView data logger by clicking on the Run button, clicking on the “OK” button, and entering the name of a data collection file (or accepting the name which you previously chose).
- Plug the water cooler into the power meter, and the power meter into the wall outlet.
- Make sure the water cooler power switch is on. (On the back of the cooler).
- Begin observing and recording pressures, power, and flow rate. During the first few minutes, pressures and power may change rapidly as the system goes through its startup transient, so attempt to get a measurement every 30 seconds or so. After about five minutes, temperatures and power change slowly, so you may take a measurement only every two minutes (approximately). After about ten minutes, things change very slowly, so you can take a measurement only once every 5 minutes (approximately). There is no harm in having too much data.

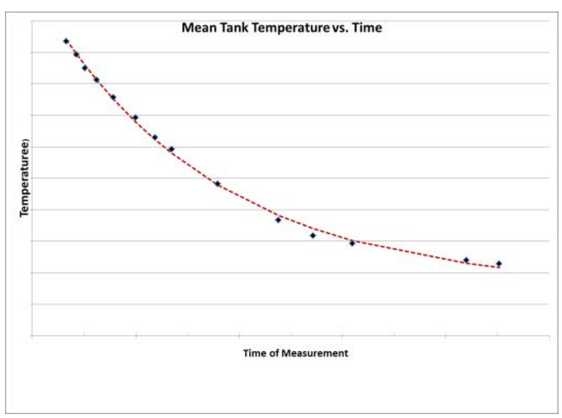
- Your measurements should include data at water temperatures down to 10° C. If the water temperature has not reached 10° C within 90 minutes you may stop measuring.

In-Process Checks

- Knowing only the energy consumed, the mass of water chilled, and the amount by which it has been chilled (temperature drop), you can calculate an overall coefficient of performance (COP) for the chiller. You will not need to use any details of the refrigerant cycle itself. Calculate the COP on roughly fifteen-minute intervals. Is it constant? If not, is it increasing or decreasing? To do this calculation in real time during the lab you will need to track water temperature and compressor power on paper, i.e., outside the computer-generated file.
- Using temperature and pressure readings from the Front Panel, calculate COP according to the example you did in the pre-lab preparation. How good is the agreement between the COP calculated from a black box view and the COP calculated from thermodynamics of the refrigeration cycle? Why might the calculations differ? ***Report your results as part of your lab report.***

After-lab exercises

- Using data taken approximately fifteen-minutes after you turn on the compressor, estimate the mass-flow rate of the R-134a refrigerant. Express your answer in kg/minute.
- The thermodynamic model used in calculations assumes that all energy flowing into the system comes from the compressor or from the heat picked up by the evaporator. It also assumes that all heat flowing out of the system exits through the condenser. From your observations of the water cooler, name, if you can, other sources of energy gain or loss. Quantify at least one of these gains or losses. **Include your answers in your lab report.**
- The following three-part question is a stretch ecercise.. Each of its three sections is progressively harder.
  - Plot water temperature vs. time. Your plot will probably resemble the graph shown. In



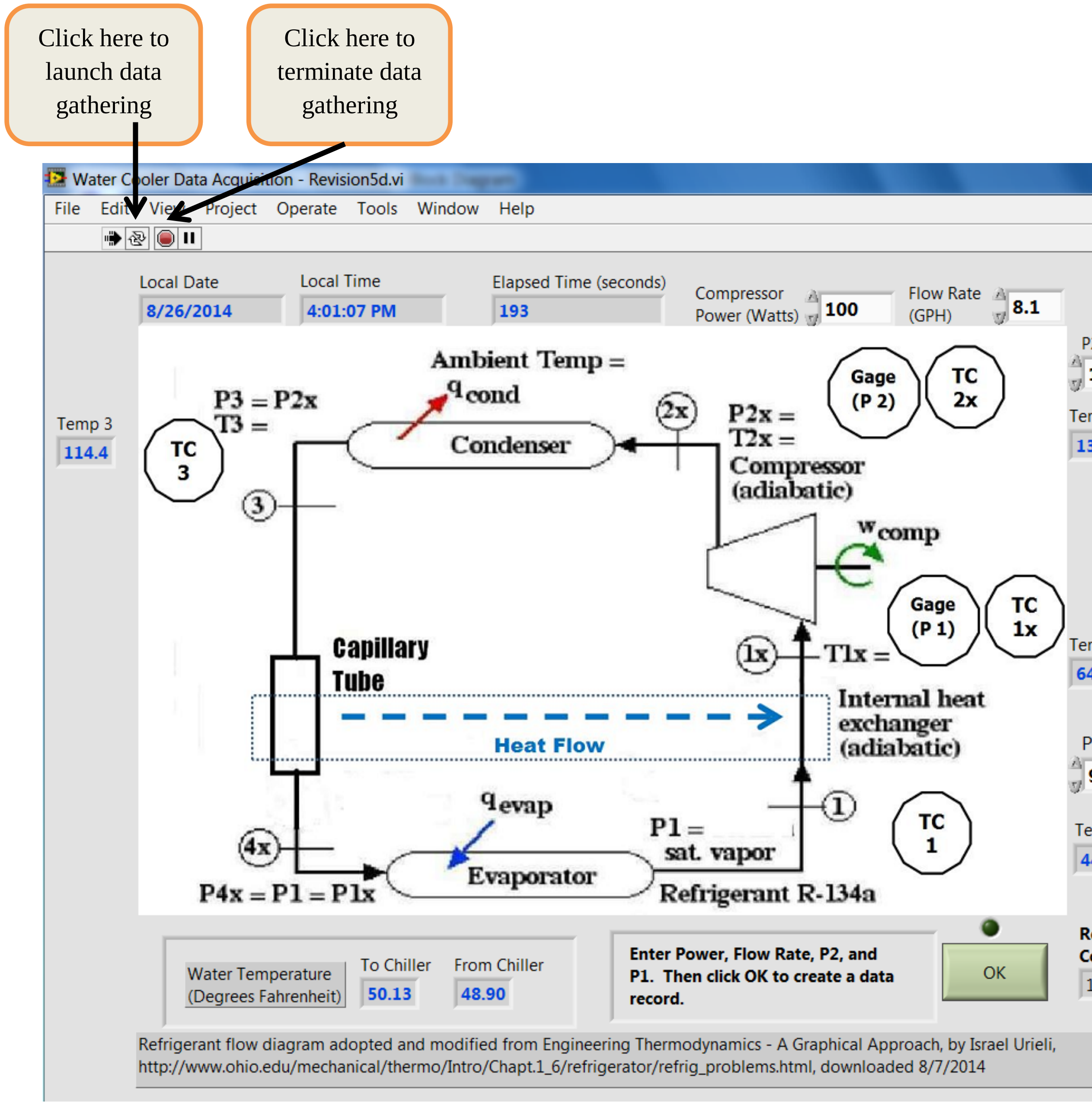
    qualitative terms, describe what is happening in this graph?
  - Write a general equation T = f(t) which describes what you see. You are not required to specify the coefficients that appear in your equation. For example, you might say T = A*exp(-at), without specifying the values of A and a. [This is NOT the equation I would

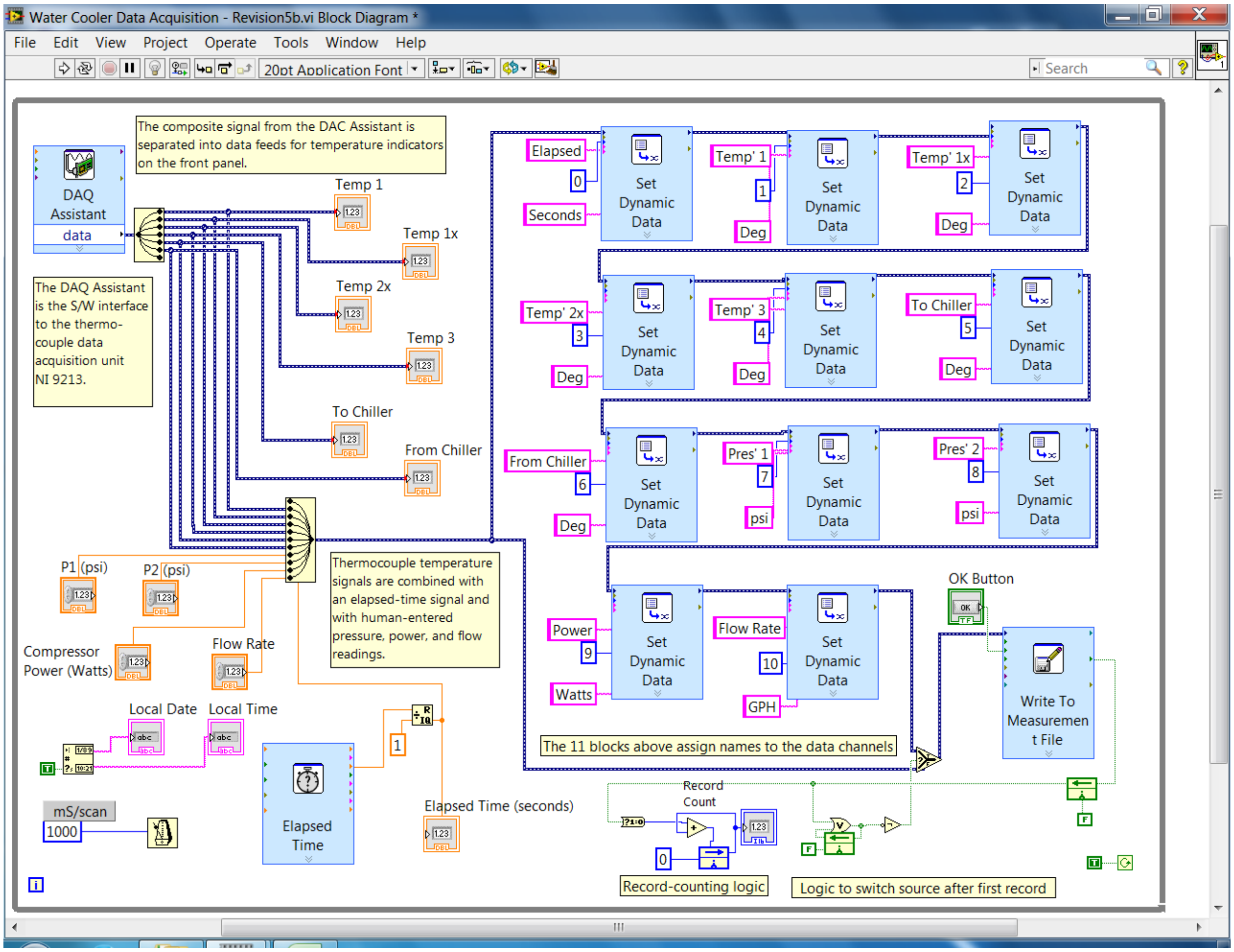
write, but it gives the idea of supplying the form of an equation without specifying coefficients.]

- Now specify coefficients. On the same graph, plot the experimental data and your equation. You can get a pretty good fit using *guess and test*. A *best-fit* curve is most easily done with specialized curve fitting software or by minimizing the sum-of-squared-errors with Excel's *Solver* routine. You are not required to produce this degree of precision.[4,5]

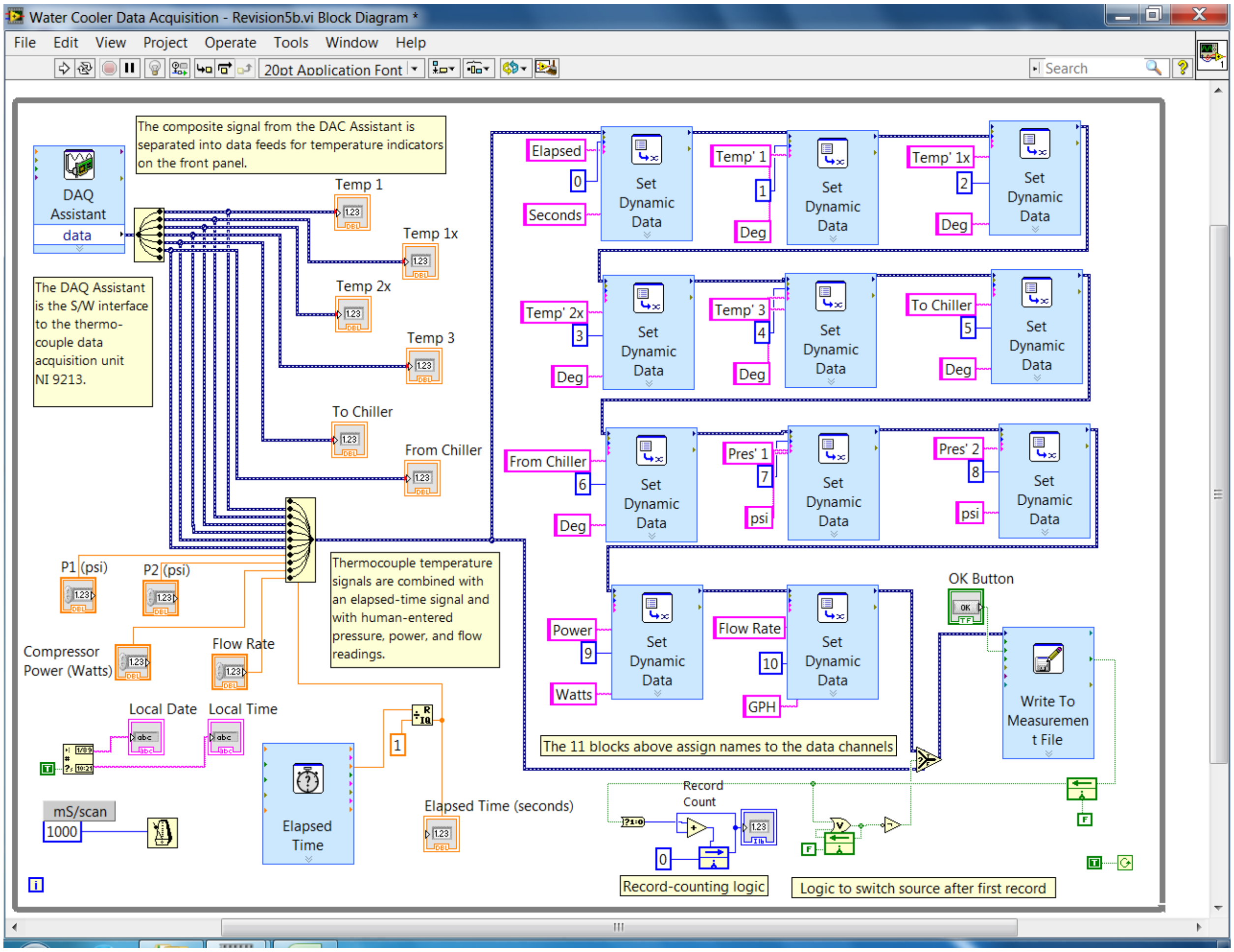
[4] For a compact explanation, see *Fitting More Complex Functions*, at http://www.jkp-ads.com/articles/leastsquares.asp,

[5] For a step-by-step explanation, see http://www.csupomona.edu/~seskandari/documents/Curve_Fitting_William_Lee.pdf

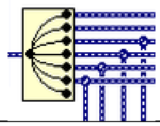
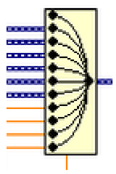
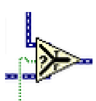
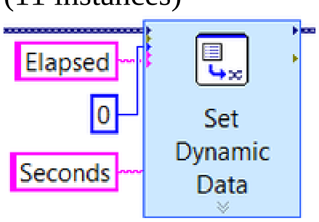
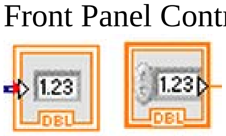

Click here to launch data gathering
Click here to terminate data gathering
Water Cooler Data Acquisition - Revision5d.vi
File
Edit
View
Project
Operate
Tools
Window
Help
Local Date
8/26/2014
Local Time
4:01:07 PM
Elapsed Time (seconds)
193
Compressor Power (Watts)
100
Flow Rate (GPH)
8.1
Temp 3
114.4
Ambient Temp =
q cond
P3 = P2x
T3 =
TC 3
Condenser
2x
P2x =
T2x =
Compressor (adiabatic)
Gage (P 2)
TC 2x
3
w comp
Gage (P 1)
TC 1x
Capillary Tube
1x
T1x =
Internal heat exchanger (adiabatic)
Heat Flow
q evap
1
P1 = sat. vapor
TC 1
4x
Evaporator
P4x = P1 = P1x
Refrigerant R-134a
Water Temperature (Degrees Fahrenheit)
To Chiller
50.13
From Chiller
48.90
Enter Power, Flow Rate, P2, and P1. Then click OK to create a data record.
OK
Refrigerant flow diagram adopted and modified from Engineering Thermodynamics - A Graphical Approach, by Israel Urieli, http://www.ohio.edu/mechanical/thermo/Intro/Chapt.1_6/refrigerator/refrig_problems.html, downloaded 8/7/2014



Water Cooler Data Acquisition - Revision5b.vi Block Diagram *
File Edit View Project Operate Tools Window Help
20pt Application Font
Search
The composite signal from the DAC Assistant is separated into data feeds for temperature indicators on the front panel.
DAQ Assistant
data
The DAQ Assistant is the S/W interface to the thermo-couple data acquisition unit NI 9213.
Temp 1
Temp 1x
Temp 2x
Temp 3
To Chiller
From Chiller
P1 (psi)
P2 (psi)
Compressor Power (Watts)
Flow Rate
Thermocouple temperature signals are combined with an elapsed-time signal and with human-entered pressure, power, and flow readings.
Local Date
Local Time
mS/scan
1000
Elapsed Time
Elapsed Time (seconds)
Elapsed
Seconds
Temp' 1
Temp' 1x
Temp' 2x
Temp' 3
From Chiller
Pres' 1
Pres' 2
Power
Watts
GPH
psi
Deg
Set Dynamic Data
OK Button
Write To Measurement File
The 11 blocks above assign names to the data channels
Record Count
Record-counting logic
Logic to switch source after first record


Water Cooler Data Acquisition - Revision5b.vi Block Diagram *
File Edit View Project Operate Tools Window Help
20pt Application Font
Search
The composite signal from the DAC Assistant is separated into data feeds for temperature indicators on the front panel.
DAQ Assistant
data
The DAQ Assistant is the S/W interface to the thermo-couple data acquisition unit NI 9213.
Temp 1
Temp 1x
Temp 2x
Temp 3
To Chiller
From Chiller
P1 (psi)
P2 (psi)
Compressor Power (Watts)
Flow Rate
Thermocouple temperature signals are combined with an elapsed-time signal and with human-entered pressure, power, and flow readings.
Local Date
Local Time
mS/scan
1000
Elapsed Time
Elapsed Time (seconds)
Elapsed
Seconds
Temp' 1
Temp' 1x
Temp' 2x
Temp' 3
From Chiller
Pres' 1
Pres' 2
Deg
psi
Power
Watts
Flow Rate
GPH
Set Dynamic Data
OK Button
Write To Measurement File
The 11 blocks above assign names to the data channels
Record Count
Record-counting logic
Logic to switch source after first record

<table>
<tr><th>Element or Feature</th><th>Description</th></tr>
<tr><td>DAQ Assistant

</td><td>The DAQ Assistant is the software interface between the thermocouple hardware module and the remainder of the system. The DAQ assistant maps thermocouple terminals to data channels (0 through 6). It is also used to choose between Fahrenheit and Celsius representation. Property settings are revealed by double clicking on the DAQ Assistant icon.</td></tr>
<tr><td>Signal Split
</td><td>The signal splitter splits the composite signal from the DAQ Assistant into separate channels fed to temperature indicators on the front panel.</td></tr>
<tr><td>Signal Merge
</td><td>The signal merge unit recombines the six thermocouple signals and adds to them
a measure of the number of seconds elapsed from the start of LabView data scanning
four meter readings that are observed manually: water flow rate, electrical power consumption, high-side refrigerant pressure and low-side refrigerant pressure.
These eleven channels of data then flow out to two data sinks: a chain of eleven “Set Dynamic Data” functions, and a channel selector switch which will be explained later. Each of the Set Dynamic Data functions attaches a name to each of the 11 data channels.</td></tr>
<tr><td>Signal Source Selector Switch
</td><td>The Signal Selector Switch is a work-around to a limitation of the Write to Measurement File function. Write to Measurement File creates an output file in one of several formats. When configured to produce an Excel file, the first column of the spreadsheet contains the measurement time. The remaining columns contain the readings for elapsed seconds, temperatures, pressure readings, power, and flow rate. Write to Measurement File has the limitation, however, that, when column labels are attached to channels, it records time for only the first data record. All subsequent records have a timestamp of January 1, 1904. This limitation is a known bug. In order to attach timestamps to all records, it is necessary to feed Write to Measurement File a signal in which the channels are not labeled. The selector switch, and associated logic, feeds labeled data for only the first data record; subsequent records are unlabeled, and thus time-stamped. This workaround is original.</td></tr>
<tr><td>Channel Labeler
(11 instances)

</td><td>This function assigns names to the data channels embedded in the composite signal coming from the Signal Merge function.</td></tr>
<tr><td>Front Panel Controls

</td><td>Indicators for Temperature, Date, Time, Elapsed Time, and Count of Records; and Controls to enter Power, Water Flow-Rate, Compressor-High-Side Pressure and Compressor-Low-Side Pressure.</td></tr>
</table>


NATIONAL INSTRUMENTS
Hi-Speed USB Carrier
NI USB-9162
GPH – WATER – READ TOP OF FLOAT
LG
NSA36LACG


Capillary Tube and Suction Line
lashed together to form a
Heat Exchanger


Complete Suction Line and
Portion of Capillary Tube
Covered by Insulation